Energieforschungsprogramm

Publizierbarer Endbericht

Programmsteuerung:
Klima- und Energiefonds

Programmabwicklung:
Österreichische Forschungsförderungsgesellschaft mbH (FFG)

Final Report

06/11/2018

Project Title:

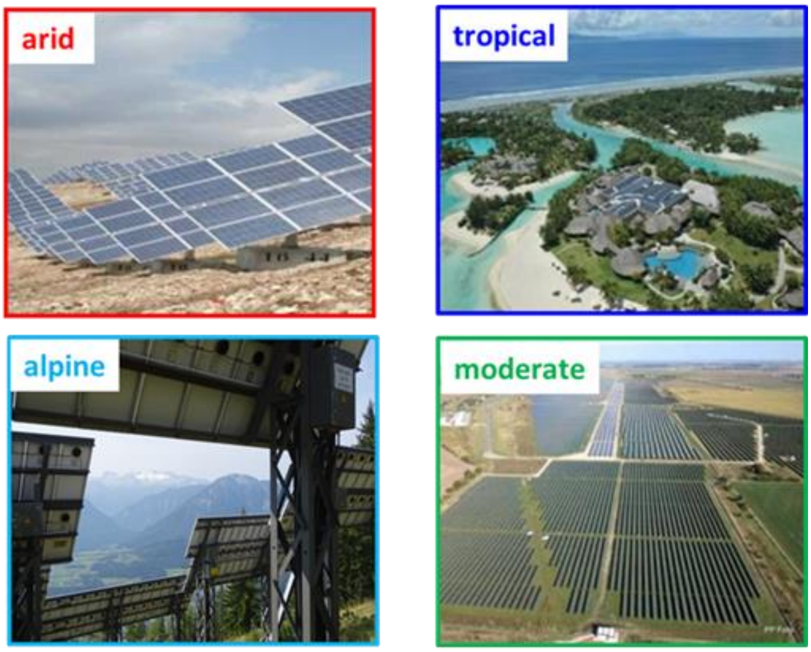
INFINITY - CLIMATE SENSITIVE LONG-TIME RELIABILITY OF PHOTOVOLTAICS

Project Number: 850414




Ausschreibung	1. Ausschreibung Energieforschungsprogramm
Projektstart	01/11/2016
Projektende	31/10/2018
Gesamtprojektdauer (in Monaten)	36 Monate
ProjektnehmerIn (Institution)	AIT Austrian Institute of Technology GmbH (A) ENcome Energy Performance GmbH (A) FH Technikum Wien (A) Fronius International GmbH (A) Infineon Technologies Austria AG (A) Isovoltaic SOLINEX GmbH (A) PV Products GmbH (A) OFI Technologie & Innovation GmbH (A) PCCL Polymer Competence Center Leoben GmbH (A) Polytec PT GmbH (D) PVI GmbH (A) PVSV e.U. (A) Ulbrich of Austria GmbH (A)
AnsprechpartnerIn	Dr Christina Hirschl, CTR
Postadresse	Europastraße 12, Technologie Park, 9524 Villach
Telefon	+43 4242 56300 260
Fax	+43 4242 56300 400
E-mail	Christina.hirschl@ctr.at
Website	www.ctr.at

CLIMATE SENSITIVE LONG-TIME RELIABILITY OF PHOTOVOLTAICS



Authors:
Dr Christina Hirschl, CTR
Lukas Neumaier, MSc, CTR
Dr Rita Ebner, AIT
Dr Gabi Eder, OFI
Dr Gernot Oreski, PCCL
DI Karl Knöbl, FHTW

1 Table of contents

2 Introduction

The project INFINITY aimed for **solutions for the future climate-related challenges** of the PV market and the **global need for cost-efficient materials** for PV systems with enhanced energy yields optimised for different climate zones. The specialty of INFINITY was the **combined bottom up and top down approach** (Vision of Infinity, see Figure 1). Thus, an analysis of shortcomings, failures and degradation processes of existing PV materials, components, and modules was performed related to the stress conditions. It was followed by an adaptation along the module value chain, including embedding foils, ribbons, inverters, etc., through application-customized solutions. The **industry-driven** consortium worked on elaborating technically customized and site-sensitive guidelines for the effective monitoring and maintenance of PV modules. As a result, optimised materials for PV modules with **climate-related**, increased system life-times were developed and implemented to guarantee PV-competitiveness and reach the goal of a reliable and stable future energy source.

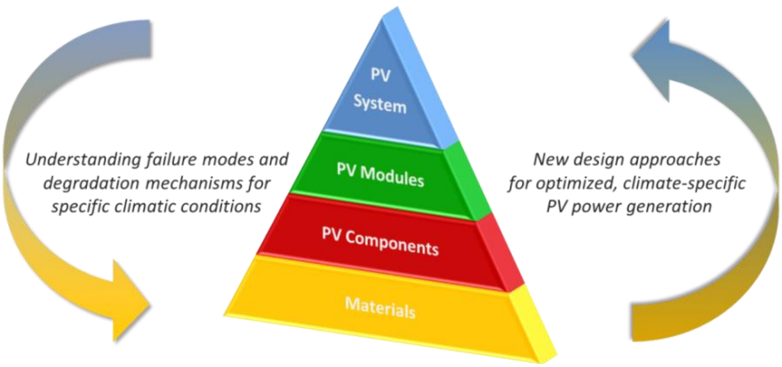


Figure 1 Vision of INFINITY

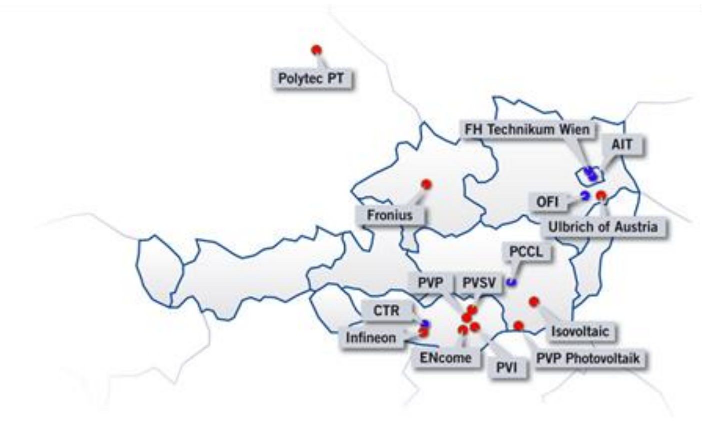


Figure 2 INFINITY Consortia

Aiming for excellence requires a perfect consortium for the challenges mentioned above. Using an integrated approach, in INFINITY **9 industry partners** and **5 research organisations** worked together, as illustrated in Figure 2. The consortium was built up by eight Austrian company partners (PVP Photovoltaik, Fronius, Infineon, ENcome, PVI, PVsV, Ulbrich, Isovoltaic) - many of them with an **international lead position** in their sector - one international partner (Polytec PT) and five experienced Austrian R&D institutions (CTR, AIT, PCCL, OFI, FH-TW). The project coordination rests at CTR and the scientific leadership at AIT. Four of the industry partners are SMEs.

Each partner contributed its own outstanding technological competence and application experience to the cooperation, ensuring the intended **application-oriented focus** of the flagship project INFINITY and warranting full technological and economic coverage, efficient, targeted work execution, and optimal exploitation of the project results. The research work took place in constant close collaboration; permanent work coordination streamlined the efforts and helped avoiding unnecessary redundancies. Related activities include regularly held project meetings, expert discussions and also personnel exchange between the partners. A good indicator for the resulting fruitful cooperation between the consortium members are already discussed **further project ideas** (only the ones for 2018: Advanced, INCREASE, OptPV4.0).

The available expertise in this core consortium is further complemented by a number of interested supplementary partners and discussion partners all around the world (Chilean Solar Strategy-Chile, Lux Research Inc.-USA, IRESEN-Morocco, Swimsol-Maldives, Leoni from Switzerland).

The project was structured in six work packages where the overall structure was always divided in three parts (see Figure 3):

- Analysis of failures, understanding of failures
- Material/component conception and development
- Climate-specific solutions

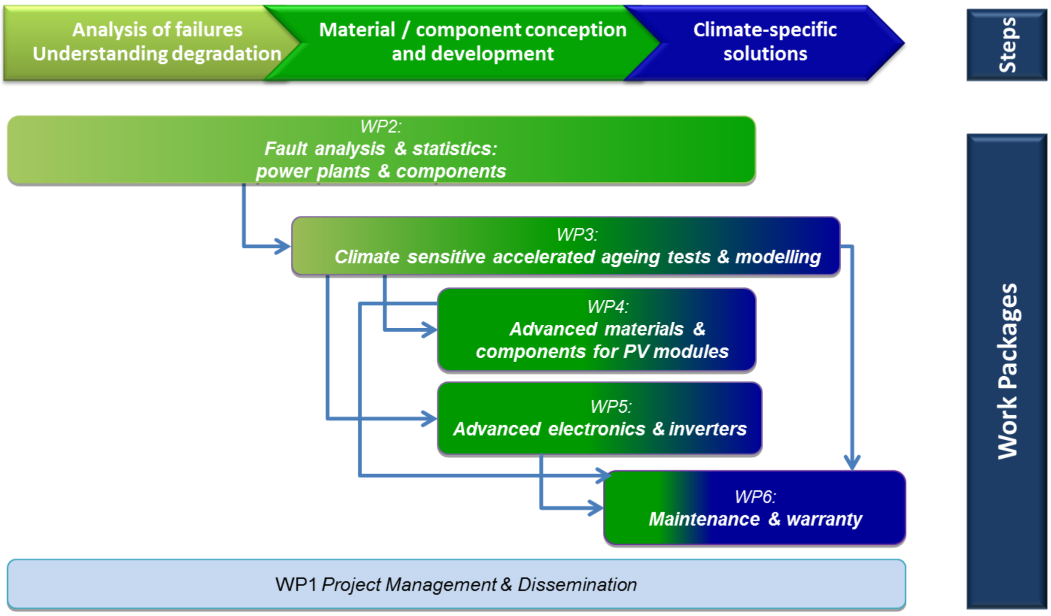


Figure 3 Example Work Package structure of INFINITY

The key objective was to jointly conduct application-oriented research in the areas of

i) **application-, climate- and life-time-optimised components and materials for photovoltaic systems** and

ii) innovative **methods and tools for PV installation analysis, monitoring and control.**

The project addresses call topic 3 - **Renewable Energy**, sub-topic 3.2 – **Photovoltaics** of the project call, and contributes to all three goals of the call as follows:

- With the flagship project INFINITY more PV could be installed that will produce energy for a longer period of time, due to the **higher reliability and improved materials and systems** (call Goal 1).

