PV-Module's Backsheet Compositions Affecting PV-system's Yield and Degradation

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ABSTRACT This study links chemical analysis of PV-module's backsheet components with the monitored yield and voltage of PV. WE investigated several PV-systems all with two or more module types and differing backsheet types. We identified three classes of backsheets with respect to their influence on module performance. First, double-fluoropolymers are robust and modules perform constantly well over years. Second, non-fluoropolymers, show approximately linear performance and degradation and third, single-fluoropolymers show drastic performance losses, including inverter shut-downs. Humidity was identified as an important driving factor for the faster ageing process of modules with critical backsheets und isolation issues. A correlation between obvious backsheet defects, e. g. cracks or isolation issues and inverter shut-downs was not found.

INTRODUCTION

As part of the expansion of renewable energies with solar power worldwide, longer operating times (> 25 years) are increasingly being planned. When the time of "infant" failures (after the first 2 years) is over, it was previously assumed that only maintenance and servicing measures would be necessary. Recent publications show problematic performance losses due to degradation of the polymer components in the backsheets [1], e.g. "chal-king" [2], cracking [3] or delamination of EVA [4], after a few years of operation. In particular, Lechner et al. point out the critical ageing of polyamide (PA)-backsheets [3, 5]. The knowledge of the impact of certain backsheets on yield has not yet been presented, except for a study by Mütter et al. [6].

This work is in line with last year's EU-PVSEC presentations about problematic back-sheet performance in the field by Mütter and Lechner and provides insights into differing and sometimes catastrophic degradation rates of particular modules and backsheets of top-10 module sellers. Statistical evaluations (t-test, chi-square-test, two factorial analysis of variance) also support the statements regarding other causes of error, e. g. cell fracture.

EXPERIMENTAL PROCEDURE

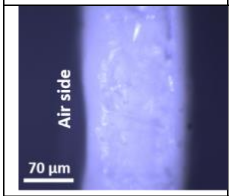
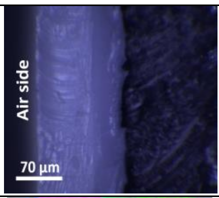
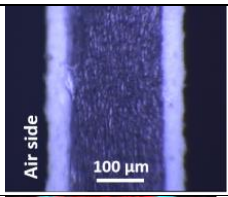
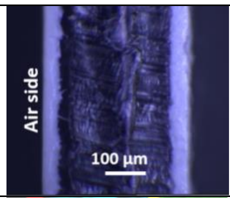
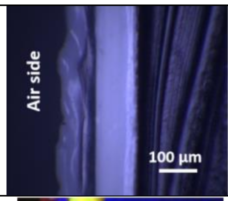
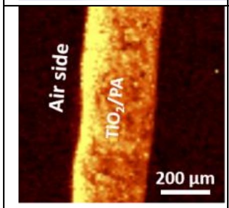
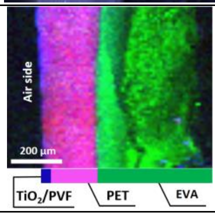
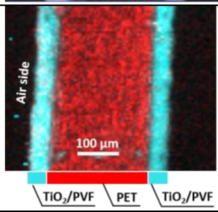
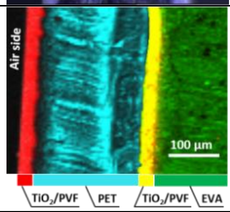
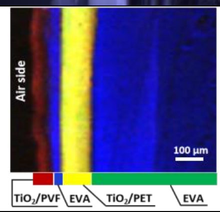
PV-modules of the top-ten-sellers worldwide and PV-systems with such modules were analyzed. The detailed discussion shown here includes three manufacturers A, B, C, and different module power classes I, II, III (190 W to 255 W). Beside the chemical analysis of the modules' backsheets, the electrical performance was studied using multi-year monitoring data (> 5 years) and IV-curves of single modules. The results are described exemplarily for mid-scale, roof-mounted PV-systems (200 kWp – 1 MWp) in Germany and a 1 MWp field installation in Southern Italy. The PV-systems were commissioned between 2010 and 2012. Typical for the inspected systems was the installation of at least two nominally identical module types exhibiting different bills of materials (BOM) - particularly different backsheets - at the same site. This enabled the comparison of the performance data.

