Modeling Aging PV Systems: An Integrated Workflow for Operational Decision-Making

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Objective

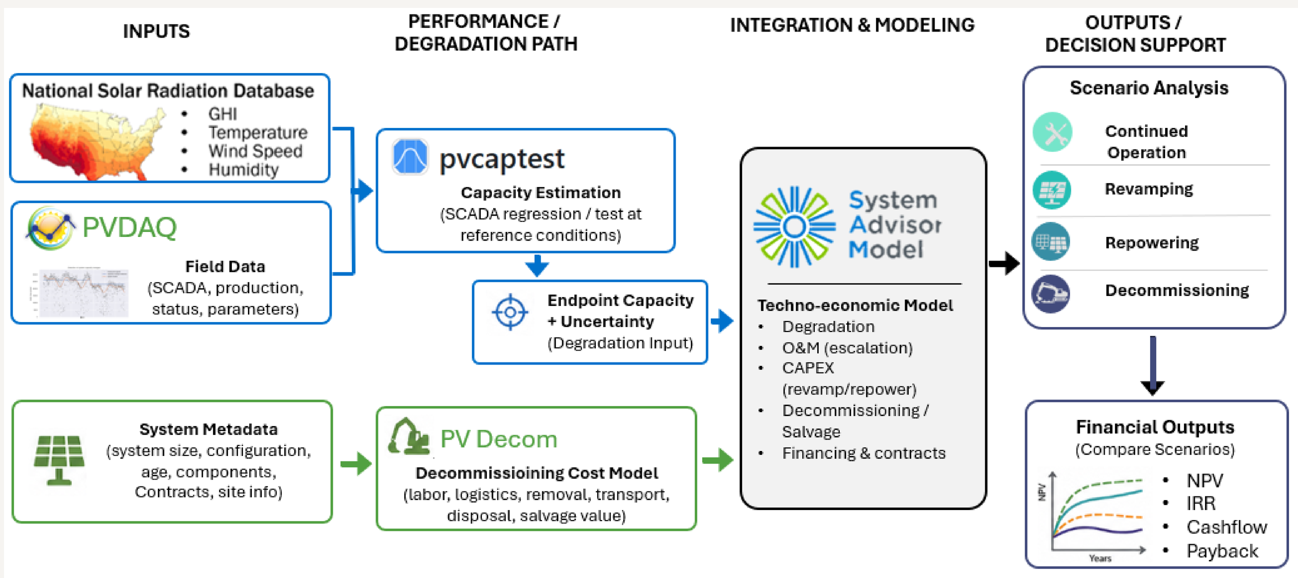
Framework to evaluate aging PV systems using scenario-based techno-economic modeling (operation, revamp, repower, decommissioning).

Why this matters:

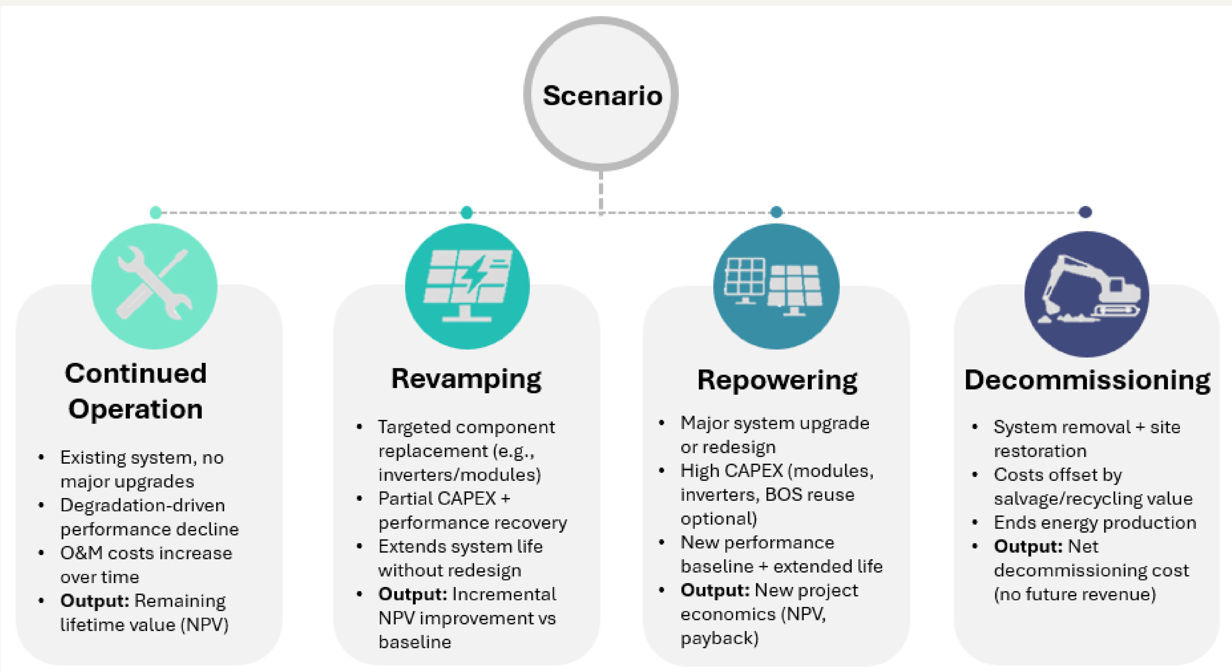
- **Aging fleet → decisions beyond "as-built assumptions"**
- **Degradation + O&M + uncertainty → financial outcomes diverge**

