

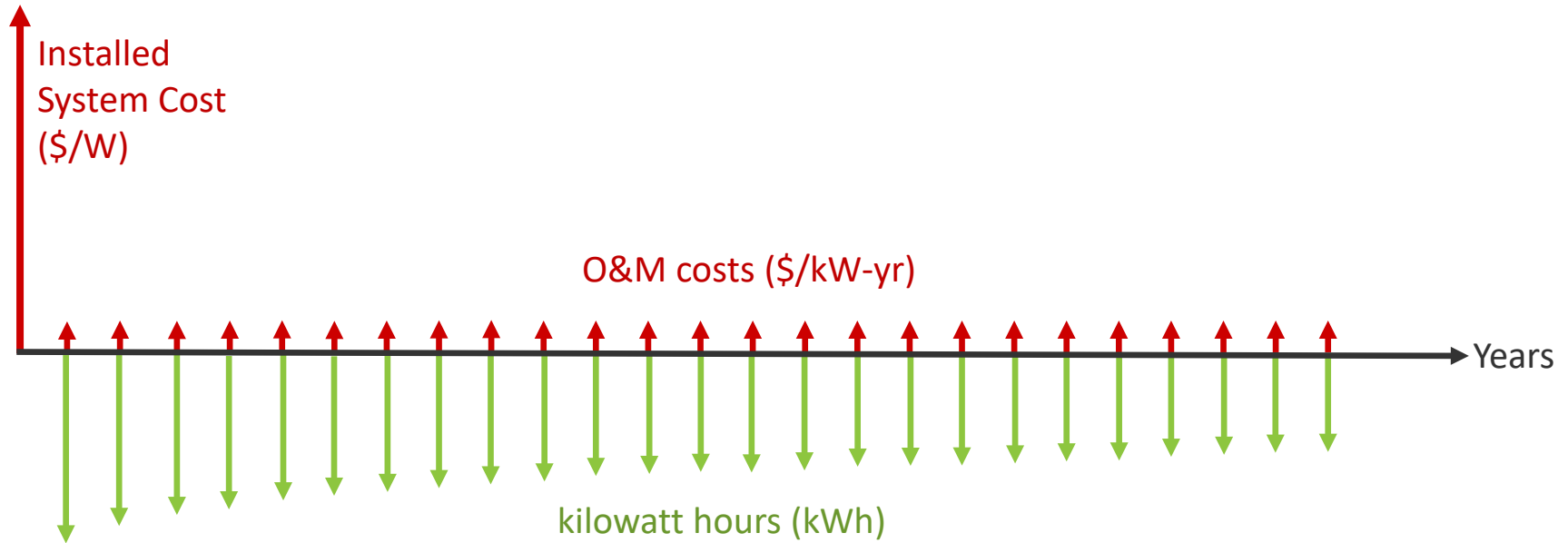
Adding Climate Effects to NREL's Online LCOE Calculator for the DuraMAT Data Hub

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DuraMAT Webinar
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Levelized Cost of Energy

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



LCOE Calculation Option: SAM

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 potentially introducing confounding factors

Simplified PV-Specific Calculator

<http://pvlcoe.nrel.gov/>

- Available online since 2018

<https://github.com/NREL/PVLCOE>

- Source code on GitHub since July 2020

<https://www.nrel.gov/analysis/solar-levelized-cost.html>

- Tutorial on calculator use, online 9/15/20

Inputs

Use the **presets** button (below) to choose a different cell technology, system type, or location. Use the **copy from baseline** button (below) to make the proposed inputs match the baseline inputs.

Baseline	PRESETS	Proposed	COPY FROM BASELINE
Cost			
Front layer cost (USD/m ²)	4.06	4.06	
Cell cost (USD/m ²)	34.4	34.4	
Back layer cost (USD/m ²)	2.32	2.32	
Non-cell module cost (USD/m ²)	18.01	18.01	
Extra component cost (USD/m ²)	0.00	0.00	
O&M cost (USD/kW _{DC} /year)	15.41	15.41	
BOS cost, power-scaling (USD/W)	0.31	0.31	
BOS cost, area-scaling (USD/m ²)	63.0	63.0	
Performance			
Efficiency (%)	19.0	19.0	
Energy yield (kWh/kWDC)	147E	147E	
Reliability			
Degradation rate (%/year)	0.36	0.36	
Service life (years)	25	25	
Common settings			
Financial			
Discount rate	6.3		
Results			
LCOE result			
Baseline LCOE (USD/kWh)	0.0670	Proposed LCOE (USD/kWh)	0.0670
Additional results			
Baseline		Proposed	
Module price (USD/W)	0.36	Module price (USD/W)	0.36
Total installed system cost (USD/W)	1.00	Total installed system cost (USD/W)	1.00

