A Comprehensive Database Approach to Track Industry Trends and Parameter Evolution in Photovoltaic Modules

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INTRODUCTION

"Specifications subject to change without notice"

Manufacturers of photovoltaic modules frequently update specification sheets throughout a product's commercial lifespan, making each version a unique revision. However, consumers, researchers, and academics often treat these sheets as consistently representative of a module, which they are not. This work presents data and observations from our module specification sheet database, designed to track revisions over time, identify industry trends, and assess how changes impact system modeling, performance analysis, and experimental work that compares module behavior to published data.

OBJECTIVES

1) Develop a methodology to determine cell architecture and size from provided data for modules lacking this detail.
2) Analyze parameter evolution over time and technology.
3) Determine the prevalence of revised specification sheets.
4) Identify which parameters are revised.

METHODS

Specification Sheet Data Collection

- Scraped from live websites and the Internet Archive [1]
- PDF uniqueness: SHA-512 checksum, part number
  9530 unique specification sheets collected (so far)
  850 sheets analyzed: 134 manufacturers for 3438 entries
- Manual data entry; creates a validation dataset for machine learning tools for automation
- Focus on electrical, mechanical, and thermal parameters

Analysis

- Procedures to determine cell size and architecture from layout and electrical parameters
- Current density estimates assume rectangular cells; precise cell area values cannot be determined from specification sheets
- Time series analysis for parameter evolution

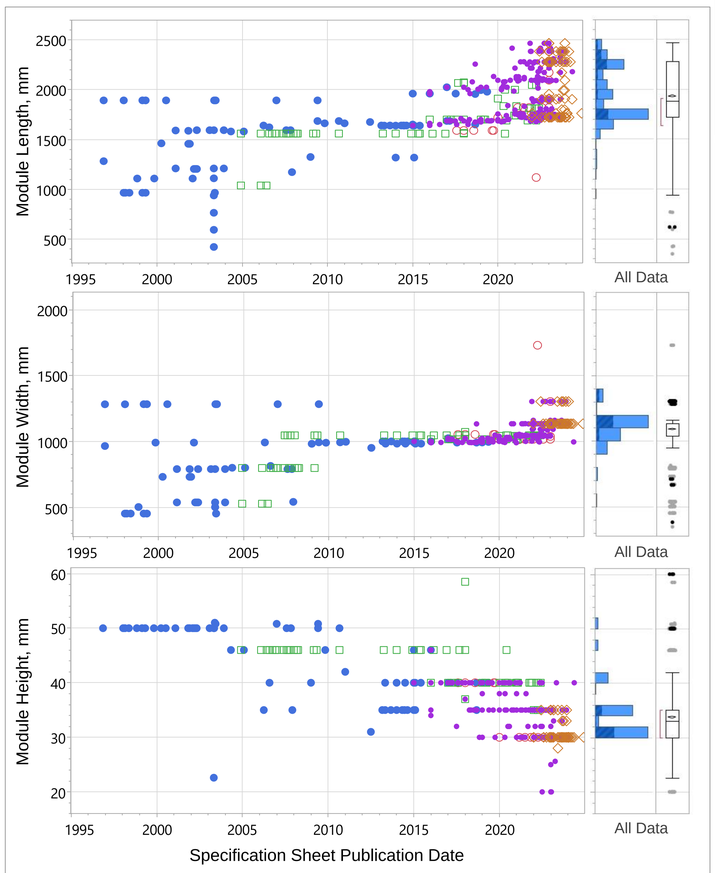

Fig. 1 – Module dimension evolution: longer, wider, and thinner.

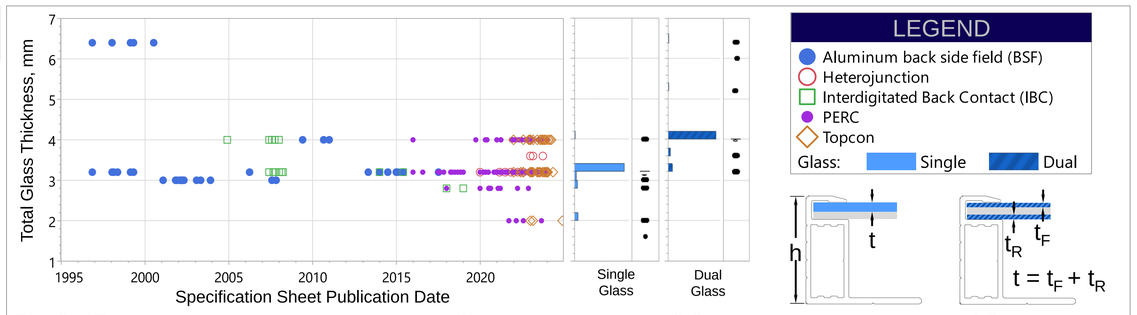

Fig. 2 – Total glass thickness is not trending. Single glass is mostly 3.2mm while dual glass totals 4.0mm.