Conceptual Framework

The approach is applied on a case study using the System Advisory Model (SAM) by performing four different scenarios



The economic results, including Net Present Value (NPV) and Cashflow from each scenario are key to inform decision-making.



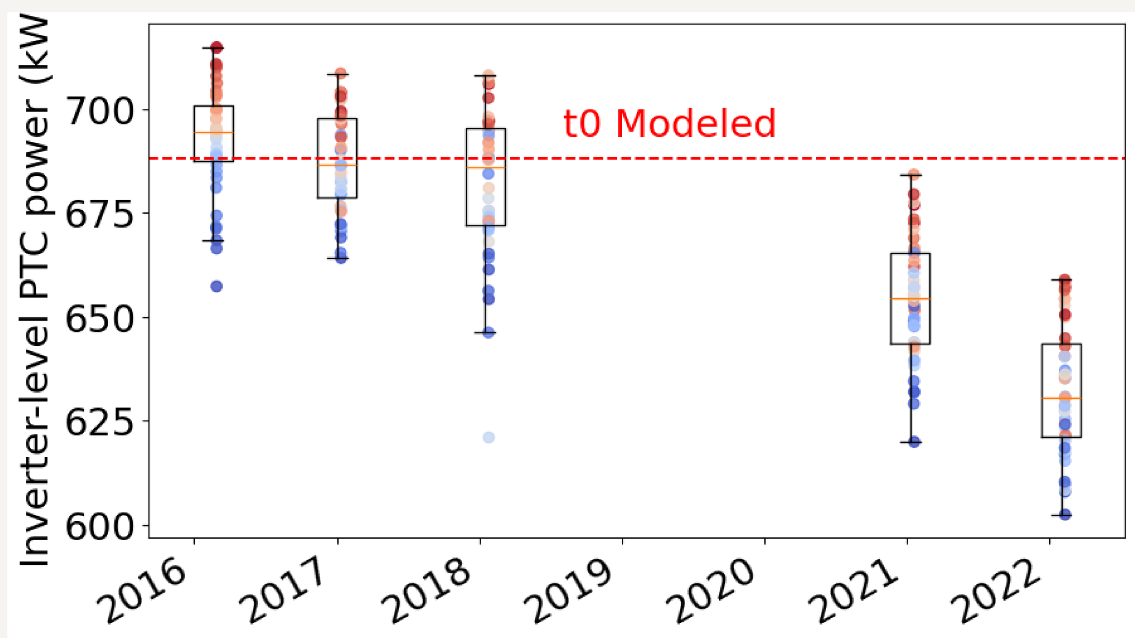
Category	Key Assumption	Typical Approach	Most Sensitive Scenario
Degradation	Site-based or 0.5–0.9%	Measured + literature	Continued operation
CAPEX	EPC / cost model	Project-specific	Repowering
Data Quality	Availability of historical data (SCADA, Maintenance logs)	Use measured data when available; otherwise apply assumptions with uncertainty ranges	All (especially continued operation)
Revenue / Contracts	PPA price, duration, penalties, merchant exposure	Use existing contract terms or forecast post-PPA pricing	Repowering, continued operation
Salvage	Cost model	**PV-Resolve**	Decommissioning

