Accelerating a sustainable, just, and equitable transition to zero-carbon electricity generation by 2035.

DuraMAT — Durable Module Materials Consortium

PVDeg: Development of a streamlined tool for PV degradation modeling

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PVDegradationTool | Multi-Scale, Multi-Physics Model

https://github.com/NREL/PVDegradationTools

Awarded FY22 Core Modelling Call

Period of Performance: FY23-26
Funding: $750k

Contribution to DuraMAT Consortium Goals – Project Overview

The goal of this work is to create an online tool that can be used to search for degradation information and extrapolate PV module performance and durability to field exposure. A graphical user interface will aid in the understanding of the results. The prediction tool will be built modular and published open-source allowing users to expand on the existing framework.

Project Highlights

- Searchable database of PV related degradation parameters.
- Open-source library for degradation analysis.
- Geospatial analysis via high-performance computing (HPC) and in aws (under development).
- User-friendly web application for single locations.

Impact

- Degradation occurs by many different modes and mechanisms each with very different dependencies on stress factors.
- To develop a 50-year module, one must individually address every failure mode and either eliminate it or minimize its effect. To do this, you first need to determine if it will happen in the field.
- The most difficult task in performance prediction is determining a degradation model and obtaining relevant degradation parameters. After that, the extrapolation is carried out using time consuming, repetitive and standardized methods for field extrapolation.
- This project is making simplified code enabling researchers to do this in a matter of hours instead of weeks. This will dramatically improve the accuracy, depth, and utility of these calculations.

How YOU can help

This will become a repository for a wide range of models and material parameters focused on PV degradation and failure analysis. If you have any Python code, Excel functions, formulas, data, or a impactful project you need help on, please contact us!

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Check out our GitHub repository!

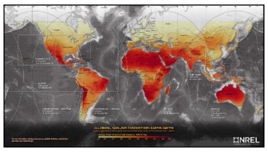
https://github.com/NREL/PVDegradationTools

GitHub

…and our example Jupyter notebooks in the demo folder!

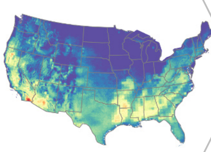
PV Degradation Tools – The PV focused, open-source, integration pipeline for PV degradation analysis!

Stressors – NSRDB | **Material Libraries** | **Degradation models** | **Geospatial Analysis**



DuraMAT DataHub

$$R_D = R_o G^p e^{\left(\frac{-E_a}{RT}\right)}$$



powered by: reV &gaps, pvlib, python, jupyter, The HDF Group, aws, binder

Python code library to simplify repetitive tasks

- Access meteorological data, perform geospatial analysis or monte-carlo simulations…
- Allow for easy extensibility to add new degradation related functions
- Standardize variable names and code communication.

Create living databases of information on degradation and material properties

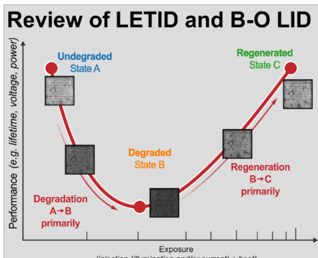
- Pre-defined set of material and degradation properties
- Allow users to add their own

Focus user experience

- Tutorials – based on Jupyter notebooks
- Create simple interfaces such that one does not need to be a Python expert to use the code.
- Scalability – from laptop to HPC for production of maps.

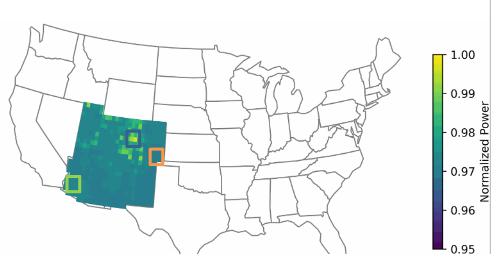
Example Application – Geospatial evaluation of LeTID

Review of LETID and B-O LID



J. Karas *et al.*, *Progress in Photovoltaics: Research and Applications*, 2022, doi: 10.1002/pip.3573.
I. L. Repins *et al.*, *MRS Bulletin*, 2023, doi: 10.1557/s43577-022-00438-8.

- Light- and elevated temperature-induced degradation (LETID)
  - Relatively recently-discovered degradation mode in silicon
  - Some early cases showed ~10% degradation; more typically 0-3%
  - Losses will eventually "regenerate", but this may take decades, depending on climate and technology
- Boron-oxygen light-induced degradation (B-O LID)
  - More well-known and better understood defect in mono c-Si
  - Motivated the industry transition to Ga-doped wafers
  - Compared to LETID: faster and less severe. Often accounted for by "First Year" losses in warranties and financial models.
- Both LETID and B-O LID can be described by a 3-state model
  - Degradation (A → B) followed by regeneration (B → C)
  - Kinetics and time constants are different in LETID and B-O LID, but they can be modeled similarly.
- Progression between states depends on time, carrier injection (either illumination or electrical current), and temperature.



LETID and B-O LID Modeling

Performance loss is a function of the number of defects in state B. → $Degradation \propto N_B$

Defect state transitions depend on simultaneous, competing reaction rates

$$\frac{dN_A}{dt} = k_{AB} \cdot N_A + k_{BA} \cdot N_B$$

$$\frac{dN_B}{dt} = k_{AB} \cdot N_A + k_{CB} \cdot N_C - (k_{BA} + k_{BC}) \cdot N_B$$

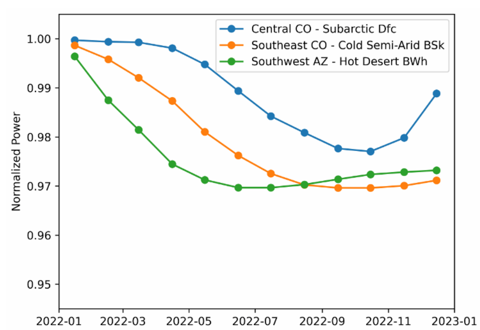
$$\frac{dN_C}{dt} = k_{BC} \cdot N_B - k_{CB} \cdot N_C$$

Reaction rates (k_{ij}) have Arrhenius behavior, with modification for injection (excess electronic carrier density in the device)

Kinetic parameters compiled from literature: $E_{a,ij}$ | v'_{ij} | x_{ij}

$$k_{ij} = v_{ij} \cdot \exp\left(\frac{E_{a,ij}}{kT}\right)$$

$$v_{ij} = v'_{ij} \cdot \Delta n^{x_{ij}}$$



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