BERNELL
SLAC
REGULATORY
LABORATORY

Simplified PV-Specific Calculator

If you make a module bifacial...

The image displays two side-by-side calculator interfaces. The left interface is labeled 'Baseline' and the right is 'Proposed'. Both have a 'PRESETS' button. The 'Proposed' interface has a 'COPY FROM BASELINE' button. An arrow points from the 'Baseline' to the 'Proposed' interface. In the 'Proposed' interface, the 'Back layer cost (USD/m²)' is highlighted with a red box and set to 4.06. The 'Proposed LCOE (USD/kWh)' is also highlighted with a red box and set to 0.0676. The 'Performance' section shows 'Efficiency (%)' at 19.0.

Category	Parameter	Baseline Value	Proposed Value
Cost	Front layer cost (USD/m ²)	4.06	4.06
	Cell cost (USD/m ²)	34.40	34.40
	Back layer cost (USD/m ²)	2.32	4.06
	Non-cell module cost (USD/m ²)	18.00	18.00
	Extra component cost (USD/m ²)	0.00	0.00
	Q&M cost (USD/kW _{DC} /year)	15.40	15.40
	BOS cost, power-scaling (USD/W)	0.31	0.31
Performance	BOS cost, area-scaling (USD/m ²)	63.04	63.04
	Efficiency (%)	19.0	19.0
LCOE (USD/kWh)	Baseline LCOE	0.0670	
LCOE (USD/kWh)	Proposed LCOE	0.0676	

Simplified PV-Specific Calculator

How efficient should it be to break even?

Baseline PRESETS

Cost

Front layer cost (USD/m²)
4.06

Cell cost (USD/m²)
34.40

Back layer cost (USD/m²)
2.32

Non-cell module cost (USD/m²)
18.00

Extra component cost (USD/m²)
0.00

Q&M cost (USD/kW_{DC}/year)
15.40

BOS cost, power-scaling (USD/W)
0.31

BOS cost, area-scaling (USD/m²)
63.04

Performance

Efficiency (%)
19.0

Baseline LCOE (USD/kWh) **0.0670**

Proposed COPY FROM BASELINE

Cost

Front layer cost (USD/m²)
4.06

Cell cost (USD/m²)
34.40

Back layer cost (USD/m²)
4.06

Non-cell module cost (USD/m²)
18.00

Extra component cost (USD/m²)
0.00

Q&M cost (USD/kW_{DC}/year)
15.40

BOS cost, power-scaling (USD/W)
0.31

BOS cost, area-scaling (USD/m²)
63.04

Performance

Efficiency (%)
19.0

Proposed LCOE (USD/kWh) **0.0676**



Baseline PRESETS

Cost

Front layer cost (USD/m²)
4.06

Cell cost (USD/m²)
34.40

Back layer cost (USD/m²)
2.32

Non-cell module cost (USD/m²)
18.00

Extra component cost (USD/m²)
0.00

Q&M cost (USD/kW_{DC}/year)
15.40

BOS cost, power-scaling (USD/W)
0.31

BOS cost, area-scaling (USD/m²)
63.04

Performance

Efficiency (%)
19.0

Baseline LCOE (USD/kWh) **0.0670**

Proposed COPY FROM BASELINE

Cost

Front layer cost (USD/m²)
4.06

Cell cost (USD/m²)
34.40

Back layer cost (USD/m²)
4.06

Non-cell module cost (USD/m²)
18.00

Extra component cost (USD/m²)
0.00

Q&M cost (USD/kW_{DC}/year)
15.40

BOS cost, power-scaling (USD/W)
0.31

BOS cost, area-scaling (USD/m²)
63.04

Performance

Efficiency (%)
19.3

Proposed LCOE (USD/kWh) **0.0670**

System Options

Baseline presets

Use these menus to choose a set of cost and performance values for the Baseline module.