Performance → Degradation Input

Method 1) Capacity Test (measured or virtual) — preferred

- Use SCADA data near end-of-period (~1 month)
- Filter for stable conditions
- Regress Power vs POA (with T, wind corrections)
- Evaluate at reference conditions (e.g., 800 W/m², 20° C)
- Apply per inverter → distribution of capacity

Example: ~630 kW mean across ~40 inverter channels at year 6



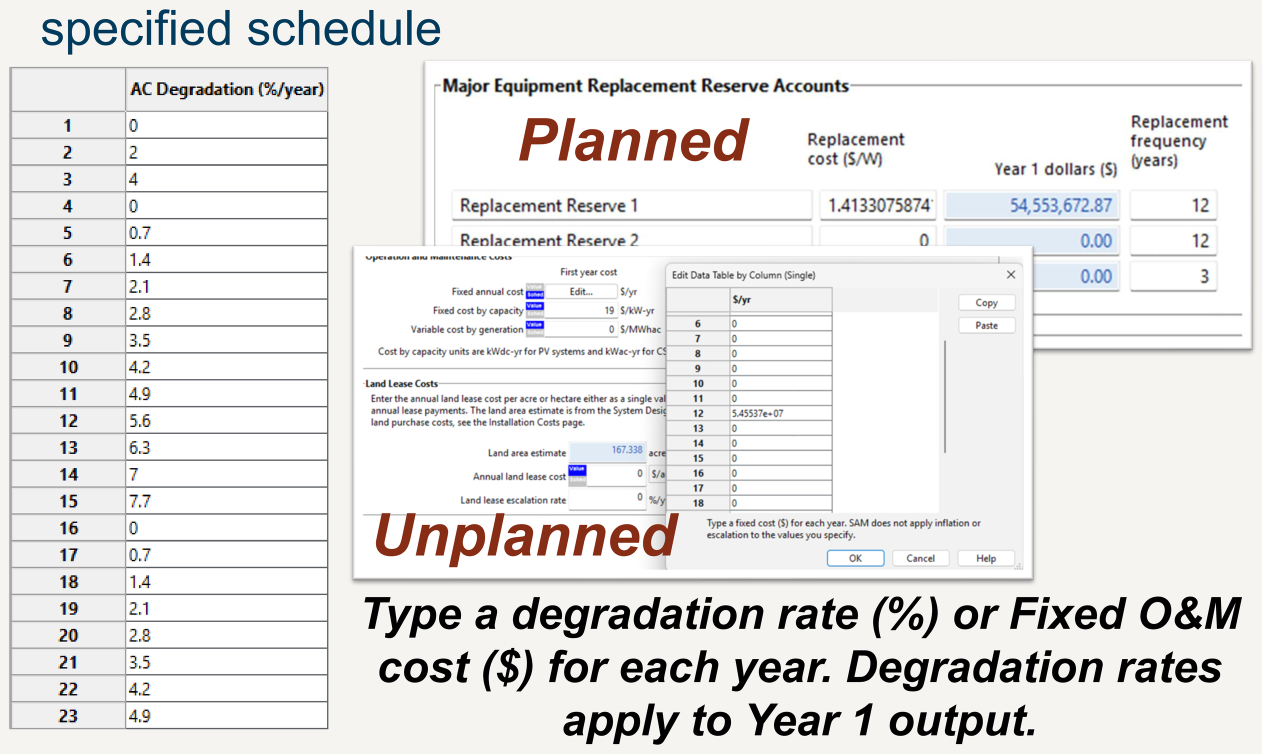
Method 2) PR (alternative, lower fidelity)

- Aggregated performance metric (energy-based)
- Sensitive to weather filtering and system availability
- Does not directly yield capacity at reference conditions

Endpoint capacity is used to calibrate degradation inputs in techno-economic models; the method used directly affects inferred degradation and, therefore, financial outcomes.