- In INFINITY the consortium worked successfully to ensure **affordable, reliable** and **sustainable** energy supply in different climate zones and make PV System in general more durable. With developing optimised materials and maintenance strategies PV should become **cheaper and more efficient** within the upcoming years (call Goal 2).
- The flagship project INFINITY succeeded at contributing significantly to creating technically and commercially viable solutions to these challenges (call Goal 3)
  - Improving **applicability**, **performance** and **operational life-time** of PV systems
  - **Methods** and tools for PV installation **analysis**, **monitoring** and **control**
  - Creating **new markets** and improving the **international competitiveness**

With these contributions INFINITY improved technological leadership and enhancing international competitiveness for company and scientific partner as well.

3 Content-related description

There have been **six major objectives** defined as overall goals for the flagship project INFINITY. The first objective was the **identification of shortcomings** of the presently produced and installed "**standard**" PV materials/components/modules/inverters with focus on the dependence of aging, degradation and failure behavior on the **environmental and climatic conditions**, where the modules and inverters were operating in.

- ➢ Establishment of the INFINITY Failure Data Base (Figure 4)
- ➢ Huge knowledge on different failure modes
- ➢ Statistical evaluation of gathered data
- ➢ Correlation of failures and climate zones

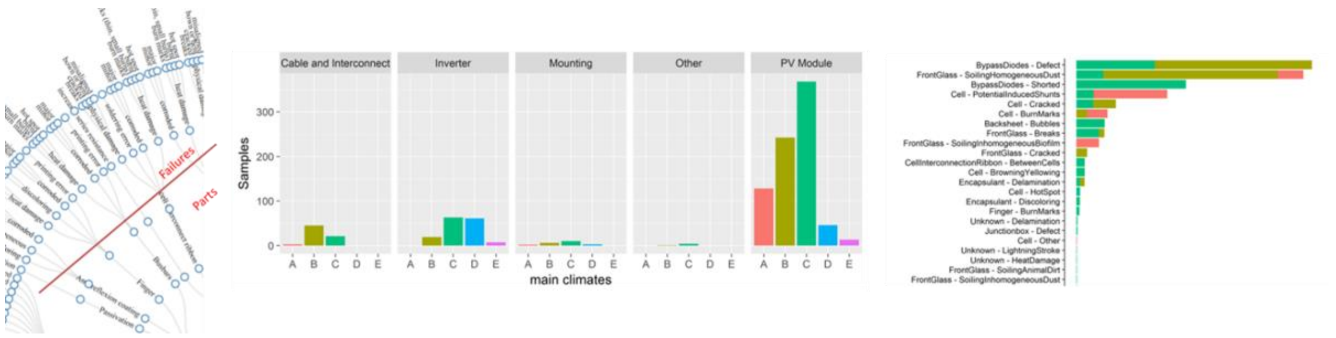


Figure 4 Example Results of WP2- Statistical evaluation of failures

Second objective was based on the **novel definition of various climate profiles** for testing novel materials (dry and hot - desert, temperate, humid and hot - tropic, high irradiation - alpine, corrosive – near the sea, …) together with a **detailed analytical characterization** of degraded modules and inverters that were exposed to these specific conditions (see Figure 5).

Climate profile specific test conditions for accelerated ageing tests

- ➢ A **theoretical model** describing the "cause - effect – relationship" to simulate the long term stability of innovative materials/components under specific climatic and environmental conditions
- ➢ **Climate specific ageing test procedures** defined and evaluated

- Extensive **data acquisition** during accelerated ageing test
- PV modules/materials/components way more robust than expected → Unplanned **elongation of ageing durations**
- Simulations based on that data was not possible to perform within the given timeframe → **follow-up project** ADVANCED

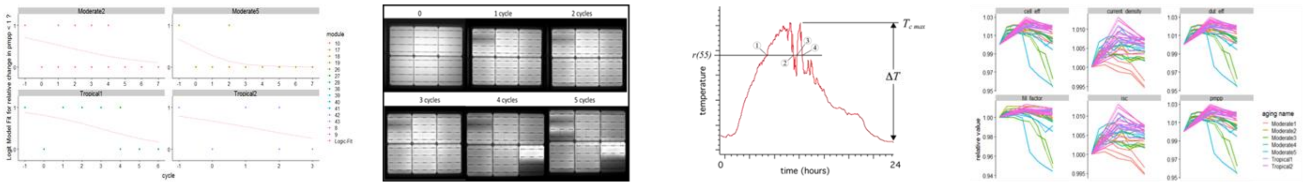


Figure 5 Example Results of WP3- Measurements of modules aged with procedures of different climate zones

After the definition of requirement profiles for PV materials/components/modules/inverters and subsequent **development of innovative products optimized for the various climate zones** (third & fourth objective), the focus was put on the following topics with a close cooperation of manufacturers and research institutions (Figure 6).

- Development of **new approaches** for durable, affordable and highly effective polymer **encapsulants & backsheets** as well as **conductive adhesives**
- **Electronic components for inverters**, inverters themselves and junction-boxes
- **Optimised backsheet** material
- **New ECA formulations** with higher flexibility for harsh environment
- **Lead-free solders and anti-corrosion coatings** for Cu-ribbons evaluated and optimised
- **Robust power switches** immune against cosmic rays (DE102015115679A1, 2016.03.24) and function proven in synchrotron experiment **patented**
    - **cosmic ray protection** for inverters
- Possibility for **module failure detection** at inverter level shown (e.g. PID)

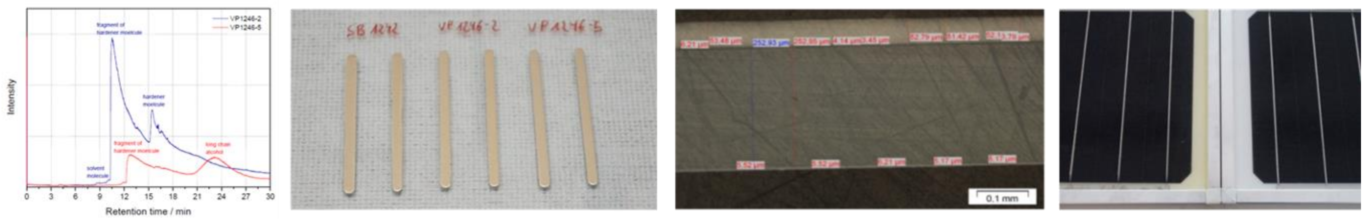


Figure 6 Material development examples of WP4

The fifth objective was the agreement on **technically & economically optimized and site-sensitive guidelines** for operation and maintenance of existing PV power plants (e.g. alpine → device for removal of snow loads; arid - cleaning procedure; anti-soiling) (Figure 7).

- Optimized approach for **operation** and **maintenance** services
- Suggestion for **cleaning procedure** → Internal report on efficient power plant analysis
- Suggestion for fighting **against PID issues**
- Peer reviewed paper concerning **plant inspection** → Renewable energy „method comparison“

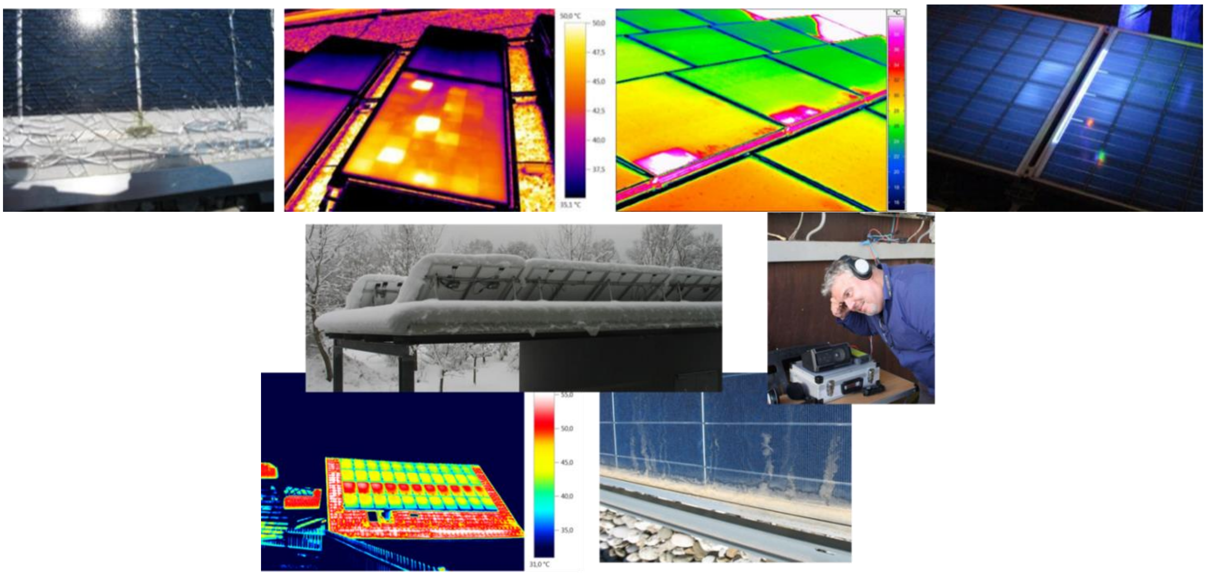


Figure 7 Example of different module failures in different climatic regions

The last objective was based on the development of scientific basics for a **fast, economic and efficient in-field characterization** of PV systems allowing for a performance-optimized operation of PV systems installed in various climates and environments.

- Quality/warranty **expert workshop**
- **Technical** and **economic** comparison of in-field strategies

Although some topics developed in different directions during the project, the **overall goals of the project could be fulfilled** (for details see WP descriptions below). The main challenges can be summarized as followed:

- Although the gathering of failure data around the world was a very hard and resource intensive task, the number of entries in the data base is still too low. On the other side it can be stated as a **highlight** that **1243 failure cases in 40 countries** could be added to the data base.
- The **major challenges** within INFINITY were the **(unexpected) long testing periods** of the materials until they failed and changes (e.g.: in the power output) could be detected. On the other side it is very promising that actual materials and even novel material developments within INFINITY **proved their stability** and **long term performance**.
- It turned out that for inverters, climate sensitive housing was not an easy option, because of the much **stronger dependence to microclimatic conditions** (inverter in an air-conditioned room in the desert or outside in the sun). The findings for the inverter (material development, improved power switches, etc.) will therefore be integrated in the next generations of inverters.