For characterizing the PV-system, visual in-spections, IR-imaging, analysis of the moni-toring (AC and DC voltage and yield data on string-, tracker-, and inverter-level as well as temperatures for > 5 years) and weather data [7] were carried out. The lab analysis of several modules from the same PV-system included Raman microscopy and Near Infrared absorption (NIRA) spectroscopy [8], thermogravimetry (TGA), differential scanning calorimetry (DSC) of the backsheet and IV-measurements and EL-imaging of the modules.

RESULTS AND DISCUSSION

How complex the impact of backsheets on the performance of PV systems can be, is discussed using five examples. These examples are from 2 PV-systems, modules with BS1, BS2 and BS3 are installed in a German roof-top system, modules with BS4 and BS5 are in an

Table 1: Microscopic and Raman analysis of five backsheets BS1 – BS5, (from top to bottom: chemical components including layer thickness d, microscopic image, Raman image visualizing the component distribution, module types)

BS1	**BS2**	**BS3** – close to standard Tedlar	**BS4**	**BS5**
	Air layer: PVF/TiO_2 ***d* = 15 - 20 µm**	Air layer: PVF/TiO_2 *d* = 45 - 50 µm	Air layer: PVF/TiO_2 *d* = 30 - 40 µm	Air layer: PVF/TiO_2 *d* = 50 - 60 µm
core layer: TiO_2/PA *d* = 300 - 350 µm	core layer: PET *d* = 220 - 250 µm	core layer: PET *d* = 240 - 250 µm	core layer: PET *d* = 200 - 210 µm	core layer: EVA (+glass fibres) *d* = 30 - 40 µm
		inner layer: PVF/TiO_2 *d* = 45 - 50 µm	inner layer: PVF/TiO_2 *d* = 30 - 40 µm	inner layer: PET/TiO_2 *d* = 100 - 110 µm
				
				
Module type AI[1] Module type AIIa	Module type AIIb Module type AIII	Module type BI	Module type CIa, CIIa	Module type CIb, CIIb
	Thin PVF air layer		No adhesive, delamination	Thin backsheet

[1]A, B, C = module manufacturer, I-III = power class, a, b = variations of one module type

Italian PV-plant. Thus, differing backsheets at one or the other PV-installation at comparable operating conditions.

Visual inspection

Visual inspection of the roof-mounted modules AI, AIIa and B revealed no abnormalities. Modules from type AIIb, AIII showed micro- or macrocracks in the EVA and corroded interconnects in some modules. In the field PV-system (with 4,500 modules C), a matt (85% of all modules) and a glossy (15%) backsheet had been used for the installed module types. 8.5% of all backsheets showed cracks, blisters and tattered/burst areas. Statistically significantly more affected back-sheets were glossy ones by 9%, whereas from the matt ones only 3.6% show damage.

IR inspection, thermography

Infrared inspection of the Italian PV-system in 2017 revealed thermal irregularities of about 4 K for roughly 9% of the modules. A significantly higher amount of suspicious modules was found in the lower row than in the upper one. IR-images of the German PV-systems were without irregularities.

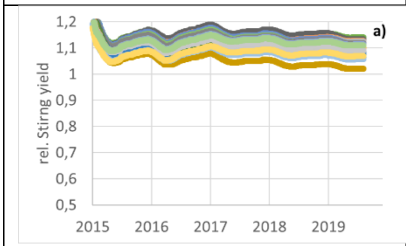
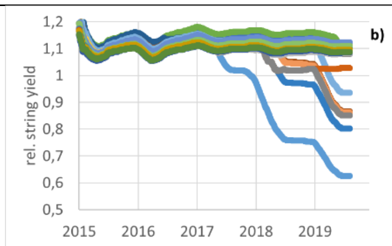
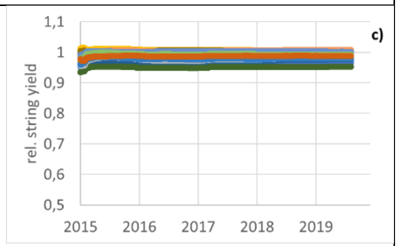
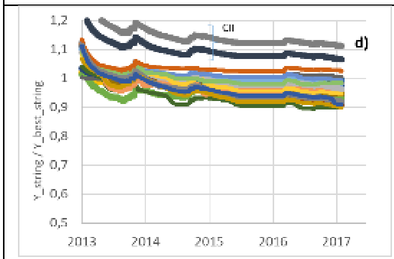
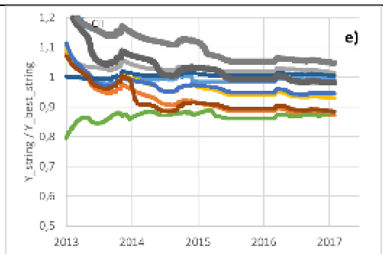
Chemical analysis