Cell technology

- ✓ mono-Si
- multi-Si
- CdTe

available values for package type and system type.

Package type

glass-polymer backsheet

Package type affects back layer cost

System type

fixed tilt, utility scale

System type affects energy yield and BOS cost

Location

USA MO Kansas City

Location affects energy yield and BOS cost

CLOSE USE THIS PRESET

Baseline presets

Use these menus to choose a set of cost and performance values for the Baseline module.

Cell technology

mono-Si

Cell technology affects cell cost, efficiency, energy yield, degradation rate, BOS cost, and the available values for package type and system type.

Package type

- ✓ glass-polymer backsheet
- glass-glass

System type

fixed tilt, utility scale

System type affects energy yield and BOS cost

Location

USA MO Kansas City

Location affects energy yield and BOS cost

CLOSE USE THIS PRESET

Baseline presets

Use these menus to choose a set of cost and performance values for the Baseline module.

Cell technology

mono-Si

Cell technology affects cell cost, efficiency, energy yield, degradation rate, BOS cost, and the available values for package type and system type.

Package type

glass-polymer backsheet

Package type affects back layer cost

System type

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

Location

USA MO Kansas City

Location affects energy yield and BOS cost

CLOSE USE THIS PRESET

Baseline presets

Use these menus to choose a set of cost and performance values for the Baseline module.

Cell technology

mono-Si

Cell technology affects cell cost, efficiency, energy yield, degradation rate, BOS cost, and the available values for package type and system type.