Many of the results have been **honored with awards** during the project lifetime. Some examples are (see Figure 8):

- Best Poster Award – „Österreichische PV Tagung 2016“
- Best Video Award - „Österreichische PV Tagung 2018“
- Energy Globe Award Carinthia – Winner category „Earth“

- Finalist "Umweltpreis der Stadt Villach 2018"
- Highlight presentation at EU-PVSEC 2017, 2018

Figure 8 INFINITY awards in the scientific PV community

During the last three years many fundamental research findings have been generated and for each company the highlights, that will affect their future business, differ. In the final meeting (see Figure 9) the consortia tried to summarize their highlights in the project as follows:

- **High scientific output** (three times higher than planned, shown by number of publications)
- Data base with **1243 cases in 40 countries**, about 20 real-world failure modules analyzed and the findings could be converted to material development improvements
- **Accelerated ageing procedures** for different climate zones defined and evaluated
- **Systematic analysis** for the **investigation of failures** of field PV modules conducted
- **Primary stress factors** for PV materials and components identified
- **Optimised backsheet and encapsulant** performance (excellent performance, selective permeation properties, …)
- New ECA formulations with **higher flexibility for harsh environment and lead-free solders and anti-corrosion coati**ngs for Cu-ribbons evaluated and optimized
- Robust power switches immune against cosmic rays **patented** (DE102015115679A1 2016.03.24) and **function proven** in synchrotron experiments
- Roadmap for **new inverter quality standards** established
- Possibility for **module failure detection at inverter level** shown (e.g. PID)
- **Quality/warranty expert workshop** held with component/material/module industry, lawyers and legally sworn experts
- **Technical and economic comparison** of different in-field analysis investigation tools for failures and O&M strategies
- **Inverter maintenance possibilities** were successfully analyzed and demonstrated

Figure 9 Final meeting INFINITY

In general, **all milestones and deliverables have been fulfilled**. Looking more into the details of the work packages, the results can be summarized as follows.

WP1 Project management and dissemination

Within the project INFINITY **4 General Assembly** and **8 overall project meetings** have been carried out. Additionally, many WP meetings, general working meetings for data interpretation and regularly held Telco's have been performed.

Due to the **high scientific participation** in this project, much more publications have been written than initially planned. Also one **patent application** was filed by Infineon (DE102015115679A1 2016.03.24). Therefore **all KPIs** have been more then **fulfilled** within INFINITY. In total **10 peer reviewed publications** have already been published, 3 more are currently submitted and **69 other scientific publications** have been held. Furthermore, **39 marketing publications** have advertised INFINITY and several more will follow with the end of the project.

Additionally, **two workshops** in cooperation with the Technologie Plattform Photovoltaik (TPPV) have been organized:

- INFINITY – TPPV Workshop **"Climate-Sensitive Photovoltaics"**, 23.5.2017, Leoben, 34 participants
- INFINITY – TPPV Workshop **"Qualität und Garantien in der Photovoltaik Branche"**, 24.01.2018, FEEI Vienna, 30 participants

Besides these public workshops with 14 external speakers an **internal workshop** for potential induced degradation (26th August 2016 at the AIT) has been organized to discuss novel possibilities for **PID prevention and healing strategies**.

For a better visibility each project partner has its own **INFINITY project information page** on their website. The monitoring of CTR's INFINITY page shows that the project homepage was assessed around **250 times** within the reported timeframe. Here, also special interest comes from regions with **non-moderate climates** (see Figure 10), whereas the highest local accesses are coming from central Europe.

Figure 10 Marketing publications of INFINITY, total CTR webpage views by countries

<u>WP2 Fault analysis & statistics: PV-power plants & components</u>

The aim of this work package was to summarize the relationships between the

- climatic conditions,
- PV modules,
- system design parameters,
- the failure mechanisms observed,
- outages and performance losses.

This was achieved by means of a detailed analysis and evaluation of **literature data** combined with an extensive analysis of **plant data** provided by the partners.

In WP2 the goal was to examine the relationship between climatic conditions, PV modules and system design parameters, observed failure mechanisms as well as performance losses **for building up the basis** for all further investigations in the other work packages. In cooperation with the IEA PVPS Task 13 so called failure surveys for in total **488 sub-systems comprising 1243 different failure entries** were created, collected and stored in a SQLite database (project database). The defective PV plants from which the surveys were created are located in more than **40 countries** spread all over the world. Hence a significant amount of **climate specific data** is available for more detailed analysis. Besides these failures also a structured module failure classification was made (see Figure 11).

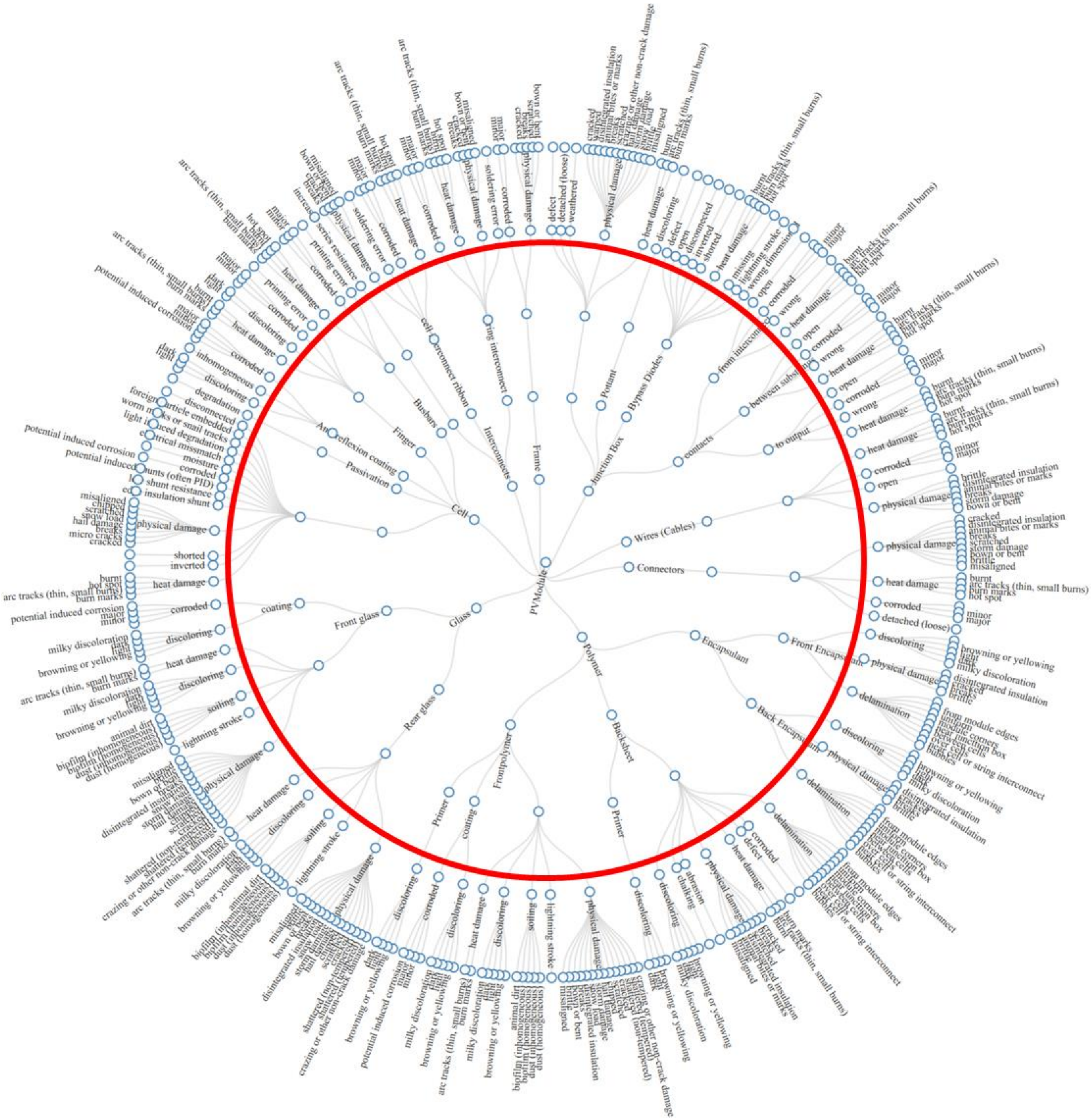


Figure 11 Structure of PV module failure classification, developed and used for characterization of failures in INFINITY

Although for certain parts and regions in the world the lack of data makes a statistical evaluation impossible, many **statistical considerations** could be established, which were incorporated in the other work packages.

The elaboration of different characteristics of the collected data set is performed with different visualizations and mathematical methods:

- Sankey diagrams (see Figure 12)
- Power loss evaluation
- Logistic regression
- Cluster analysis

The main outcomes can be summarized as:

- Most challenging climatic conditions for modules are **hot and humid**
- Inverters are primarily sensitive to **microclimate**, not directly to the climate zone itself
- PV systems in climate zones **Tropical (A) and Boreal (D)** were identified as the ones most susceptible to **power loss**
- **1048 PV module failures** from 340 (sub-) systems with a total installed power of about 567 MWp and a total lost system power of about 50 MWp were identified (~10 % of capacity)
- **Classification of failures** according to respective climate zone is possible
- Several failures are significantly **affected by the climate zones**. For example, PID appears mainly in tropical and moderate climate close to the sea and additionally this failure did not appear in older PV-plants before 2000.
- Climate zone **Aride (B)** seems to be the only climate zone with a high amount of **bypass diode failures and pottant discoloration**. This might be triggered by the high module temperatures and high irradiance modules have to face, if installed in arid environments.
- For PV modules installed in **climate zone D (cold/snow)** on the other hand the most frequently observed failures were **physical damages** of front glass and cells by heavy snow and hail. For **climate zone C (moderate/temperate)** also a high amount of hail damage was reported.
- **Discoloring and delamination** were spotted usually in older installations in **climate zone A**. In **climate zones B and C** these failures occurred less, but were still among the top ten of the reported failure modes.
- The **main identified module failures** were delamination and discoloring in climate zone A, B and C. In climate zone D heat damage and physical damage are very frequent and in climate zone E discoloration and physical damage were the most detected failures.

