Techno-economic Analysis of Novel PV Plant Designs for Extreme Cost Reductions

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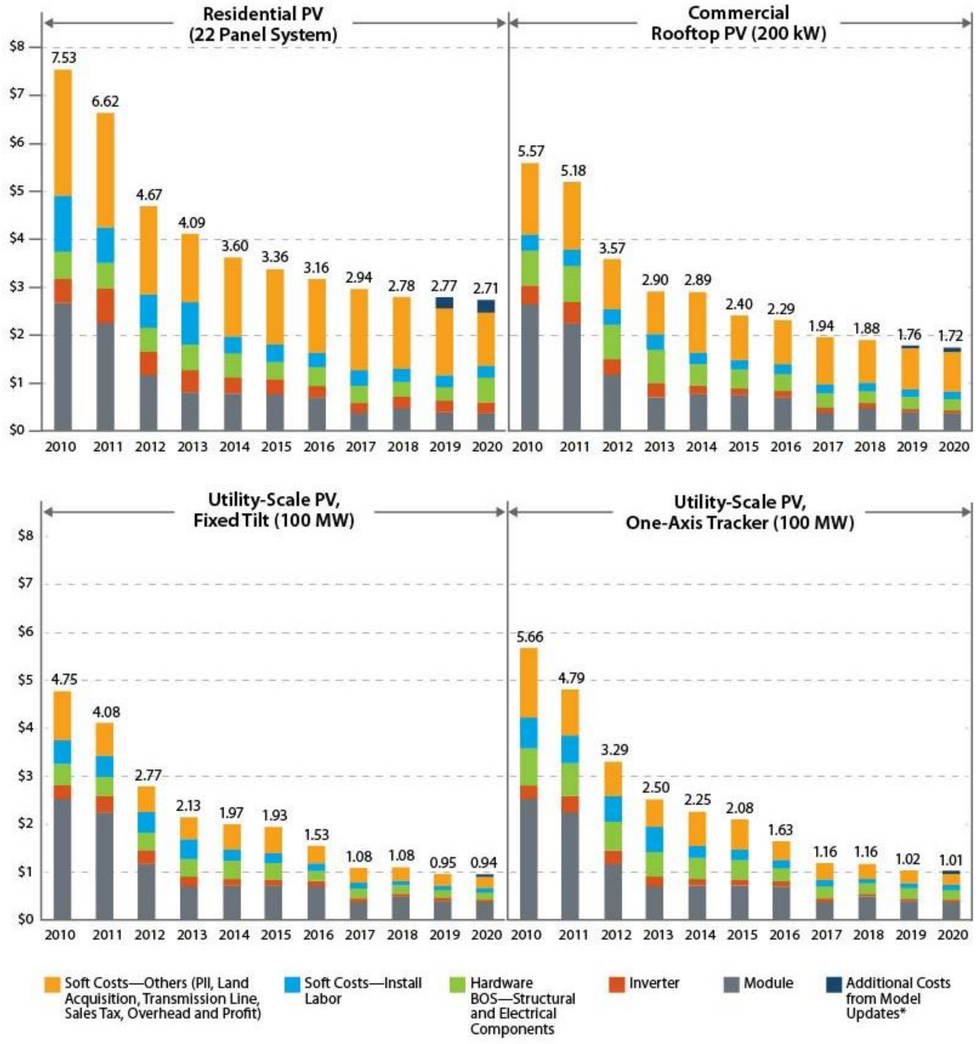
Introduction & Background

- Cost reductions and efficiency improvements in traditional c-Si PV modules are anticipated to asymptote.
- More research is needed on how individual innovations can best come together to provide the lowest levelized cost of electricity (LCOE).
- It is not readily apparent how low of a LCOE can be achieved by any given combination of technologies and plant designs.



Source: Feldman, David, Vignesh Ramasamy, Ran Fu, Ashwin Ramdas, Jal Desai, and Robert Margolis. 2021. U.S. Solar Photovoltaic System Cost Benchmark: Q1 2020. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-77324. https://www.nrel.gov/docs/fy21osti/77324.pdf.