Table 1 gives an overview the backsheets architecture. Whereas BS1 is PA-based, the others are polyethylene terephthalate (PET)-based backsheets. PET films are coated with protective layers to improve their weather resistance, e. g. (polyvinyl fluoride PVF, “Tedlar”), compare BS2 - BS5. However, for sufficient mechanical, electrical and chemical protection an (outer) air layer of at least 25 µm is recommended [9]. The air layer of BS2 with 15 to 20 µm is rather thin. BS3 and BS4 could be considered a typical “Tedlar”-based backsheet. However, glossy BS4 shows a rather thick but delaminated PVF/TiO_2-layer without any contact to the core PET-layer. This is probably due to a degraded or missing adhesive. Thus, a robust double-fluoromeric backsheet requires besides a thick PVF air-layer a good adhesive for a stable and long-lasting backsheet architecture. Matt, textured BS5 is a fairly thin and flexible backsheet and features a noticeably thin PET layer. The total BS-thickness of about 200 µm in combination with the layer composition seem to be an unsufficient protection for the PV-module due to the observed blisters, cracks and torn areas. It is not unusual to find different backsheets with different properties on modules of the same type. We identified three classes of backsheets: double-fluoropolymers, single-fluoropolymers and non-fluoropolymers.

Analysis of electrical data

For performance and degradation analysis the yield of the strings, trackers, inverters and PV-plants are analyzed. For better comparison, data are normalized to a nominal power and the number of modules per unit (string, tracker, inverter). Then, the string and inverter data are cumulated over time and related to the best performing unit in the PV-system (consequently, the analysis does not show the reduction in yield over time that is typically associated with degradation) [10]. The performance analysis of the backsheets BS1 – BS5 is compared in Table 2. Modules with the PA-based BS1 show a fairly constant and equal yield reduction of 0.12 ± 0.3%/year. The yield of modules with PET-based BS (BS2-BS5) can differ strongly. While BS3, whose BS architecture is close to standard “Tedlar”, shows constant yield throughout the investigated period, BS2, BS4 and BS5 degrade significantly, most likely due to isolation issues. BS2 has a rather unpredictable performance, is ranges from continuous yield reduction of 0.6 ± 0.5%/year to spontaneous, catastrophic yield loss of more than 20% in one year for 25% of the strings if there is no intervention in the electrical operation of the affected system part. For modules with BS4 and BS5 the yield loss is about 1-5% per year. In this case, modules CIa and CIb perform worse than CIIa and CIIb, probably due to differences in module quality. The strongest yield loss is observed for module CI with BS4. With increasing module number with torn backsheets the yield drops drastically.

Table 2: Ratio of the string yield versus the yield of the best performing string for the PV-system. Values above 1 indicate that the reference, the best-performing string is not necessarily the string with the highest performance, respectively the largest yield. BS1, BS2, and BS3 belong to one PV-system in Germany, BS4 and BS5 to one in Italy. Each line marks a different string.

BS1	BS2	BS3
		
BS4	**BS5**	
		

Analysis of weather data

Analysing the weather data, a connection between the relative string voltage and relative humidity in dependence of the backsheet type was observed. Figure 1 depicts the relative string voltage for the same time period of five years as shown in Table 2 for BS1, BS2, and BS3 for every day. In the middle of the year the relative humidity is rather low, for autumn, spring and winter the rel. humidity increases up to 100%. Whereas modules with double fluoropolymeric BS3 in Figure 1c show no changes of relative string voltages, changes throughout the years of operation are observed for the modules with other BSs. Modules with non-fluoropolymeric BS1 in Figure 1a perform equally in the first years. With beginning of 2017 (after approx. five years of operation) the voltage is negatively influenced by increased humidity. A drastic impact of the humidity on the voltage is registered for modules with single-fluoropolymeric BS2 as seen in Figure 1b. This is a strong indication of humidity-driven BS degradation, which is fairly slow for non-fluoropolymers but fast for single-fluoropolymers. Thus, isolation issues affect the string / system performance significantly and may even result result in inverter shut-downs.