Package type

glass-polymer backsheet

Package type affects back layer cost

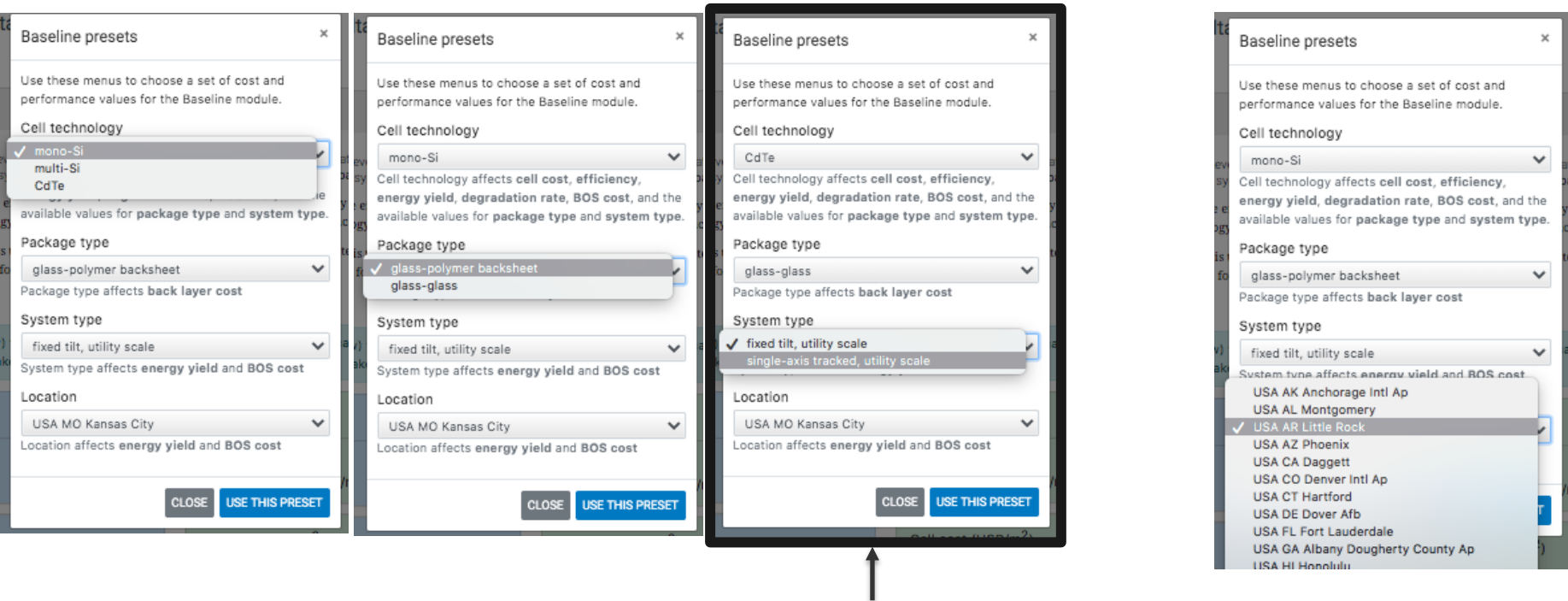
System type

fixed tilt, utility scale

System type affects energy yield and BOS cost

- ✓ USA AR Little Rock
- USA AZ Phoenix
- USA CA Daggett
- USA CO Denver Intl Ap
- USA CT Hartford
- USA DE Dover Afb
- USA FL Fort Lauderdale
- USA GA Albany Dougherty County Ap
- USA HI Honolulu

System Options



Certain selections limit which other options are available

Preset Default Values

Default values pre-populate based on your drop-down selections, but values can be adjusted.

Currently,

- Cell technology affects:
 - **cell cost**
 - **efficiency**
 - **energy yield**
 - **degradation rate**
 - **BOS cost**
 - available options for **package type** and **system type**
- Package type affects: **back layer cost**
- System type affects: **energy yield** and **BOS cost**
- Location affects: **energy yield** and **BOS cost**

Baseline PRESETS

Cost

Front layer cost (USD/m²)
4.06

Cell cost (USD/m²)
34.40

Back layer cost (USD/m²)
2.32

Non-cell module cost (USD/m²)
18.00

Extra component cost (USD/m²)
0.00

O&M cost (USD/kW_{DC}/year)
15.40

BOS cost, power-scaling (USD/W)
0.31

BOS cost, area-scaling (USD/m²)
63.04

Performance

Efficiency (%)
19.0

Energy yield (kWh/kW_{DC})
1475

Reliability

Degradation rate (%/year)
0.36

Service life (years)
25

Preset Default Values

Default values pre-populate based on your drop-down selections, but values can be adjusted.

Currently,

- Cell technology affects:
 - **cell cost**
 - **efficiency**
 - **energy yield**
 - **degradation rate**
 - **BOS cost**
 - available options for **package type** and **system type**
- Package type affects: **back layer cost**
- System type affects: **energy yield** and **BOS cost**
- Location affects: **energy yield** and **BOS cost**

Add effects on degradation rate

Baseline PRESETS

Cost

Front layer cost (USD/m²)
4.06

Cell cost (USD/m²)
34.40

Back layer cost (USD/m²)
2.32

Non-cell module cost (USD/m²)
18.00

Extra component cost (USD/m²)
0.00

O&M cost (USD/kW_{DC}/year)
15.40

BOS cost, power-scaling (USD/W)
0.31

BOS cost, area-scaling (USD/m²)

Energy yield (kWh/kW_{DC})
1475

Reliability

Degradation rate (%/year)
0.36

Service life (years)
25


Where to Update Default Values

Here's how the GitHub repository is organized:

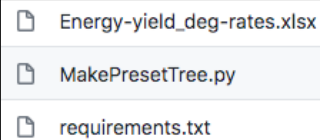
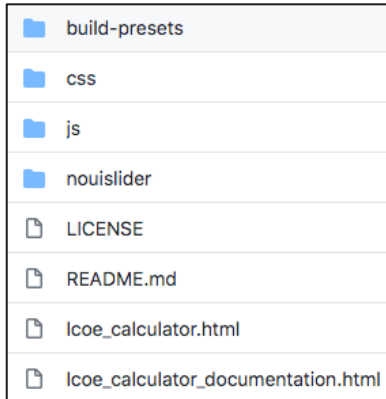
build-presets
css
js
nouislider
LICENSE
README.md
lcoe_calculator.html
lcoe_calculator_documentation.html

