Rijksdienst voor Ondernemend
Nederland

Final report

Energy yield assessment of neXT gENeration and SustaInaBLE backsheets (EXTENSIBLE)

Public summary

Project information

Project number: TEuE119008

Project title: Energy yield assessment of next gENerartion ans SustainaBLE backsheets (EXTENSIBLE)

Project manager and participants:

- Endurance Solar Solutions bv (penvoerder)
- IMEC/EnergyVille
- DSM ACC
- SmartGreenScans

Project duration: 01-03-2020 – 31-08-2022

Het project is uitgevoerd met subsidie van het Ministerie van Economische Zaken en Klimaat en het Ministerie van Landbouw, Natuur en Voedselkwaliteit, Nationale regelingen EZK- en LNV-subsidies, Topsector Energie uitgevoerd door Rijksdienst voor Ondernemend Nederland.

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1. Summary

1.1. Introduction

In the past years, solar PV has established itself as the main pillar for a carbon-free energy system that should limit the consequences of global warming to a minimum in this century. Rapid scaling and innovation of the supply chain are key to secure continued growth in PV deployment. Cost, efficiency, reliability and sustainability. They all need to be improved. However, PV modules and materials are mostly selected based on their €/Wp cost and minimum performance requirements under accelerated test conditions. This neglects improvements that lead to lifetime energy yield increase as well as environmental impact reduction. Today, these kind of innovations are confronted with a long acceptance time by the downstream market. Requiring years of field proof before large volume demand can kick off. This raises the need for a novel approach in assessing performance of PV materials and technologies.

Backsheets are a typical examples of module components that play a critical role in the lifetime yield and environmental impact of the PV module, while having less direct impact on module nameplate capacity and total module cost. Most polymeric backsheets are laminated multi-layer films based on an electrical insulating PET core film. Fluorine containing outer layers provide the backsheets with sufficient outdoor durability (sun, rain, temperature). These are either coated or laminated (as a film), using solvent based adhesives, onto the PET core film. The use of fluorine, adhesives and multi-material stacks increase the environmental impact of backsheets and make them more difficult and costly to recycle.

1.2. Objective

The main goal of EXTENSIBLE was the lifelong and precise energy yield and lifecycle assessment (LCA) of novel backsheets at various climates. The project partners gathered data to precisely calculate two key metrics: kWh/kWp and environmental impacts per kWh produced in the lifetime of the PV system. On the short-term these indicators will enable the selection of the relevant backsheet types for specific climates. Moreover, the project aims to prove that halogen-free backsheets can meet and even outperform conventional ones. On the longer-term, the insights will provide guidelines to more sustainable material formulation. Developing a degradation rate modelling is an enormous undertaking, beyond the grasp of this project, however, we used a semi-empirical method to resolve the evolution of the backsheet, laminates related to degradation.

1.3. Method

Within the EXTENSIBLE project, the partners have gathered input data to calculate through simulations two key metrics: kWh/kWp energy yield and environmental impacts per kWh produced during the lifetime of the PV system. Input data for the lifetime yield simulations were generated via accelerated aging tests and 1 year of outdoor exposure. By combining initial yield simulations with degradation rate predictions the lifelong energy yield has been estimated. Finally, through life cycle analysis (LCA), the environmental impact per kWh produced was calculated.

In total, 7 different polymeric backsheets and a glass-glass reference have been evaluated. The group of polymeric backsheets includes 3 traditional PET based backsheets with a fluorine containing outer layer. Two of them are white pigmented and 1 is fully transparent. The other 4 backsheets belong to a new group of co-extruded polyolefin backsheets (HPO). They all consist of a robust polyolefin core layer and differ by the outer layer polymer, i.e. polyamide, polyester or polyolefin. Also in this HPO group of backsheets there is one transparent version.
In the mini-module evaluations, two types of EVA encapsulants have been assessed, an ultra-fast and standard cure type of EVA encapsulant.