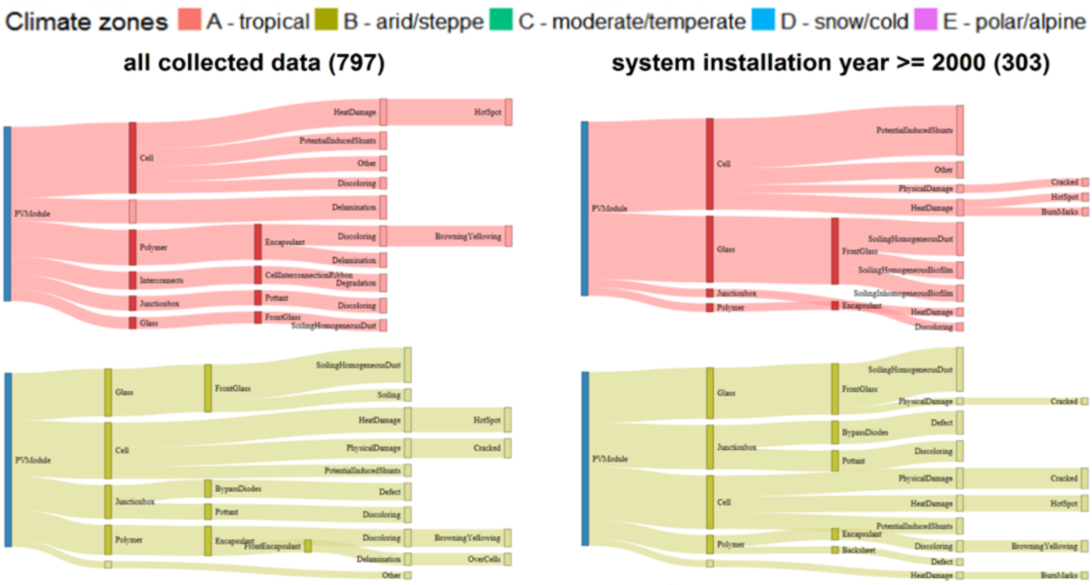


Figure 12 Sankey diagrams for the top ten failure modes for climate zones (exemplarily for climate zone A & B); columns show diagrams created from all collected data (left), and the subset of data, relating to PV installations after and including the year 2000 (right); number of total underlying failure modes → column header

WP3 Aging – climate sensitive accelerated ageing tests & modelling of ageing processes

The goals of WP3 are (see also Figure 13)

- the **characterization** of the **ageing and degradation behavior** of PV materials/components/ modules
- **description** of the prevailing **degradation modes** on molecular and system level for the different climate profiles
- **development** of climate-specific, **accelerated ageing tests**

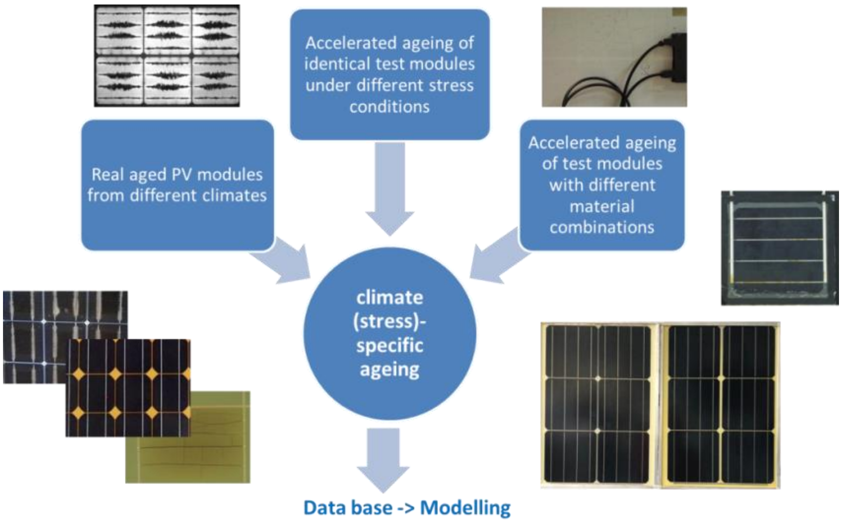


Figure 13 Concept of WP3

In a first step, **selected aged/defective PV-modules** which had been installed in different climates and environmental conditions in real-world environment were transferred to the laboratory and characterized by **non-destructive** methods like visual inspection, electroluminescence, thermography, UV-fluorescence and electrical performance measurements. Then, a thorough material characterization of the involved module components (encapsulation, backsheet…) was performed to be able to describe the ageing/degradation also on a **material based level** (see Figure 14).

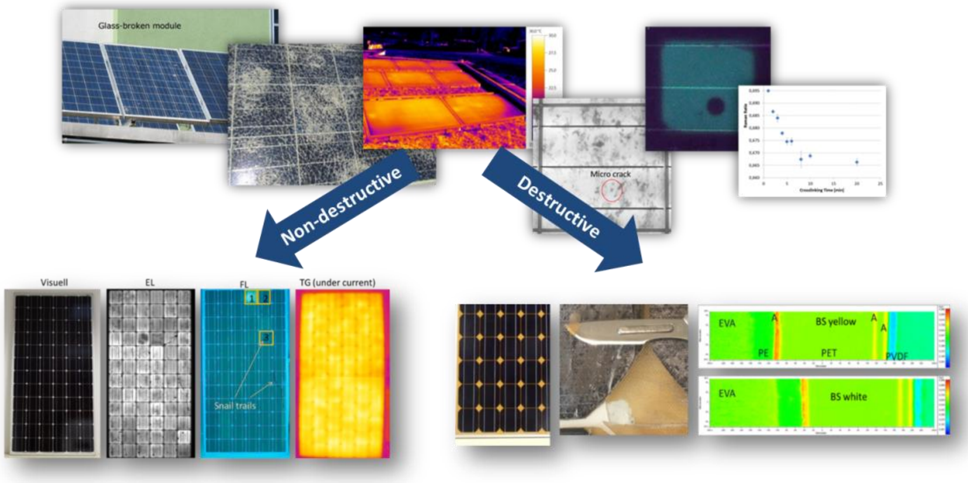


Figure 14 Analysis of real world aged modules with failures

The development of **climate-specific ageing tests** (accelerated ageing procedures) was one of the main important issues of the project. Based on the definition of 4 climate profiles (with reference to the

Köppen-Geiger climate classification) a program was worked out comprising **14 climate specific stress combinations** for accelerated ageing tests. Special test sequences were developed to **mimic the environmental stress** imposed on the modules in different climate zones: arid, moderate, tropical and alpine. In order to be able to describe the stress induced changes on the electrical side (performance loss) and material side (degradation effects) of specific test modules in detail, a set of identical test modules (more than **200 samples**, 6-cell and 1-cell test specimen) was produced and exposed to the various stress combinations. As the test-program with all the intermediate measurements was very time consuming, not all tests could be finished within the project period of 3 years but the **major findings are available and published** for future standardization initiatives.

The data obtained from the thorough **material and electrical characterization** of these (identically composed) test modules under the influence of the various stress parameters were collected in a newly designed **data base**. The data will be a basis for the modelling of the ageing/degradation behavior (see Figure 15).

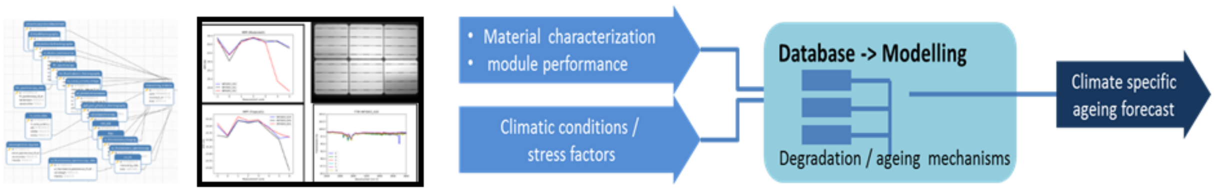


Figure 15 Method for material Simulation in WP3

Exemplarily, the query of the (i) change of the electrical performance of the whole module (P_{MPP}) and (ii) the color change of the backsheet with storage time as well as the (iii) UV-Fluorescence of the encapsulant and the (iv) electroluminescence image at the end of the storage time (3000h) are depicted in Figure 16 for the ageing procedure tropical 2.

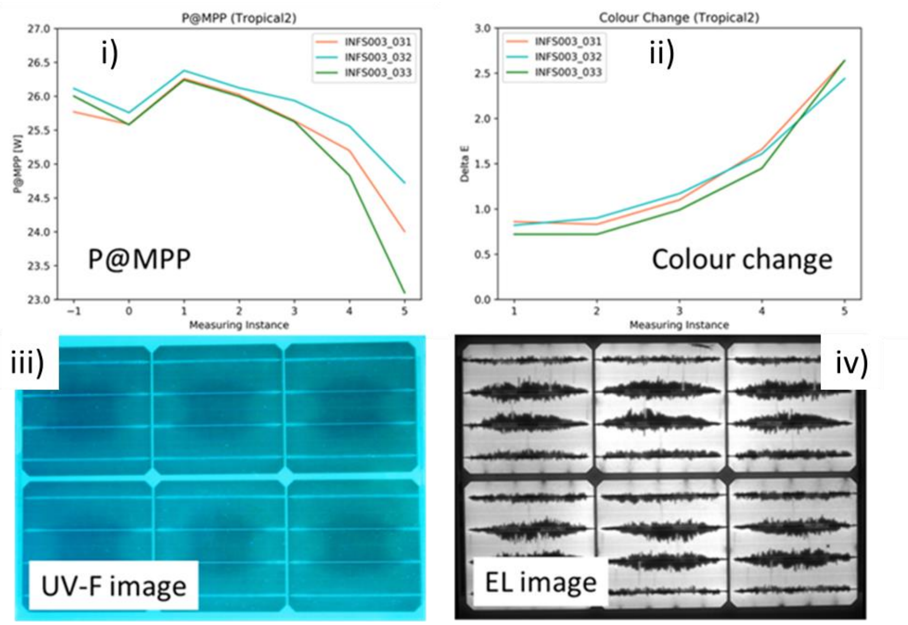


Figure 16 One example for the artificial aging results for modules in tropical climate

Summarizing, the analysis of the data showed that

- the **simulation of environmental stresses** like heavy snow- and wind loads as well as enhanced frequency of temperature cycling result in **cell cracks** and **cell connector breakages**
- additional treatment in **salty atmosphere** did not show an accelerating effect on degradation on the electrical or material (polymers, glass) side
- the **accelerating effect** of enhanced temperature, humidity or additional irradiation on the degradation of power and materials could be shown very well
- direct evidence for the **formation of acetic acid and acetates** in the encapsulant EVA is directly related to **cell corrosion effects** (EL) paralleled by power losses
- spectroscopic evidence (UV-F and FTIR) could be given for the **hydrolysis of EVA** after prolonged storage under DH85 and DH90 conditions (tropical 1 and 2)
- **cracking of PET-backsheet** after exposure to DH90 (t>2000h) and DH85+I (t>1250 h) due to degradation (chain scission)

WP4 Advanced high efficiency PV module components and materials for predefined environmental conditions

In this work package **new concepts for optimized module designs** and **material compositions** for the efficient and long lasting use under specific climatic stress factors were developed. In addition, the **development and optimization** of materials and components for highly efficient PV modules was performed. Special focus was given on the **encapsulation materials** of solar cells, the **polymeric backsheets** of PV modules, **PV ribbons** and **electrically conductive adhesives**.