SAM Inputs

- **Degradation rate**: the degradation can be set for each year, rather than just a linear rate; for repowering cases, set the degradation rate to 0 for the year of repowering (back to new modules)
- **Unplanned Repower/Revamping/Decommissioning**: Operating cost in year of decision point ($ or $/kW)
- **Planned Repower/Revamping/Decommissioning**: Reserve accounts pay the project in each year for planned equipment replacement/decommissioning on specified schedule



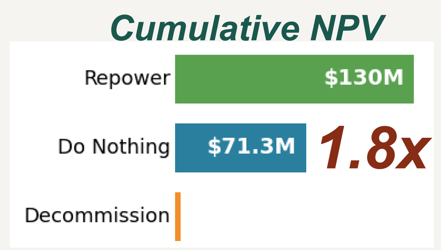
Type a degradation rate (%) or Fixed O&M cost ($) for each year. Degradation rates apply to Year 1 output.

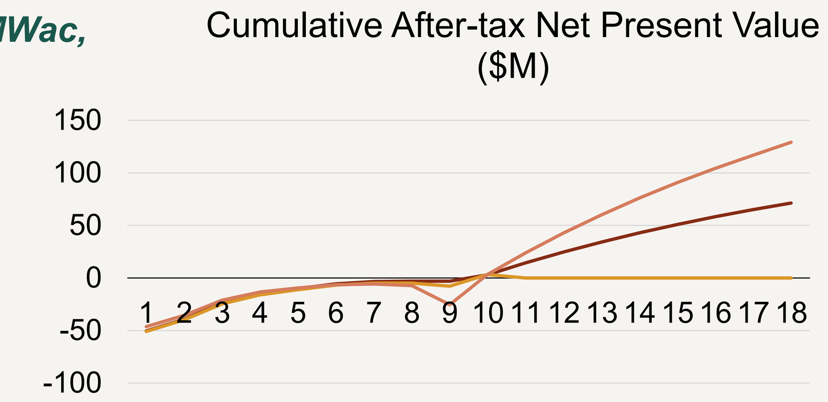
Preliminary Results

Decommissioning Cost Breakdown (Model Outputs)	
Direct Cost	**Amount**
Dismantling	
Labor Costs	15,250,770
Material Costs	262,385
Subcontract Costs (Material Management & Transportation Cost)	12,692,459
Construction Equipment Costs	2,446,175
Scrap Value	(3,301,850)
Repowering	
New Equipment Procurement and Installation Costs	180,700,000
Total Direct Cost	208,049,940
General Conditions	$43,740,965
Project Indirect Costs	$5,060,997
Contingency	$26,345,560
Escalation	
Net Repowering Cost (Dismantling Component Only)	$283,197,462
$/kWac	$1,379.43
$/module	$593.63

Decommissioning Cost Model: EPRI/NLR
A bottom-up cost model that estimates end-of-life costs for PV systems by accounting for equipment removal, labor, logistics, site restoration, and salvage value, enabling project-specific evaluation of net decommissioning costs.

***Site 1** – 2016, CA, 205.3 MWac, HSAT, deg = 0.4%/yr*





Key Insights

- Degradation + O&M ↑ → cashflow ↓
- PPA escalation partially offsets
- Financing structure creates inflection

Modeling Considerations

- In SAM, decommissioning and repowering costs may be modeled either as a reserve account (planned, anticipated costs) or as a one-time operating expense (unplanned events). Cost representation embeds financing assumptions and affects results.
  - Modeling a new mid-life investment for loan-financed repowering would require sequential modeling.
- Salvage value represents the net end-of-life cost or credit of the system, combining decommissioning costs and any residual value into a single terminal cash flow.
- Sensitivity analysis shows that degradation of systems has a big impact on the financial performance of the plant and what decisions an asset owner may make.
- While our analysis focuses on standard financial metrics (e.g., NPV, IRR), repowering and decommissioning decisions are fundamentally option-like. Asset owners retain flexibility to delay, stage, or abandon investments as uncertainty resolves—value that is not captured by static cash-flow metrics. This aligns with real options analysis, which treats repowering as a deferred or contingent investment decision rather than a fixed endpoint (e.g., see [5]). Although not implemented here, this framework is highly relevant for future work on repowering timing and financing.

What is the optimal time for repowering?
It cannot be defined in isolation—timing depends on uncertainty, asset type, site value, and comparison to competing investment opportunities.

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