bootstrap.min.js
bos_cost_tree.js
jquery-3.2.1.slim.min.js
lcoe_calculator.js
nouislider.min.js
popper.min.js
preset_tree.js
preset_tree.min.js

```
"mono-Si": {  
  "glass-polymer backsheet": {  
    "fixed tilt, utility scale": {  
      "USA AK Anchorage Intl Ap": {  
        "cost_front_layer": 4.06,  
        "cost_cell": 34.4,  
        "cost_back_layer": 2.32,  
        "cost_noncell": 18.0,  
        "cost_om": 15.4,  
        "efficiency": 19.0,  
        "energy_yield": 928.0,  
        "degradation_rate": 0.36,  
        "state": "AK"  
      },  
      "USA AL Montgomery": {  
        "cost_front_layer": 4.06,  
        "cost_cell": 34.4,  
        "cost_back_layer": 2.32,  
        "cost_noncell": 18.0,  
        "cost_om": 15.4,  
        "efficiency": 19.0,  
        "energy_yield": 1486.0,  
        "degradation_rate": 0.36,  
        "state": "AL"  
      },  
    },  
  },  
}
```

Most default values are called from the preset tree, which looks basically like this  (except BOS costs, which are called from the bos_cost_tree)

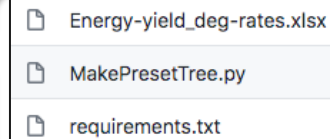
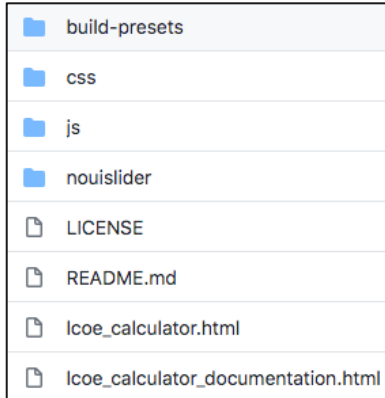
How to Update Default Values



This is the script that builds the preset tree. It provides the default values for efficiency and non-BOS costs in-line.

How to Update Default Values

This provides the default values for energy yield and degradation rates (previously, only energy yield)



How to Update Default Values

	A	B	C	D	E	F	G
	Cell Technology	Package Type	System Type	Location	First year energy (kWh)	First Year Energy Yield (kWh/kWp)	Degradation Rate (%/year)
1	multi-Si	glass-polymer	fixed tilt, utilit	USA NM Albuquerque (TMY2)	1.83E+08	1832	0.65
2	multi-Si	glass-polymer	fixed tilt, utilit	USA NV Las Vegas (TMY2)	1.85E+08	1846	0.65
3	multi-Si	glass-polymer	fixed tilt, utilit	USA TX San Antonio (TMY2)	1.57E+08	1569	0.65
4	multi-Si	glass-polymer	fixed tilt, utilit	USA AL Montgomery (TMY2)	1.48E+08	1484	0.65
5	multi-Si	glass-polymer	fixed tilt, utilit	USA AR Little Rock (TMY2)	1.48E+08	1480	0.65
6	multi-Si	glass-polymer	fixed tilt, utilit	USA AZ Phoenix (TMY2)	1.82E+08	1822	0.65
7	multi-Si	glass-polymer	fixed tilt, utilit	USA CA Daggett (TMY2)	1.89E+08	1895	0.65
...							
198	multi-Si	glass-glass	single-axis tra	USA WI Madison (TMY2)	1.75E+08	1750	0.65
199	multi-Si	glass-glass	single-axis tra	USA WV Charleston (TMY2)	1.62E+08	1622	0.65
200	multi-Si	glass-glass	single-axis tra	USA WY Cheyenne (TMY2)	2.15E+08	2153	0.65
201	multi-Si	glass-glass	single-axis tra	USA AK Anchorage Intl Ap (TMY3)	1.19E+08	1195	0.65
202	mono-Si	glass-polymer	fixed tilt, utilit	USA NM Albuquerque (TMY2)	1.83E+08	1828	0.36
203	mono-Si	glass-polymer	fixed tilt, utilit	USA NV Las Vegas (TMY2)	1.85E+08	1848	0.36
204	mono-Si	glass-polymer	fixed tilt, utilit	USA TX San Antonio (TMY2)	1.57E+08	1572	0.36
205	mono-Si	glass-polymer	fixed tilt, utilit	USA AL Montgomery (TMY2)	1.49E+08	1486	0.36
206	mono-Si	glass-polymer	fixed tilt, utilit	USA AR Little Rock (TMY2)	1.48E+08	1480	0.36
...							