The main objectives of WP4 have been the (i) identification of **primary stress factors** for PV module materials and components under different climatic conditions, (ii) the development of **new concepts for optimized module** design and material composition addressing different climatic stress factors and (iii) evaluation of **optimization strategies for PV module components** (encapsulant, backsheet, ribbons and adhesives) towards reliability and longevity under predefined environmental conditions (see Figure 17).

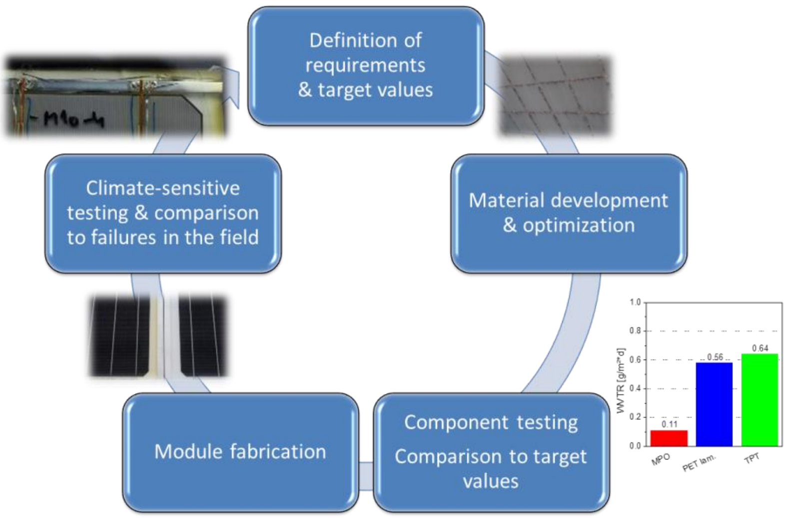


Figure 17 Schematic description of WP4

Material interactions between the different PV module components leading to degradation and subsequently a power loss of the PV module have been analyzed in detail (see Figure 18). Based on these critical issues, **concepts for optimization strategies** and **development targets** were derived and defined for each component (encapsulant, backsheet, PV ribbon and ECA) and stress situation. The right combination of encapsulant and backsheet materials was found as main factor in order to achieve **climate sensitive PV modules**, as their properties and long term behavior influence the main PV module degradation modes like yellowing, PID, corrosion or snail trails significantly. Of special interest are the interactions between the encapsulation materials and the interconnection system as well as the permeation properties of backsheets. Hence, to better understand this **material interaction and its influencing factors** a comprehensive test plan was implemented and carried out. Test modules with different combinations of material and combinations were specified to achieve the targets. On one hand, existing materials and components were used as a reference, on the other hand already newly developed materials and components were incorporated.

Figure 18 Examples for material interactions

The main findings for polymeric materials can be summarized in the following:

- Materials and components in general are **sensitive to different loadings and environmental stresses**
- For polyethylene-based thermoplastic encapsulants (TPO)
  - Hydrophobic, **chemically highly stable** material
  - Elimination of corrosive degradation products and peroxidic crosslinking
  - Reduced corrosion
    - ✓ No PID
    - ✓ No hydrolysis
- Modified polyolefine backsheets (MPO)
  - **Selective permeability** - low WVTR & high AATR
    - ✓ Reduced corrosion & PID
  - No hydrolysis
  - No backsheet delamination
    - ✓ No cracking due to hot-humid conditions

This lead to **special advantages** for:

- high UV irradiance
- hot & humid conditions
- high thermo-mechanical loads

The main results for novel ribbons and electrical adhesives are:

- SnBi-based solders
  - Increased **corrosion resistance**
    - ✓ No interaction with TPO encapsulant
    - ✓ Behaviour comparable to traditional SnPb solders
  - Void formation during lamination at high temperatures when used with crosslinking encapsulants

- Modified epoxy formulations
  - New ECA formulations with **higher flexibility**
  - Increased fatigue resistance and adhesion
  - Low decrease in power output after accelerated aging tests
    - ✓ Good processability
    - ✓ Behavior and reliability comparable to solder-bonded strings

These findings lead to **special advantage** for climates with:

- Hot & humid conditions
- High thermo-mechanical loads

WP5 Optimization of electronic components & materials regarding predefined environmental conditions

The aims of WP5 can be summarized as follows:

- **Roadmap** for new quality standards for inverter
- Solutions for **robust power switches** (esp. cosmic rays)
- **Improvements** for connection boxes and cables

Based on data and knowledge provided by WP2 and WP3, the analysis of the **inverter failures** in the field and an extensive **FMEA** have been performed (Figure 19).

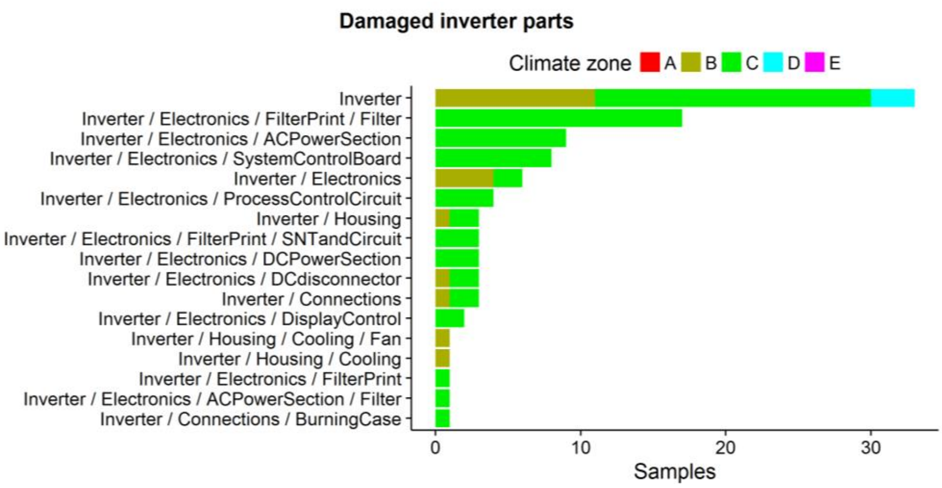


Figure 19 Failed inverter parts

From the statistical evaluation of WP2 it turned out that **installation failures** are still an issue, therefore **robust and save installation** of inverters and PV systems by poorly trained persons have been also evaluated.

From this starting point a roadmap for the standardization committee in agreement with industrial partners for **climate specific tests** has been defined (see Figure 20). Based on the results of the project, the already extensive device tests at Fronius were again **reviewed, improved** and **supplemented**. The focus was on the comparison of the target markets with the respective climatic conditions. Here a special focus was to cover as many climate zones as possible with the different test scenarios. After the learnings from this project it makes today no sense from **economical point of view** to build extra inverters for special climates.

Figure 20 Inverter in climate chamber under freezing test

Within the project different **climate sensitive test procedures** have been developed, tested and adopted. Besides this major research topic the consortium worked for solutions for **robust power switches**, especially to **prevent cosmic ray impacts** and their interaction with the PV system. Cosmic rays contain an immensely high level of radiation energy. Upon impact with the earth's atmosphere, cosmic rays can burst into a shower of secondary particles. Those secondary cosmic rays include neutrons, pions, positrons and muons. Neutrons appear mostly at sea level, whereas pions are more frequent in higher regions and these have the ability to **damage semiconductors**[1]. For cosmic ray prevention Infineon **developed a protective circuit and field a patent**. These ideas have been successfully evaluated within INFINITY (Figure 21).

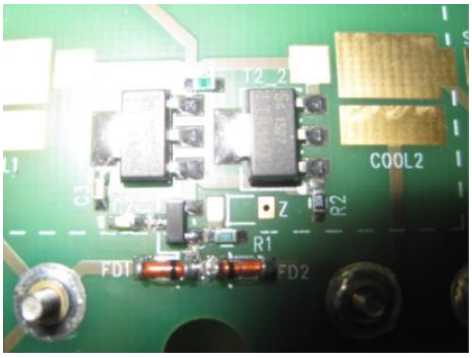


Figure 21 Test PCB for protection circuit

[1] Kaindl, W., „Modellierung höhenstrahlungsinduzierter Ausfälle in Halbleiterleistungsbauelementen." Technische Universität München, München, 2005

Here, basic solutions for robust power switches with focus on **climate specific failures,** determined within WP3, were examined. Despite the fact that theory for robust power switches already exists, **technology measures to increase the robustness** against environmental stresses (temperature, temperature cycling and humidity) were in the focus.
Reliability tests on IGBT's and Diodes for PV applications were performed in several **learning cycles**. An impressive improvement of the **humidity robustness** of the power semiconductor chips could be achieved based on highly accelerated high voltage humidity test (HV-H3TRB). The device lifetime under accelerated test conditions could be improved by a factor of 5 to 10 compared to state of the art technologies. In summary the new concept offers a huge improvement potential for **PV applications** located in **harsh environments**. But the new material cannot fulfil **important requirements** for mass production. Therefore further development work has to be performed mainly on the material side and by the supplier in order to prepare the way towards technology implementation and mass production.