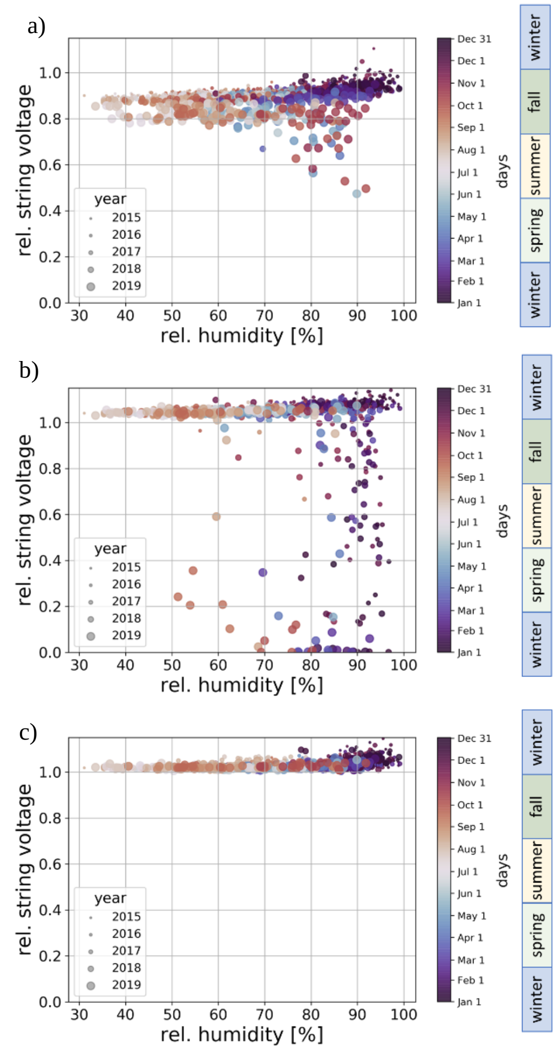


Figure 1: Relative string voltage versus relative humidity for five years for module strings with differing backsheets at the same site, a) non-fluoropolymer BS1, b) single fluoropolymer BS2, c) double fluoropolymer BS3

Exposition of main findings

The long-term stability of the backsheet can differ strongly, as shown exemplarily for three manufacturers. Independent from the manufacturers, three main backsheet classes are identified according to their impact on the electrical performance. Inverter shut-downs are often related with isolation issues of the modules. The ageing can be slow but at a constant rate for years, as seen e. g. in PA-based backsheets (non-fluoropolymeric backsheet) or PET-based backsheets with thick outer PVF-layer (double-fluoropolymeric backsheet). On the other hand, the ageing of PET-based back-sheets with only one outer PVF-layers (single-fluoropolymeric backsheet) and double-flouropolymeric backsheets with improper stack properties seem to follow two time regi-mes: 1) slow and constant ageing, 2) strong spontaneous ageing, as described by Mütter et al. [6]. Humidity is the dominant driving factor for isolation issues and early ageing results [11, 12]. Furthermore, thick backsheets may fail due to missing or degraded adhesives or degraded air layers, as seen for BS4 and BS5.

In conclusion, several factors are of importance for backsheet failure. Examples are choice of material, stacking, and layer thickness of the backsheet, module quality, and environmental conditions.

CONCLUSION

The importance of this work becomes clear when one considers the global installations of 202 GWp in the years 2010 to 2015, with a single top-ten module manufacturer having delivered around 12 GWp of modules in that period alone. Many of these modules have back-sheets that are similar to the ones we studied, and many more backsheet related failures can be expected in the coming years.

The relationships that lead to material failure, isolation issues and operational failure are complex. The use of fluorinated Tedlar components does not yet mean that a backsheet performs well, or that a PV module is weather-resistant and durable. A potential risk to product safety only becomes apparent after years of operation and is not necessarily reliably identified during the warranty check nor included in the system invest. This means that more attention will have to be paid to the bill of materials (BOM) in the future and that the understanding of material degradation and interaction under operating conditions must be deepened.

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