Introduction & Background

- There are two broad areas for opportunity for innovation in PV plant design:

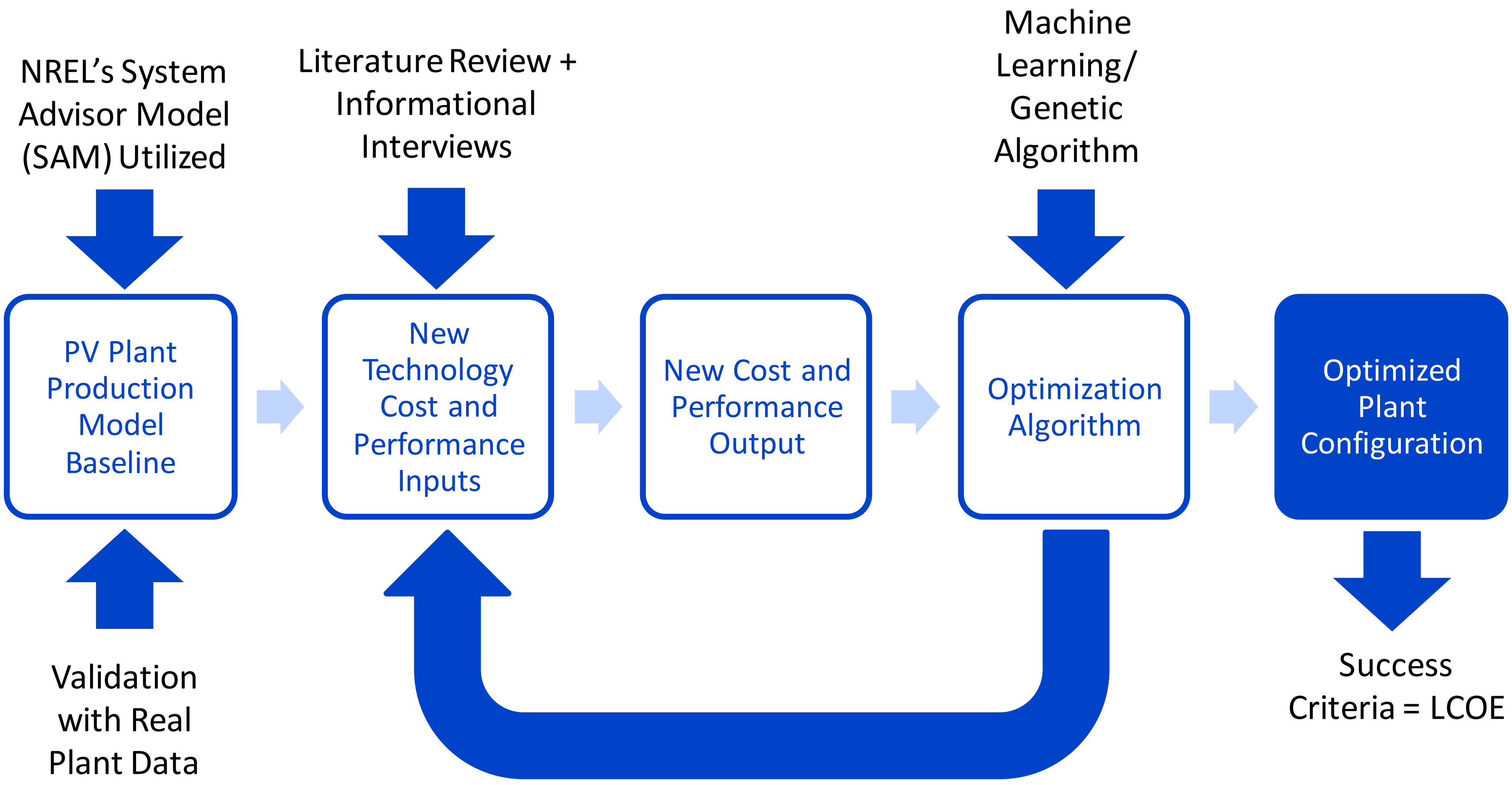
  1. Improvements in the individual components that make up a PV plant.

  2. Optimizing the integration of the plant components as a whole.

- This research analyses novel PV technologies, how they can be integrated into a plant, and how they can be optimized through an evolutionary algorithm to achieve optimal plant LCOE.