Main results of WP5 can be summarized as follows:

- Roadmap for **new quality standards** for inverter with an FMEA proven approach
- **Novel test procedures** for different climates for inverters defined and evaluated
- Evaluation of **novel housing material** analyzed
- Extensive analysis of failed parts in **reliability stress-tests** for power electronic showed:
    - Critical aging in the high voltage edge termination
    - Humidity and electrical field induced electro-chemical reactions (corrosions and dendrite formation)
    - Al corrosion not fully blocked by the design measures but strongly slowed down (first corrosion artefacts typically visible earliest after more than 1000h testing time)
    - Ag dendrite structures identified on a few chips with low statistic (< 5 ppm)
    - Untypical (early) corrosion spots on a few chips found with low statistic (< 5 ppm)
- Circuit to **protect IGBTs** against the impact of a hit by cosmic rays:
    - A protection circuit was designed and tested in the lab (Patent)
- PID process simulated and **prevention measures** evaluated and designed
- **Early detection** of PID proven for inverters (see Figure 22)
- Different **cables** and **connection boxes** evaluated and optimized

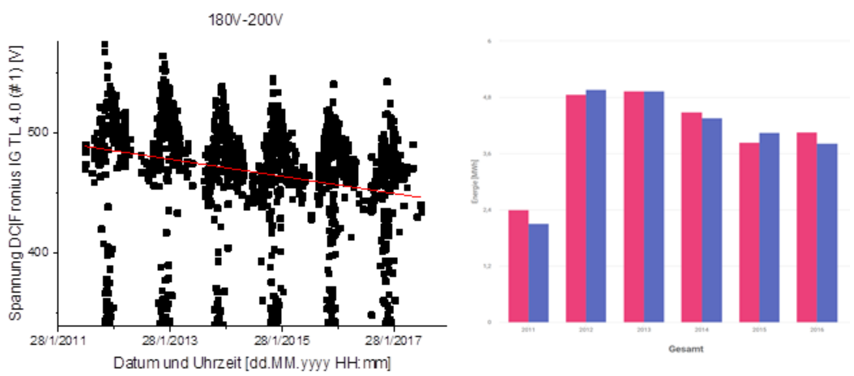


Figure 22 Degradation of voltage over the years due to PID; a loss in yield was also measured

WP6 Climate optimized maintenance and warranty strategies

The aims in WP6 were:

- Development of the scientific basics for **fast, standardized, economic and efficient** methods for the in-field characterization of PV power plants
- Inverter **maintenance strategies**
- Definition of optimal **basic and climate sensitive requirements** for operation and maintenance
- Analysis of **warranty regulations** and development of improved warranty regulations
- Development of **in-field recovery system** for PID

The **overall goals** of this WP could be met within the three years project except the in-field recovery system for PID, due to the fact that there have been **existing solutions** on the market already when the project was started. The on depth analysis within INFINITY gave the consortia, especially for inverter technology, new inputs in terms of **future development and product strategies**. Furthermore the **warranty regulation** was discussed within the consortia and it was worked on an **improved warranty regulation** (see Figure 23). Here it must be stated that a coordinate solution between material supplier, module manufacturer and O&M provider is not within reach due to the **high complexity of the challenge**.

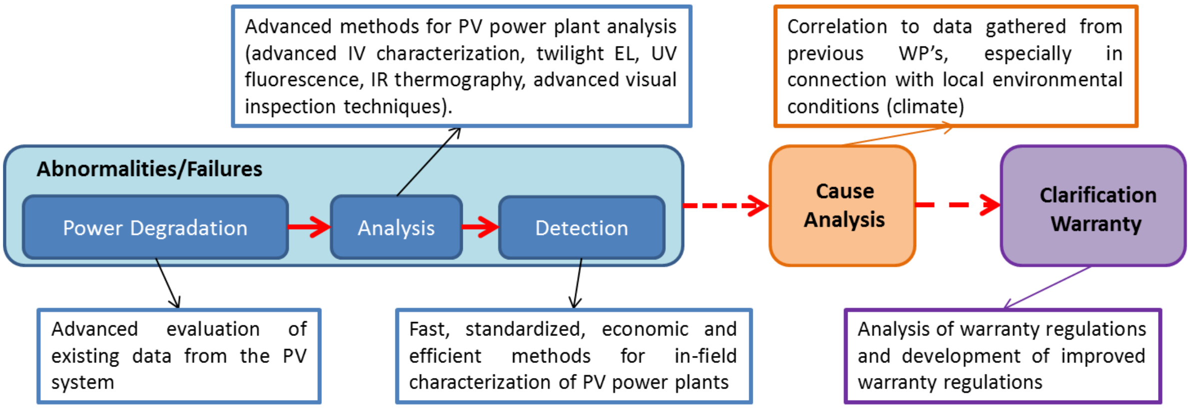


Figure 23 Workflow warranty regulation analysis

A lot of information has been shared and all players at the **value chain** learned a lot from the workshop and the discussion but for a solution more work will be needed and the final decision will be a regulatory one.

The main findings of WP6 have been:

- **Rapid measurements on site** are possible now, since devices for outdoor hand-suitable are available
- "Leave the modules installed in the system" - **String energization**
- Error identification by **combination of measuring equipment** significantly facilitates on-site analysis (differentiation of error pattern, error effect, cause of error are necessary; see Figure 24)

- The **standard measuring equipment** includes: one's own eye (VIS), thermography (TG), electroluminescence (EL), UV fluorescence (UV-F), current-voltage characteristic (IV)
- Much **experience** is needed to inspect PV systems (see Figure 25)
- The problem of potential induced degradation (PID) has been analyzed accurately
- **PID in-field regeneration** is possible but with residual loss
- **PID detection** by inverter or monitoring portal is possible
- Photovoltaic **guarantees are perceived differently** - a workshop has encouraged various industry representatives to debate. The most important point is to know the contracts and the legal situation. Unjustified guarantees are to be rejected or to be handled on the basis of goodwill (see Figure 26).

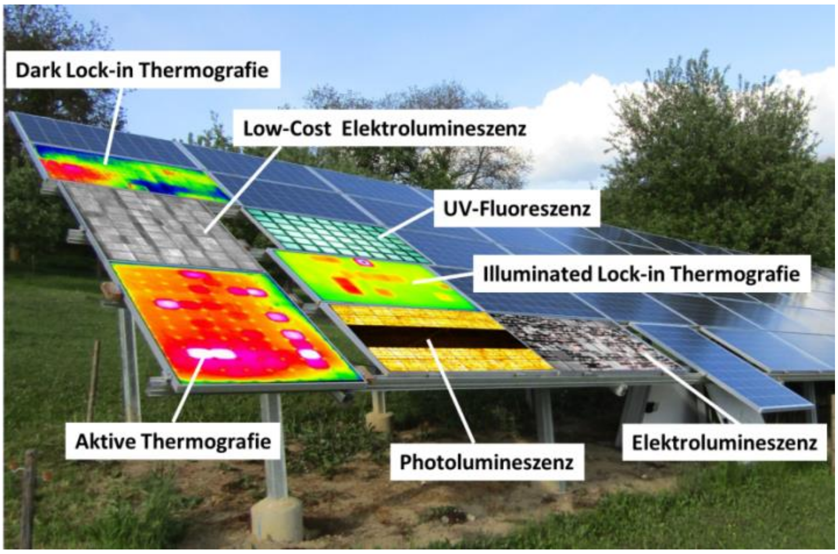


Figure 24 Example picture of the different most common failures possible at PV modules and the most effective analyses methods

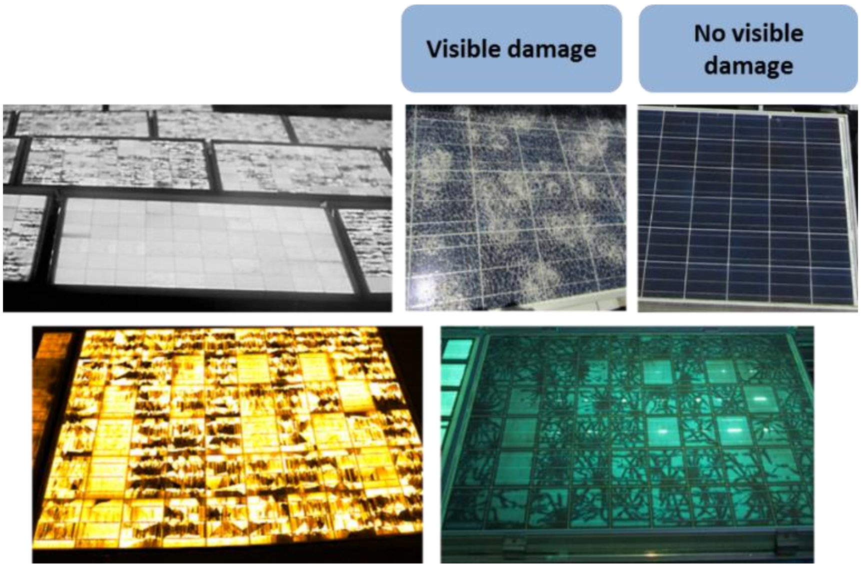


Figure 25 Inspection of PV after a hail storm with visible damage (glass breakage) and invisible damage with visible inspection, only with advanced tools like UV fluorescence and EL the damages got visible. On-site inspection reveals substantial invisible damage (broken cells due to hail impacts, without damage to glass etc.)

Figure 26 TPPV Workshop about guarantees in PV Industry

4 Results and Conclusion

The goal of the project was to develop **new concepts for optimized components for PV modules and systems** for different environmental conditions. The industrial and scientific project partners along the PV value chain offered a **high potential** for innovative enhancement of solar components and systems, both in **functionality** as well as in **cost effectiveness**. The whole PV value chain can benefit from the project results (optimized PV materials/components/modules). This opens additional markets for PV solutions, especially in developing and emerging countries which require dedicated products in remote or extreme climatic areas.

The **PV systems** using these new modules and components will exhibit **enhanced performance and reliability for harsh climatic conditions** compared to standard systems. The project supported Austria´s and Europe´s efforts to further disseminate its intelligent and adaptable PV solutions.