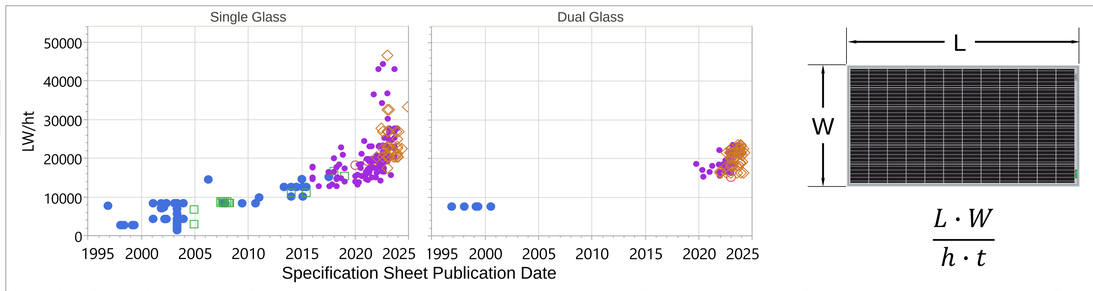

Fig. 3 – The LW/ht ratio for single- and dual-glass constructions from dated specification sheets is shown. The trend is driven by increasing 3.2mm single glass module sizes, while dual-glass modules are more clustered.

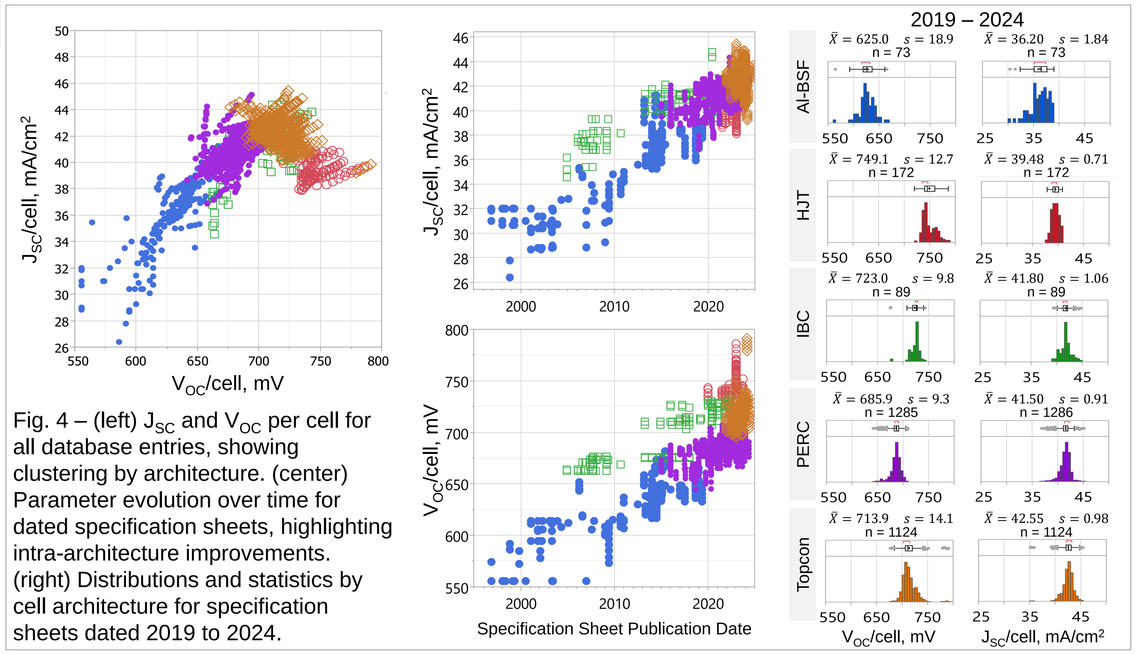

Fig. 4 – (left) J_{SC} and V_{OC} per cell for all database entries, showing clustering by architecture. (center) Parameter evolution over time for dated specification sheets, highlighting intra-architecture improvements. (right) Distributions and statistics by cell architecture for specification sheets dated 2019 to 2024.

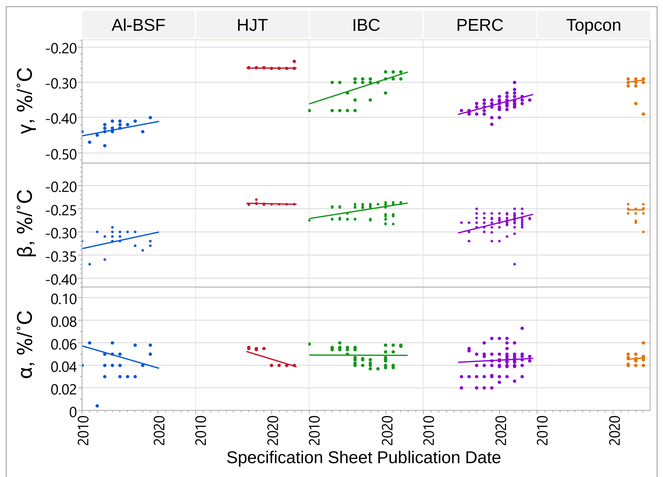

Fig. 5 – Temperature coefficient evolution by cell architecture.