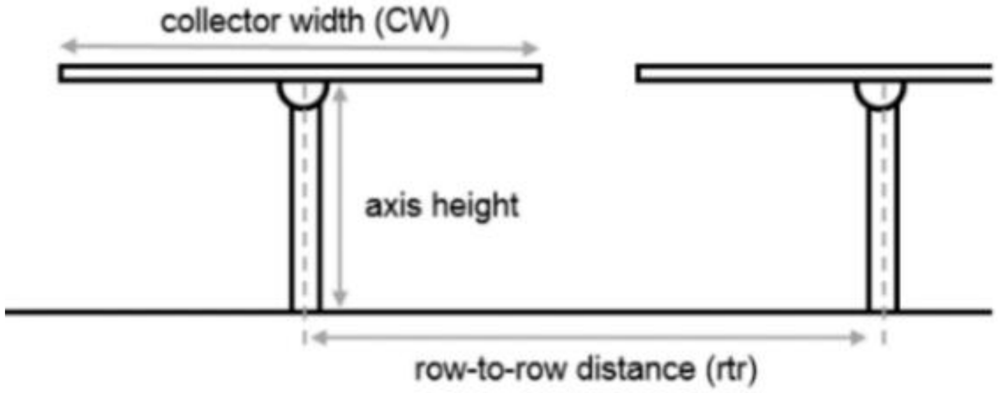
PV Plant Technology	Example Plant Design Considerations
Bifacial modules	Added energy from increasing module height vs. increased racking and wiring cost; added energy from increasing ground albedo vs. cost of solution
Tandem modules	Added energy from increasing efficiency vs. increased wiring and balance-of-plant costs
Increased plant voltages above 1500 Vdc	Reduced energy losses vs. increased component costs
Module-level power electronics for large-scale plants	Reduced energy losses and potential for lower cost per inverter vs. increased upfront and maintenance costs

Project Approach



PV Plant Performance Modeling

- Hourly albedo utilized for bifacial gain calculations.
- System design specifications adjusted were to accommodate bifacial modules.
- Bifacial module sensitivities optimized:
  - Ground coverage ratio (GCR)
  - Ground clearance height
  - Albedo grooming



Source: Pelaez, S.A., C. Deline, P. Greenberg, J. Stein, and R.K. Kostuk. 2018. "Model and Validation of Single-Axis Tracking with Bifacial Photovoltaics: Preprint." National Renewable Energy Laboratory (NREL). Revised July 2019.

PV Plant Economic Modeling

- Detailed cost breakdowns of the baseline plant technologies were developed, and cost adders were estimated for optimized bifacial plant design, including:

Module Ground Clearance Height
- Steel costs
- Wind ballasting
- Structural design
- DC wiring
- Installation
- O&M costs