In the area of PV modules, the main focus within this project was on **improvements of** the characteristics of **polymeric components (encapsulants, backsheet)**, **PV ribbons** and **electronically conductive adhesives** with respect to the challenges of different **climatic conditions**. These optimized PV module components were aimed to show an **advanced reliability and durability** for the respective environmental stresses. The electrically conductive adhesive and PV ribbons, which were used and developed in this project, can compete with standard soldered PV ribbons and drastically reduced the needs of the toxic lead. In the long term, when the developed concepts are realized, highly optimized PV modules specified for different climatic zones can be offered and then the Austrian industrial partners will have a unique selling point within the volatile PV market, especially with regard to the emerging markets.

With the project results in hand, these advantages could be realized by the PV module manufacturers on a fast time scale, as there are only comparatively small investments necessary for new processing technology. Furthermore, the improvement of the efficiency of the modules is an important criterion to extend technological leadership of the European PV sector. An **increase in the sales rates of Austrian**

products of 10-15% should be feasible by increasing the product offering by climatically specified modules.

Regarding Balance of System components (BOS) several benefits and unique selling propositions were expected. One major goal of this project was the **enhancement of the quality of future installed photovoltaic systems** by improving the quality, reliability and lifetime of photovoltaic inverters and other electronic BOS components for extreme climates.
For all partners in the value chain, product warranty was a critical issue and topic of the INFINITY project. Customers expect high reliability and flawless operation of installed PV systems over a longtime span. If these expectations are not met, PV manufacturers have to handle costly reclamations. The composition of the consortium of INFINITY provided the unique opportunity that all partners along the value chain work out agreeable **warranty regulations**. INFINITY also strived for the implementation of adoptable failure avoidance strategies, as well as recovery methods for the defective modules. A **recovery method for PID**, which can save the module producers a lot of money as they would otherwise have to substitute the modules due to the yield warranty (20 years and more), was tested.

INFINITY further aimed to cover an underestimated aspect of the PV lifecycle: the maintenance of PV systems. So far, PV maintenance technologies were not in the main focus of scientific research. The widespread customer opinion was that PV systems do not need dedicated Operation and Maintenance (O&M). In practice however, **efficient, fast and regular O&M** strategies and technologies have enormous potential to significantly **increase the sustainable performance of PV power plants**. An early identification of faults and defects will help to limit costs caused by repairing and yield losses. Different analyzing tools were successfully tested and applied in this project.

<u>Scientific Dissemination:</u>

- 10 peer reviewed publications (see Appendix)
- 69 conference publications (see Appendix)
- 2 PhDs and 1 Master Thesis within the project:
  - DI Jan Slamberger (AIT), PhD, *Topic:* “Potential induced degradation (PID)”, finished 01/2019
  - Mag. Ing Antonia Omazic (PCCL), PhD, *Topic*: “Weathering stability of polymeric materials for PV modules operating in harsh climatic conditions”, completion until mid 2019
  - Thomas Schlager (AIT), Master of Science in Engineering (BSc), *Topic:* „Messhardware zur Charakterisierung von Photovoltaikmodulen mittels Dunkelkennlinien-Messung”

<u>Economic Exploitation</u>

1 Patent filed:

- DE102015115679A1 2016.03.24 (Infinoen)

39 marketing publications (see Appendix)

16 product ideas from the company partner that will go into project development and next generations of existing materials

Figure 27 Exploitation and dissemination activities

5 Outlook and Recommendations

Many more ideas for **innovations** exist within the consortia and we all use the ideas for upcoming **research project ideas**. Furthermore many more publications will be possible with the data available from the INFINITY project. All project partners have access to the **INFINITY failure database** and will collect further data for new analysis. Furthermore they will also have access to the measurement data based on WP3 for further investigations. Several additional publications are currently under progress and hopefully some of the follow up projects will come to **develop further important improvements** for the Austrian PV industry.

Novel project Ideas already submitted:

- INCREASE (Energieforschung, Flagship project, submitted 2017, not funded)
- Power4Life (H2020, submitted 2017, not funded)
- HiPerfPV (Solar.era.net, submitted 2017, not funded)
- INCREASE_NEXT (Energieforschung, Flagship project, submitted 2018, pending)
- PVRE^2 (Energieforschung, Flagship project, submitted 2018, granted)
- EXTREME (Energieforschung, Cooperative Reserach, submitted 2018, pending)
- Advanced (Energieforschung, Basic Research, submitted 2018, pending)
- OPTPV4.0 (Energieforschung, Cooperative Reserach, submitted 2018, pending)
- PowerPV (Solar.Era.net, submitted 2018, pending)

6 Appendix

Scientific Publications:

1. W. Mühleisen, L. Neumaier, C. Hirschl, M. Spielberger, H. Sonnleitner, R. Hirschl, B. Hirschmann, G. Oreski, K. Berger, G. Eder, „Langzeitstabilität der Komponenten in einem PV Modul – bestandene Normprüfung kein Allgemeinschutz“, 31. Symposium Photovoltaische Solarenergie, Deutschland, (2016)
2. M. Kraft et al., „Raman Spectroscopy for Industrial In-Line Process Analysis – Application Case Quality Control of Photovoltaics Modules”, Seminar Moderne Analytische Chemie, TU Wien & 8. PAC-Talk des österr. Forschungsnetzwerks Process Analytical Chemistry, (2016)
3. L. Neumaier, W. Mühleisen, T. Fischer, J. Scheurer, W. Pranger, C. Hirschl, „Contact-free Raman spectroscopic measurement of residual stress in silicon solar cells caused by stringing”, 32th European Photovoltaic Solar Energy Conference and Exhibition (32th EU PVSEC), (2016), DOI: 10.4229/EUPVSEC20162016-1BV.5.4
4. Ch. Hirschl, L. Neumaier, W. Mühleisen, G. Eder, G. Oreski, E. Rüland, S. Seufzer and M. Kraft, „In-line Raman Analysis of Ethylene Vinyl Acetate Curing for and in Industrial PV Module Manufacturing”, Polymers in Photovoltaics 2016, Düsseldorf/Germany (2/2016)
5. L. Neumaier, Ch.Hirschl, Chr. Berge, E. Rüland, “Raman-based inspection for non-destructive, inline quality control to enable smart production in photovoltaic industry”, Smart System Integration – International Conference and Exhibition SSI, München/Germany, (3/2016)
6. M. Köntges, S. Altmann, T. Heimberg, U. Jahn, K. A. Berger, “Mean Degradation Rates in PV Systems for Various Kinds of PV Module Failures”, 32nd EU PVSEC 2016, Munich, 5DP.1.2, DOI: 10.4229/EUPVSEC20162016-5DP.1.2
7. G. Oreski, A. Mihaljevic, Y. Voronko, G. Eder, ”Acetic Acid Permeation through PV-Backsheets: Dependence of the Composition on the Permeation Rate”, Vortrag 32nd EU PV SEC, 06.2016, München;
8. G. C. Eder, Y. Voronko, A. Mihaljevic, G. Oreski, ”Evaluation of the acidic acid permeability of PV-backsheets”, 6th SOPHIA PV-Reliability Workshop, 04.2016, Vienna.
9. R. Hirschl, “Potenzialinduzierte Degradation - Wirtschaftliche und Wissenschaftliche Aspekte“, PID Workshop Firma Padcon, Würzburg/Germany (11/2015)
10. W. Mühleisen, L. Neumaier, C. Hirschl, S. Seufzer, M. Trobej, W. Pranger, J. Scheurer, R. Lorenz, M. Schwark, “New promising c-Si solar cell and busbar concepts for industry application”, 32th European Photovoltaic Solar Energy Conference and Exhibition (32th EU PVSEC), (6/2016), DOI: 10.4229/EUPVSEC20162016-2AV.3.6
11. A. Mihaljevic, G. Oreski, G. Pinter, “Influence of Backsheet Type on Formation of Acetic Acid in PV Modules”, 32nd European Photovoltaic Solar Energy Conference and Exhibition, München 2016, Paper DOI: 10.4229/EUPVSEC20162016-5BV.1.2
12. G. Oreski, A. Rauschenbach, C. Hirschl, M. Kraft, G. C. Eder, and G. Pinter, “Crosslinking and post-crosslinking of ethylene vinyl acetate in photovoltaic modules”, J. Appl. Polym. Sci., vol. 134, no. 23, Jun. 2017, DOI: 10.1002/app.44912
13. Ch. Hirschl, L. Neumaier, W. Mühleisen, M. Zauner, G. Oreski, G. C. Eder, S. Seufzer, Ch. Berge, E. Rüland and M. Kraft, “In-Line Determination of the Degree of Crosslinking of Ethylene Vinyl Acetate in PV Modules by Raman Spectroscopy”, Solar Energy Materials and Solar Cells, Volume 152, August 2016, Pages 10–20, http://dx.doi.org/10.1016/j.solmat.2016.03.019