1.4. Results

The two families of backsheets (PET and HPO) show different mechanical behaviors. Due to the bi-axially stretched PET base film, the PET based backsheets are stiffer (Emod) and stronger (σ_b). However, the HPO backsheets are much more ductile (ε_b) and show 15-20abs.% higher reflectance (white backsheets only). Depending on the cell gap, the latter can potentially provide higher module nameplate capacity (excluded in this study as it makes use of single-cell module system for simulations).

Retention of mechanical performance under DH and UV accelerated aging of the HPO backsheet coupons is superior. Under DH, all coupons cut from PET based backsheets become brittle after 2000h while mechanical characteristics of HPO backsheet remain stable up to DH6000. Under UV (measured till 1600h only) the difference in retention is less pronounced and retention is stable after 800h. Absolute retention rate for PET backsheets falls to 40-50% while for HPO backsheets retention remains at 60-80%.

Both PET and HPO white backsheets show yellowing under aging. For DH this yellowing is more pronounced and stronger in case of PET based backsheets. PET is more susceptible for possible oxidation reactions compared to the relatively inert PP. Both transparent backsheets show increased haziness under UV and DH aging, with this increase being larger for the PET based backsheets.

When laminated into a module stack, all backsheets provide sufficient protection to the PV cell under accelerated aging conditions to pass the 1xIEC conditions, i.e. DH1000, TC200 and UV 60kWh/m^2 (=740h). Under TC and UV aging, for all backsheets the mini-module power retention remains >95% even up to TC200 and UV4000. Only for DH aging conditions we see a strong drop in module power at longer aging times. Similar to the DH results on backsheet coupons, the mini-modules based on PET backsheets show an earlier drop compared those obtained with HPO backsheets.
Which, in terms of DH stability, even outperform the glass-glass mini-modules. EL images of the aged mini-modules confirm the IV measurement results. On the DH images dark inactive areas occur, especially along the busbars, as soon as the power starts to drop.

Due to unforeseen circumstances the planned 1-year outdoor exposure of mini-modules in three different climates could only be finished in Genk (moderate climate). No significant changes were observed for any of the mini-modules under these climate conditions for just 1 year, neither in IV results nor in EL images.

For predicting the initial energy yield, a simulation model composed of an illumination, optical, thermal and electrical model, has been created. The model is calibrated by using measured weather data and initial and aged material properties. In a bifacial system configuration (Albedo 0.2), the simulation indicates a gain of 9-12% for glass or transparent polymer backsheet vs a white backsheet. Modules with transparent backsheets generate 1-3% less yield compared to glass-glass modules despite their average operating temperature being ~0.5°C lower. In warmer climates this difference becomes less. As the white PET backsheets have less reflection and more transmission vs white HPO backsheet the PET backsheets show ~1% less yield loss vs glass-glass modules in the simulations.
In the bifacial model used, the backsheet transmittance is the main factor influencing the energy yield. In general, total optical losses are higher as thermal losses. The model neglects frontside reflection of (white) backsheets and diffuse light capturing capabilities of transparent backsheets due to which the simulation results can have a mismatch with actual yield performance of full size modules.

A lifelong energy yield prediction can be derived from the initial energy yield and degradation rate of each module. Degradation rates have been calculated using a simulation model that includes three degradation mechanisms, hydrolysis, photodegradation and thermomechanical degradation. To calibrate the model, parameters were extracted based on the 12 months outdoor testing results in Genk. It should be stressed that because the calibration was based on a single location (Genk) and just one year of outdoor performance, the calculated degradation rates have a low reliability. Nevertheless, derived degradation values are at a level normally seen in the industry. The degradation rates show large dependency on type of encapsulant (EVA standard vs ultra-fast cure) and climatic conditions. When the impact of EVA is excluded, differences in degradation rate between backsheets show a consistent picture for all climate zones. Both transparent and white HPO as well as the transparent PET backsheet based on Tedlar provide highest protection against degradation under all climatic conditions. Module protection even meets that of glass. PET backsheets with outer layers based on PVDF or fluoro-coating provide lowest protection. (see fig.1)