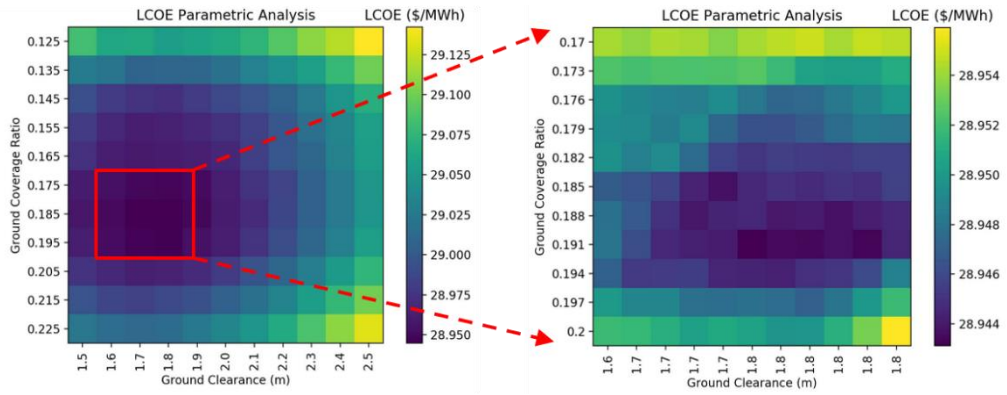
GCR
- Land cost
- AC wiring
- DC wiring

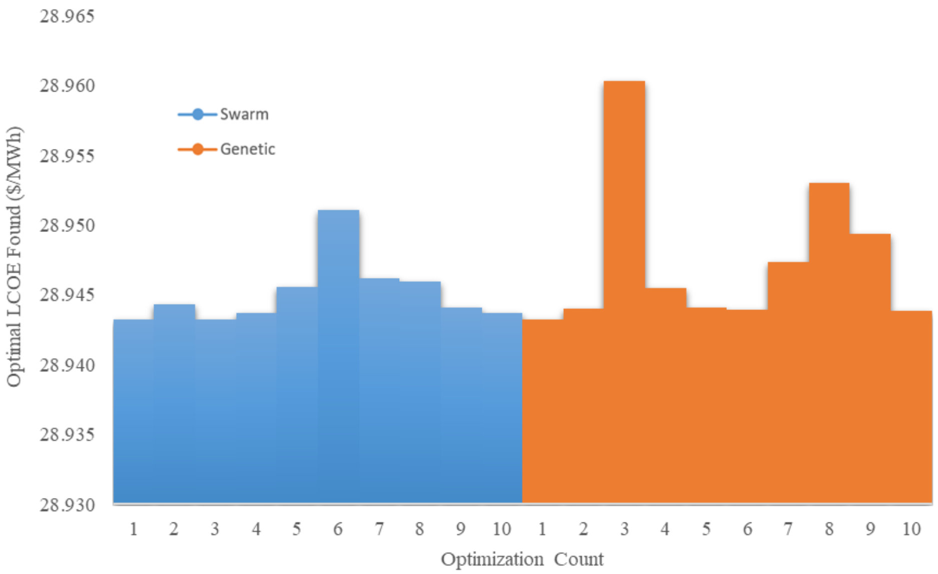
Albedo Grooming
- White gravel scenario

- These cost estimates were incorporated into each SAM sensitivity model for bifacial module LCOE analysis and optimization.

Optimization Algorithm Selection

- SAM bifacial models were exported into the PySAM Python environment.
- Parametric sweep results show multiple local minimum and the need for an evolutionary algorithm.
  - The traditional gradient descent algorithm, and the particle swarm and genetic algorithms were tested.
- The particle swarm algorithm was selected as it reached a more optimal solution in the narrowest range.





Preliminary Results & Discussion

PV Plant		GCR		Module Ground Clearance Height (m)	
		Baseline	Optimized	Baseline	Optimized
Southwest Plant	Array 1	0.463	0.192	1.00	1.82
	Array 2	0.463	0.189	1.00	1.74
	Array 3	0.493	0.185	1.00	1.57
Southeast Plant	Array 1	0.543	0.296	1.00	1.00
	Array 2	0.543	0.313	1.00	1.00
	Array 3	0.543	0.345	1.00	1.00
	Array 4	0.211	0.192	1.00	1.30
Midwest Plant		0.487	0.243	1.00	1.00

- Optimal GCR decreased by 60%, 33% and 50% on average for the optimized Southwest, Southeast, and Midwest plants, respectively, compared to the baseline.
  - Due to interaction between associated land costs and row-to-row shading
- Optimal ground clearance height increased for SAT portions of the plants but remained at 1 meter for fixed-tilt arrays.
  - Due to differences in tracking technology, combined with locational irradiance and albedo effects

Preliminary Results & Discussion

- Optimizing GCR and ground clearance height led to a decrease in LCOE by an average of 4.3%, 4.6%, and 6.9% for the Southwest, Southeast, and Midwest plants compared to the *baseline* LCOE.
- Compared to the *non-optimized* cases, optimized bifacial module LCOE decreased by 5.9%, 0.7%, and 3.0%, for the Southwest, Southeast, and Midwest plants, respectively.
- In all cases, the optimized configurations resulted in increased annual energy output over both the baseline and non-optimized cases.

PV Plant		Nominal LCOE ($/MWh)		
		Baseline	Non-Optimized	Optimized
Southwest Plant	Array 1	35.62	37.11	35.18
	Array 2	35.62	37.11	34.91
	Array 3	38.95	37.71	35.19
Southeast Plant	Array 1	53.05	51.14	50.17
	Array 2	52.15	50.32	49.79
	Array 3	51.90	50.76	50.19
	Array 4	47.50	45.14	45.10
Midwest Plant		58.02	55.68	54.03

PV Plant		Annual Energy Production (MWh)		
		Baseline	Non-Optimized	Optimized
Southwest Plant	Array 1	89,914	90,674	99,087
	Array 2	25,688	25,932	28,313
	Array 3	30,094	31,370	34,420
Southeast Plant	Array 1	367	383	394
	Array 2	373	389	396
	Array 3	409	425	432
	Array 4	449	471	474
Midwest Plant		4,313	4,517	4,701

Preliminary Results & Discussion

- The albedo grooming sensitivity results in higher GCRs and lower ground clearance heights than the optimized, non-groomed albedo cases.
- Despite increases in annual energy yield, increased land preparation costs due to albedo grooming results in elevated LCOE compared to the optimized, non-groomed cases.