Table I: Temperature coefficient statistics (dated 2019-2024)

Cell Architecture	n	α %/°C $\bar{X}$	α %/°C s	β %/°C $\bar{X}$	β %/°C s	γ %/°C $\bar{X}$	γ %/°C s
Al-BSF	77	+0.0481	0.0102	-0.322	0.0213	-0.411	0.0215
HJT	180	+0.0408	0.0027	-0.239	0.0058	-0.259	0.0101
IBC	98	+0.0498	0.0084	-0.243	0.0143	-0.286	0.0128
PERC	1372	+0.0461	0.0072	-0.274	0.0183	-0.348	0.0182
Topcon	1124	+0.0458	0.0023	-0.252	0.0072	-0.299	0.0129

Table II: Specification sheet revisions

Revision Count	Percentage
1	85.2
2	10.8
3	2.8
4	0.74
5	0.07
6	0.11
7	0.28

Table III: Specification sheet date types

Date Category	Percentage
No Date	33.0
Year Only	16.6
Year-Month	34.1
Complete	16.3

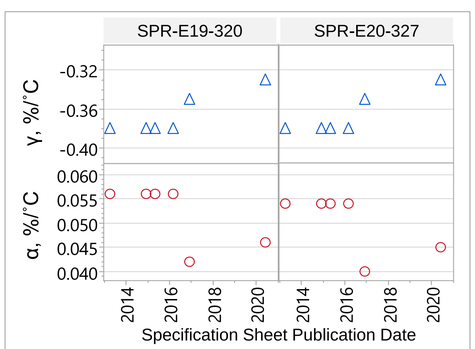

Fig. 6 – Example temperature coefficient revisions for two SunPower modules, each with six known revisions over seven years.

RESULTS AND DISCUSSION

Parameter Evolution Insights

- Modules are getting longer, wider, and thinner (Fig. 1)
- Total glass thickness is dominated by single glass (3.2mm) and dual-glass (4.0mm) with no obvious trend (Fig. 2)
- The dimension ratio trend is driven by length and width changes, primarily for single glass modules (Fig. 3).
- When not provided in the specification sheet (19.1%), cell architecture can be determined using calculated J_{SC}/cell, V_{OC}/cell, and temperature coefficients (β,γ).
- Error in calculated cell area from the rectangular cell simplification underestimates cell J_{SC}.
- Cell level V_{oc} may be impacted by cell interconnection.
- J_{SC}/cell and V_{OC}/cell scatter plot shows clustering by cell architecture (Fig. 4, left), similar to published plots [2].
- J_{SC}/cell and V_{OC}/cell time series show improvements within each architecture (Fig. 4, center). Technology distributions (2019-2024) are well defined (Fig. 4, right).
- Temperature coefficients are stable or improving over time for each cell architecture (Fig. 5). Distributions over the past 5 years are provided for comparison (*Table I*).

Specification Sheet Revision Analysis

- Up to 7 versions identified for some modules (*Table II*)
  - 14.8% of modules have multiple specification sheets
  - Major manufacturers represented up to 6 revisions
- Publication dates are important (*Table III*)
  - 67% with (year, year-month, or complete)
  - 33% without, thus lacking ability to place in context
- Parameters revised on modules with ≥3 revisions include:

Parameter	Percentage
Backsheet type, description, or thickness	44.1
Weight	36.0
Front glass thickness or type	34.2
STC current-voltage (I-V) parameters (V_{OC}, I_{SC}, V_{MPP}, I_{MPP})	26.1
Temperature coefficients (α, β, γ)	18.9
Faciality (monofacial, bifacial)	18.0
Length	14.4
Height	14.4
Series fuse rating	14.4
Snow and/or wind load	11.7
Width	9.0
System voltage (IEC or UL)	5.4
NOCT / NMOT	4.5

- Revisions may have modeling impacts, *e.g.* temperature coefficients (Fig. 6), emphasizing the importance of dates.
- Instances of "identical" specification sheets from multiple manufacturers differing only in manufacturer detail and model number – data, graphics, and text identical

CONCLUSIONS

- Parameter evolution and distributions provide context.
- A significant portion (14.8%) of the analyzed specification sheets have at least one known revision from the earliest publication.
- Revisions often affect technical parameters (I-V, temperature coefficients, physical dimensions), impacting PV array modeling and power production predictions.
- Revisions to the bill of materials may affect reliability.
- Revision dates are crucial for contextualizing technical data within a module's evolution; 33% are undated.
- Academic and research analyses should include the revision date (or other unique revision identifier) of a referenced specification sheet, not just the accessed date.

REFERENCES

[1] Internet Archive, "Wayback Machine," https://archive.org/, 2024
[2] Jordan, Dirk C., et al. "Photovoltaic fleet degradation insights." Progress in Photovoltaics: Research and Applications 30.10 (2022): 1166-1175.

This material is based upon work conducted and funded by Pordis LLC and University of Central Florida.
Presented June 9 – June 14, 2024, at the 52nd IEEE Photovoltaic Specialist Conference (PVSC) in Seattle, Washington, USA.

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