The carbon emissions (in kg CO_2-eq/kg) or Global Warming Potential (GWP) of all backsheets during production have been calculated according to IPCC2013_GWP100a using the EcoInvent database. In general, the HPO backsheet production shows significant lower GWP as for the two fluoro-backsheets. Leaving out the TiO_2 pigmentation, further reduces the GWP for the Endurans transparent backsheet. Both 2 and 3.2 mm solar glass have a GWP far beyond all other backsheets. The contribution of the backsheet to the carbon footprint of a full module production is rather small (~1%). This is also valid for all other environmental impact categories next to climate change. The only exception is the ozone depletion in case of PET based backsheets due to the emission of a bromine containing halogen compound during PET production. Due to its PO base and the absence of TiO_2 the Endurans transparent backsheet shows best environmental performance for all impact categories.

For carbon emission assessment during the end-of-life phase, two technologies have been considered. Incineration (waste-to-energy) and pyrolysis. When the backsheets are incinerated the amount of process heat generated, i.e. amount of avoided carbon emission, is more or less the same for all backsheets. However, fluoro-polymers release highly corrosive FH, so should be handled in specialty incineration plants at significantly higher cost. Treatment of the HPO transparent backsheet in a pyrolysis process results for 90% in oils and gases that can be used as feedstock again for production of chemicals. For the fluoro-based transparent backsheet this is less than 45%.

For assessing cradle-to-grave carbon emissions (GWP) and environmental impact per kWh, the calculated degradation rates and initial yields are translated into lifelong (30yrs) energy yield. The lowest GWP per kWh produced is achieved with modules that contain the HPO backsheets, irrespective of the EoL technology (incineration or pyrolysis), climate zone backsheet pigmentation (transparent or white) or even EVA type (the latter except for D-G1-HQ). Using pyrolysis i.o. incineration as EoL technology, the lower impact of HPO backsheets becomes more pronounced and the transparent HPO does even reach negative emissions in high irradiation regions. (see fig.2)

From the environmental impact assessment over the cradle-to-grave lifecycle of the backsheets it is concluded that the HPO backsheets show lowest impact per kWh produced for all categories. The production of fluoro- and PET-based backsheets cause substantial environmental impacts regarding climate change and ozone depletion.

1.5. Recommendations

Because of the bifacial simulation model used, optical transmission is the key backsheet property influencing initial energy yield. This is further strengthened by the fact that the simulation model excludes the contribution of backsheet reflection to the energy yield. For mono-facial modules with pigmented backsheets, cell side reflection of the backsheet adds several %'s to the module capacity. This is especially the case for the HPO backsheets as they have a reflection which is 15-20% higher as PET based backsheets. It is recommended to expand the optical model with internal backsheet reflection.

Because the calibration of the lifelong yield simulation model was based on only one single location (Genk) and on just one year of outdoor performance, the calculated degradation rates have a low reliability. To increase reliability of the degradation rate calculations it is recommended to improve the degradation simulation model by calibration with further outdoor data from different climate zones and longer exposure time. Also, the impact of EVA type should be studied in more detail for each type of backsheet.

The production of fluoro- and PET-based backsheets cause substantial environmental impacts regarding climate change and ozone depletion. The large ozone depletion potential of all backsheets containing PET film is due to the emission of a halon compound in production of terephthalic acid. Further validation of this high ozone depletion potential is recommended.