PV Plant		Ungroomed Albedo		Albedo Grooming Sensitivity	
		Optimized GCR	Optimized Ground Clearance Height (m)	Optimized GCR	Optimized Ground Clearance Height (m)
Southwest Plant	Array 1	0.192	1.82	0.221	1.77
	Array 2	0.189	1.74	0.214	1.70
	Array 3	0.185	1.57	0.225	1.55
Southeast Plant	Array 1	0.296	1.00	0.374	1.00
	Array 2	0.313	1.00	0.382	1.00
	Array 3	0.345	1.00	0.382	1.00
	Array 4	0.192	1.30	0.238	1.12
Midwest Plant		0.243	1.00	0.308	1.00

PV Plant		Ungroomed Albedo		Albedo Grooming Sensitivity	
		Nominal LCOE ($/MWh)	Annual Energy Production (MWh)	Nominal LCOE ($/MWh)	Annual Energy Production (MWh)
Southwest Plant	Array 1	35.18	99,087	35.99	104,266
	Array 2	34.91	28,313	35.72	29,800
	Array 3	35.19	34,420	35.99	35,741
Southeast Plant	Array 1	50.17	394	50.97	420
	Array 2	49.79	396	50.48	423
	Array 3	50.19	432	50.89	456
	Array 4	45.10	474	46.12	495
Midwest Plant		54.03	4,701	54.99	4,949

Key Takeaways & Future Work

- A coordinated strategy between novel PV technologies and plant designs such as GCR, module ground clearance height, and albedo can result in cost reductions for PV plants.

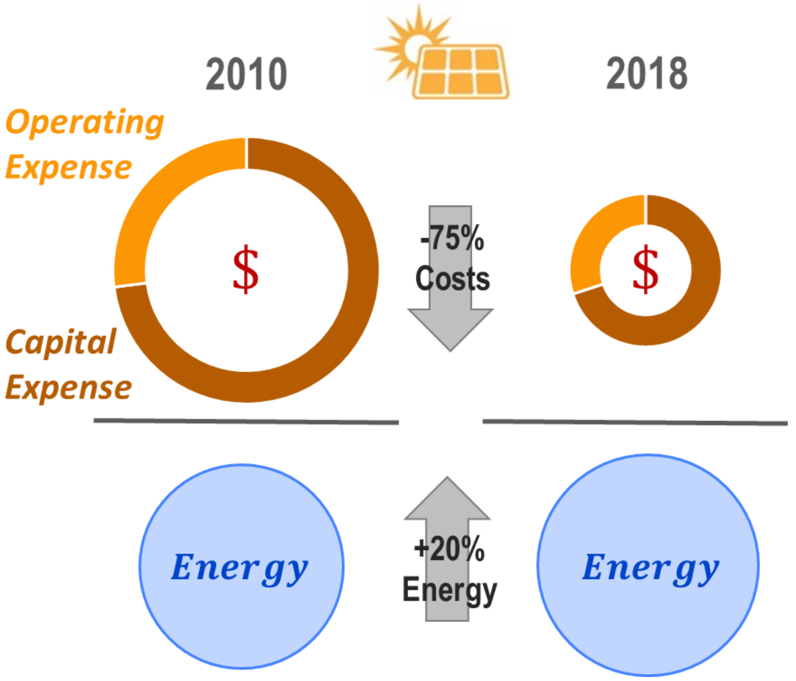
- Tandem modules, increased plant voltage architectures (1500V+), and module-level power electronic cases have been developed and will be optimized by project completion. These results will be summarized in a final report.

Optimized GCR and ground clearance height led to a decrease in bifacial module LCOE by an average of 4.8% across all three plant locations compared to the baseline.

Future of AI and Optimization in PV

- Many PV plants collect on-site performance data, however, much of this data is foregone as O&M budgets are constrained.
  - AI and optimization may be able to help cost effectively utilize this data while reducing plant costs.
- Applicable uses of AI alongside PV performance data include:
  - Detection/diagnosis of faults/failures
  - Degradation analysis or performance loss rate analysis
  - Optimization of new & existing PV plant designs

$$\frac{\textit{Lifetime Costs}}{\textit{Lifetime Energy}}$$



AI may be used to better understand PV plant performance and opportunities for improvement.

Thank You.

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