If updating values for an entire package type or system type, paste & drag might be easiest.

If updating values by location, creating a dictionary and then combining the INDEX and MATCH functions might be best.

...then, run MakePresetTree.py

Climate Effects on Degradation Rate

[Jordan, Dirk C., et al. "Compendium of photovoltaic degradation rates." *Progress in Photovoltaics: Research and Applications* 24.7 \(2016\): 978-989](#)

- 4 climate categories, but differences between degradation rates are not statistically significant
- Module and system degradation rates are each present in the data and are not analyzed separately when comparing climate categories

[Deceglie, Michael G., et al. "Fleet-scale energy-yield degradation analysis applied to hundreds of residential and nonresidential photovoltaic systems." *IEEE Journal of Photovoltaics* 9.2 \(2019\): 476-482](#)

- Shows statistically significant dependence of degradation rate on average temperature

Adding New System Options

edit MakePresetTree.py

```
9
10 # %% Define feasible system configurations
11 cell_technologies = ['mono-Si', 'multi-Si', 'CdTe']
12
13 package_types = {
14     'mono-Si': ('glass-polymer backsheet', 'glass-glass'),
15     'multi-Si': ('glass-polymer backsheet', 'glass-glass'),
16     'CdTe': ('glass-glass', )
17 }
18
19 system_types = {
20     'mono-Si': ('fixed tilt, utility scale', 'single-axis tracked, utility scale', 'roof-mounted, residential scale'),
21     'multi-Si': ('fixed tilt, utility scale', 'single-axis tracked, utility scale'),
22     'CdTe': ('fixed tilt, utility scale', 'single-axis tracked, utility scale')
23 }
24
25
26 # %% Preset values for module parameters: costs are in USD per square meter, efficiency reported as a percentage
27 module_details = {
28     'cost_front_layer': 4.06,
29     'cost_cell': {'mono-Si': 34.4, 'multi-Si': 31.45, 'CdTe': 30},
30     'cost_back_layer': {'glass-polymer backsheet': 2.32, 'glass-glass': 3},
31     'cost_noncell': 18.,
32     'efficiency': {'mono-Si': 19.0, 'multi-Si': 17.0, 'CdTe': 16.0},
33 }
```

```
9
10 # %% Define feasible system configurations
11 cell_technologies = ['mono-Si', 'multi-Si', 'CdTe', 'perovskite']
12
13 package_types = {
14     'mono-Si': ('glass-polymer backsheet', 'glass-glass'),
15     'multi-Si': ('glass-polymer backsheet', 'glass-glass'),
16     'CdTe': ('glass-glass', ),
17     'perovskite': ('glass-glass', 'polymer-polymer')
18 }
19
20 system_types = {
21     'mono-Si': ('fixed tilt, utility scale', 'single-axis tracked, utility scale', 'roof-mounted, residential scale'),
22     'multi-Si': ('fixed tilt, utility scale', 'single-axis tracked, utility scale'),
23     'CdTe': ('fixed tilt, utility scale', 'single-axis tracked, utility scale'),
24     'perovskite': ('fixed tilt, utility scale', 'single-axis tracked, utility scale', 'roof-mounted, residential scale')
25 }
26
27
28 # %% Preset values for module parameters: costs are in USD per square meter, efficiency reported as a percentage
29 module_details = {
30     'cost_front_layer': {'glass-polymer backsheet': 4.06, 'glass-glass': 4.06, 'polymer-polymer': 20},
31     'cost_cell': {'mono-Si': 34.4, 'multi-Si': 31.45, 'CdTe': 30, 'perovskite': 20},
32     'cost_back_layer': {'glass-polymer backsheet': 2.32, 'glass-glass': 3, 'polymer-polymer': 2.32},
33     'cost_noncell': 18.,
34     'efficiency': {'mono-Si': 19.0, 'multi-Si': 17.0, 'CdTe': 16.0, 'perovskite': 16.0},
35 }
```