1.6. Graphs

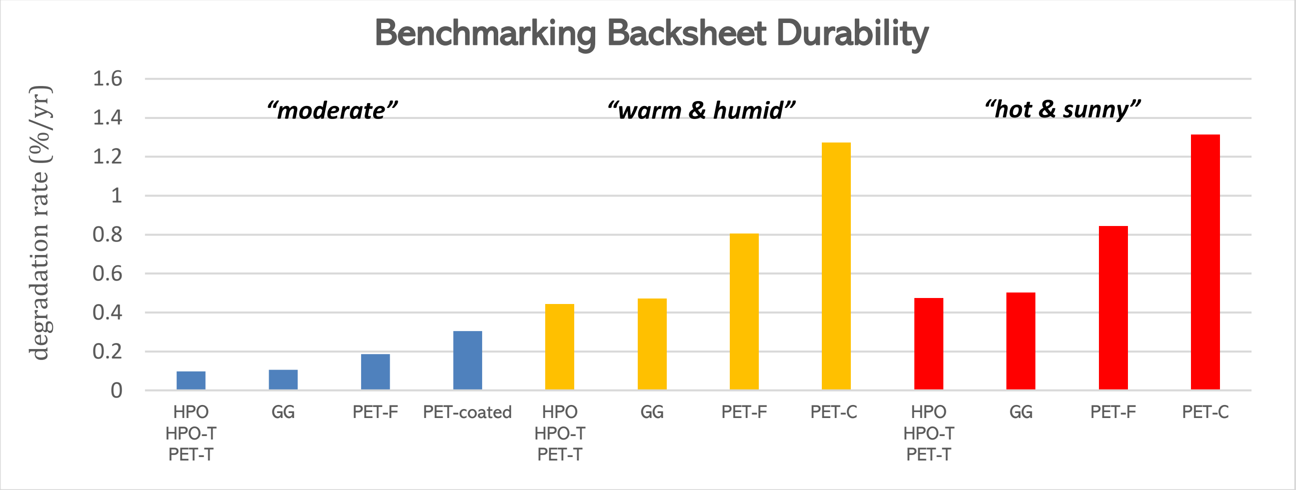

Figure 1: Module degradation rates per backsheet type under different climatic conditions.

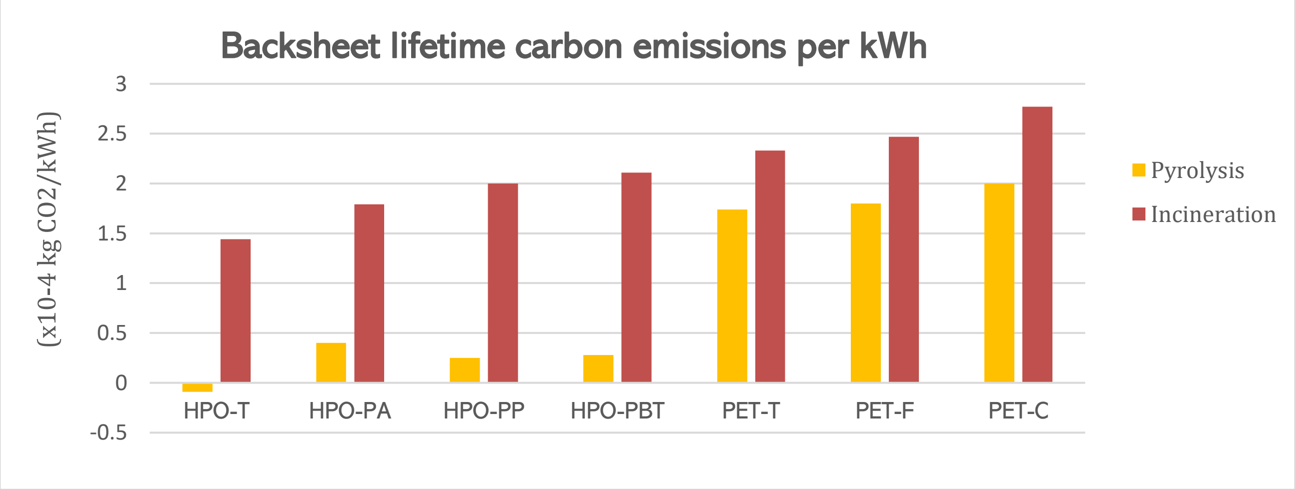

Figure 2: Backsheet cradle-to-grave carbon emissions per kWh generated (Kuwait) over 30years operational life and per EoL technology

Sample abbreviations

HPO-T: transparent polyolefin backsheet
HPO-PA: white polyolefin backsheet with PA outer layer
HPO-PP: white polyolefin backsheet with PP outer layer
HPO-PBT: white polyolefin backsheet with PBT outer layer
PET-T: transparent PET backsheet with PVF outer layer
PET-F: white PET backsheet with PVDF outer layer
PET-C: white PET backsheet with coated fluorine outer layer