Adding New System Options

edit MakePresetTree.py

```

9
10 # %% Define feasible system configurations
11 cell_technologies = ['mono-Si', 'multi-Si', 'CdTe']
12
13 package_types = {
14     'mono-Si': ('glass-polymer backsheet', 'glass-glass'),
15     'multi-Si': ('glass-polymer backsheet', 'glass-glass'),
16     'CdTe': ('glass-glass',)
17 }
18
19 system_types = {
20     'mono-Si': ('fixed tilt, utility scale', 'single-axis tracked, utility scale', 'roof-mounted, residential scale'),
21     'multi-Si': ('fixed tilt, utility scale', 'single-axis tracked, utility scale'),
22     'CdTe': ('fixed tilt, utility scale', 'single-axis tracked, utility scale')
23 }
24
25
26 # %% Preset values for module parameters: costs are in USD per square meter, efficiency reported as a percentage
27 module_details = {
28     'cost_front_layer': 4.06,
29     'cost_cell': {'mono-Si': 34.4, 'multi-Si': 31.45, 'CdTe': 30},
30     'cost_back_layer': {'glass-polymer backsheet': 2.32, 'glass-glass': 3},
31     'cost_noncell': 18.,
32     'efficiency': {'mono-Si': 19.0, 'multi-Si': 17.0, 'CdTe': 16.0},
33 }
    
```

```

9
10 # %% Define feasible system configurations
11 cell_technologies = ['mono-Si', 'multi-Si', 'CdTe', 'perovskite']
12
13 package_types = {
14     'mono-Si': ('glass-polymer backsheet', 'glass-glass'),
15     'multi-Si': ('glass-polymer backsheet', 'glass-glass'),
16     'CdTe': ('glass-glass',),
17     'perovskite': ('glass-glass', 'polymer-polymer')
18 }
19
20 system_types = {
21     'mono-Si': ('fixed tilt, utility scale', 'single-axis tracked, utility scale', 'roof-mounted, residential scale'),
22     'multi-Si': ('fixed tilt, utility scale', 'single-axis tracked, utility scale'),
23     'CdTe': ('fixed tilt, utility scale', 'single-axis tracked, utility scale'),
24     'perovskite': ('fixed tilt, utility scale', 'single-axis tracked, utility scale', 'roof-mounted, residential scale')
25 }
26
27
28 # %% Preset values for module parameters: costs are in USD per square meter, efficiency reported as a percentage
29 module_details = {
30     'cost_front_layer': {'glass-polymer backsheet': 4.06, 'glass-glass': 4.06, 'polymer-polymer': 20},
31     'cost_cell': {'mono-Si': 34.4, 'multi-Si': 31.45, 'CdTe': 30, 'perovskite': 20},
32     'cost_back_layer': {'glass-polymer backsheet': 2.32, 'glass-glass': 3, 'polymer-polymer': 2.32},
33     'cost_noncell': 18.,
34     'efficiency': {'mono-Si': 19.0, 'multi-Si': 17.0, 'CdTe': 16.0, 'perovskite': 16.0},
35 }
    
```

And append
Energy-yield_deg-rates.xlsx

601	CdTe	glass-glass	single-axis tra	USA AK Anchorage Intl Ap (TMY3)	1.22E+08	1220	0.4
602	perovskite	glass-glass	single-axis tracked, utility scale				
603	perovskite	glass-glass	fixed tilt, utilit	USA CO Denver Intl Ap (TMY3)			
604	perovskite	glass-glass	roof-mounted,	USA CO Denver Intl Ap (TMY3)			
605	perovskite	polymer-polym	single-axis tra	USA CO Denver Intl Ap (TMY3)			
606	perovskite	polymer-polym	fixed tilt, utilit	USA CO Denver Intl Ap (TMY3)			
607	perovskite	polymer-polym	roof-mounted,	USA CO Denver Intl Ap (TMY3)			
608							

Future Updates to the Calculator

- Complete update of cost and efficiency data (still 2018 data) once NREL's 2020 PV System Benchmark is out
- Improve “value of efficiency” handling
- Potentially, statistically significant degradation rate updates from PV Fleets data, based on:
 - Climate zones
 - Racking types

Thank You

www.duramat.org