14. W. Muehleisen, L. Neumaier, C. Hirschl, T. Maier, M. Schwark, S. Seufzer, R. Battistutti, M. Pedevilla, J. Scheurer, R. Lorenz, „Comparison of Output Power for Solar Cells with Standard and Structured Ribbon”, European Physical Journal Photovoltaic (EPJ-PV), Vol. 7, 70701, 2016, DOI: 10.1051/epjpv/2016003
15. B. Hirschmann, G. Oreski, G. Pinter, ”Natural and artificial ageing on backsheets – Comparison of degradation effects”, Poster 32nd EU PV SEC, 06.2016, München;
16. M. Halwachs, K. Berger, M. Schwark, R. Ebner, L. Maul, L. Neumaier, Y. Voronko, N. Vollert,W. Mühleisen, Ch. Hirschl, „Statistical Evaluation of climate related performance and reliability issues in PV plants", Poster 14.Österreichische PV Tagung, 28.-30.11.2016, Villach
17. W. Mühleisen, L. Neumaier, C. Hirschl, S. Seufzer, W. Pranger, J. Scheurer, M. Schwark, R. Ebner, T. Fischer, M. Spielberger, „ Bleifreies PV Modul – Made in Austria", Poster 14.Österreichische PV Tagung, 28.-30.11.2016, Villach
18. W. Mühleisen, L. Neumaier, C. Hirschl, S. Seufzer, R. Battistutti, W. Pranger, J. Scheurer, M. Schwark, R. Lorenz, „Zellverschaltung im Photovoltaikmodul Busbaranzahl und Leistungsgewinn", Poster 14.Österreichische PV Tagung, 28.-30.11.2016, Villach
19. S. Poetz, J. Scheurer, G. Oreski, "Electrical conductive adhesives for application in the solar module production",Poster 14.Österreichische PV Tagung, 28.-30.11.2016, Villach
20. Gabriele C. Eder, Yuliya Voronko, Antonia Mihaljevic, Gernot Oreski, "Evaluation of the acidic acid permeability of PV-backsheets", 13. Reliability Workshop, 11.2016, Vienna
21. M.Schwark, R. Ebner, G. Újvári, W. Mühleisen, Ch. Hirschl, "Verhalten von „Ingot-Randzellen“ in einem PV-Modul", Poster D9, 32. Symposium Photovolatische Solarenergie,2017,Bad Staffelstein
22. Jan Slamberger, M.Schwark, "Prognose von Leistungsverlusten bei Potentialinduzierter Degradation – PID", Poster C5, 32. Symposium Photovolatische Solarenergie,2017,Bad Staffelstein
23. Oreski, G. "Material interactions in PV modules: The role of polymers in PV module degradation", Ulbrich Symposium, 30.08.2017
24. M. Schwark, W. Mühleisen, L. Neumaier and C. Hirschl, "Low silver content, lead free modules with light capturing ribbons", 2017 6th International Conference on Clean Electrical Power (ICCEP), Santa Margherita Ligure, 2017, pp. 158-162., DOI: 10.1109/ICCEP.2017.8004808
25. C. Hirschl, G.C. Eder, L. Neumaier, W. Mühleisen, Y. Voronko, R. Ebner, B. Kubicek, K.A. Berger, "Long term development of photovoltaic module failures during accelerated aging tests", 33rd European Photovoltaic Solar Energy Conference and Exhibition (33rd EU PVSEC), (9/2017), DOI: 10.4229/EUPVSEC20172017-5BV.4.72, p.1709-1712
26. N. Vollert, L. Neumaier, W. Mühleisen, M. Halwachs, L. Maul, Y. Voronko, A. Mihaljevic, C. Hirschl, "The Use of Logistic Regression for Evaluating Climate-relevant PV Module Failures", 33rd European Photovoltaic Solar Energy Conference and Exhibition (33rd EU PVSEC), (9/2017), DOI: 10.4229/EUPVSEC20172017-6BV.1.35, p.2295-2298
27. Martin Halwachs, K. A. Berger, M. Schwark, R. Ebner, L. Maul, L. Neumaier, Y. Voronko, A. Mihaljevic, N. Vollert,W. Mühleisen, Ch. Hirschl, "Descriptive Statistics on the Climate Related Performance and Reliability Issues from Global PV Installations", 33rd European Photovoltaic Solar Energy Conference and Exhibition (33rd EU PVSEC), (9/2017), DOI: 10.4229/EUPVSEC20172017-6BV.2.21, p.2370-2374
28. M. Halwachs & M. Schwark, "Approach to Determine the Impact of Cosmic Rays on PV Systems", 33rd European Photovoltaic Solar Energy Conference and Exhibition (33rd EU PVSEC), (9/2017), DOI: 10.4229/EUPVSEC20172017-5DV.3.57, p.1868-1871

29. A.Mihaljevic, G.Oreski, G. Eder, Y. Voronko, W. Mühleisen, L. Neumaier, C. Hirschl, R. Ebner, G. Pinter, "Concept of optimized encapsulant composition for PV module reliability under different climatic conditions", 33rd European Photovoltaic Solar Energy Conference and Exhibition (33rd EU PVSEC), (9/2017), DOI: 10.4229EUPVSEC20172017-5DV.3.17, p.1779-1783
30. W. Mühleisen, L. Neumaier, C. Hirschl, M. Spielberger, H. Sonnleitner, G. Eder, Y.Voronko, "Scientific investigation of a PV generator after hail", 33rd European Photovoltaic Solar Energy Conference and Exhibition (33rd EU PVSEC), (9/2017), DOI: 10.4229/EUPVSEC20172017-6BO.8.3, p.1937-1939
31. W. Mühleisen, L. Neumaier, C. Hirschl, M. Spielberger, H. Sonnleitner, Y. Voronko, G. Eder, B. Kubicek, R. Ebner, "The practicability of outdoor measurement methods for photovoltaic installations", 33rd European Photovoltaic Solar Energy Conference and Exhibition (33rd EU PVSEC), (9/2017), DOI: 10.4229/EUPVSEC20172017-6BV.1.34, p.2291-2294
32. G. Oreski, A. Mihaljevic, G. C. Eder, Y. Voronko, L. Neumaier, C. Hirschl, R.Ebner, M.Edler and W.Krumlacher, "Evaluation of Acetic Acid Formation and Retention on PV Module Degradation", European Weathering Symposium 2017
33. A. Morlier, M. Köntges, T. Heimberg, U. Jahn, K. A. Berger, "Degradationsraten für verschiedene Arten von Photovoltaik-Modulfehlern und Zuverlässigkeit anderer Systemkomponenten" , 32. Symposium Photovolatische Solarenergie,2017, Bad Staffelstein
34. J. Slamberger, M. Schwark, "Forecasting power losses due to potential-induced degradation (PID)", 33rd European Photovoltaic Solar Energy Conference and Exhibition (33rd EU PVSEC), 9/2017, DOI: 10.4229/EUPVSEC20172017-5BV.4.56, p.1664-1666
35. M. Köntges, A. Morlier, U. Jahn, K. A. Berger, "Degradation Rates in PV Systems for Different PV Module Failures" , Vortrag IEA PVPS Parallel Workshop 2017-05-04, Intersolar München 2017, 17p.
36. Oreski, G., Mihaljevic, A., Voronko, Y., Eder, G. C. (06/2017), "Acetic acid permeation through photovoltaic backsheets: Influence of the composition on the permeation rate", Polymer Testing, Vol. 60, pp 374 - 380, DOI:10.1016/j.polymertesting.2017.04.025
37. G. Oreski, A. Omazic, G. Eder, L. Neumaier, C. Hirschl, M. Edler, W. Krumlacher, R. Ebner, "Concepts for PV modules optimized for different climatic conditions: backsheets and encapsulants", International PVSEC-27, Japan, 2017
38. W. Muehleisen, G. C. Eder, Y. Voronko, M. Spielberger, H. Sonnleitner, K. Knoebl, R. Ebner, G. Ujvari, C. Hirschl, "Outdoor detection and visualization of hailstorm damages of photovoltaic plants", In Renewable Energy, Vol. 118, 2018, p.138-145, ISSN 0960-1481,
39. G. Oreski, A. Omazic, G. Eder, C. Hirschl, W. Pranger, R. Ebner, "Material interactions in PV modules: The role of polymers in PV module degradation", 2nd International Workshop on the Sustainable Actions for “Year by Year Aging” under Reliability Investigations in Photovoltaic Modules, 2017,SAYURI-PV 2017
40. G. Oreski, A. Mihaljevic, G. Eder, Y. Voronko, "Measuring Acetic Acid Transmission Rates of PV Backsheets", International PVSEC-27, Japan, 2017
41. J. Schlothauer, C. Peter, C. Hirschl, G. Oreski, B. Roeder, "Non-destructive monitoring of ethylene vinyl acetate crosslinking in PV-modules by luminescence spectroscopy", Journal of Polymer Research (2017) 24:233; https://doi.org/10.1007/s10965-017-1409-y
42. C. Hirschl, "Infinity Climate-sensitive long-time reliability of photovoltaics", Ulbrich Symposium, 30.08.2017
43. W. Mühleisen, L. Neumaier, C. Hirschl, M. Spielberger, H. Sonnleitner, Y. Voronko, G.C. Eder, R. Ebner, „Wie praktikabel sind Photovoltaik- Inspektionsmethoden im Außeneinsatz ?", Poster 15.Österreichische PV Tagung, 13.-14.11.2017, Wien

44. M. Halwachs, K. A. Berger, L. Maul, L. Neumaier, Y. Voronko, A. Omazic, N. Vollert, W. Mühleisen, M.Schwark, R. Ebner, Ch. Hirschl, "Descriptive Statistics on the Climate Related Performance and Reliability Issues from Global PV Installations", 2018 Conference “Quality and sustainability of PV systems” on 3 May 2018 in Brussels
45. G. C. Eder, Y. Voronko, C. Hirschl, R. Ebner, G. Újvári, W. Mühleisen, "Non-Destructive Failure Detection and Visualization of Artificially and Naturally Aged PV Modules", MDPI Energies 2018, 11(5), 1053; https://doi.org/10.3390/en11051053
46. L. Neumaier, N. Vollert, W. Mühleisen, M. Halwachs, Ch. Hirschl, "Statistische Modellierung klimaspezifischer PV Modul Fehler", In Procc. of 33rd PV Symposium 2018 Bad Staffelstein
47. W. Mühleisen, L. Neumaier, A. Wurzer, A. Mihaljevic, G. Oreski, C. Hirschl, "Wissenschaftliche Begleitung einer PV Anlage auf einem Krankenhaus", In Procc. of 33rd PV Symposium 2018 Bad Staffelstein
48. M. Halwachs, K.A. Berger, M. Schwark, R. Ebner, L. Maul, L. Neumaier, Y. Voronko, A. Omazic, N. Vollert, W. Mühleisen, Ch. Hirschl, "Deskriptive Statistik über Leistungsverlust und Fehlerarten von PV-Systemen in unterschiedlichen Klimazonen", In Procc. of 33rd PV Symposium 2018 Bad Staffelstein
49. W. Mühleisen, L. Neumaier, C. Hirschl, M. Spielberger, H. Sonnleitner, G.C. Eder, R. Ebner, K. Knöbl, L. Stoicescu, "Photovoltaik Modulcharakterisierung – Messmethoden und Interpretation", In Procc. of Tagungsband RETcon 8.-9.2.2018, pp.103-115, ISBN 978-3-940820-13-6
50. J. Slamberger, M. Schwark, "Modellierung von Leistungsverlusten bei Potentialinduzierter Degradation - PID", In Procc. of 33rd PV Symposium 2018 Bad Staffelstein
51. M. Halwachs, K. A. Berger, L. Maul, L. Neumaier, Y. Voronko, A. Omazic, N. Vollert, W. Mühleisen, M.Schwark, R. Ebner, Ch. Hirschl, "Descriptive Statistics on the Climate Related Performance and Reliability Issues from Global PV Installations", Poster 15.Österreichische PV Tagung, 13.-14.11.2017, Wien
52. J. Slamberger, M. Schwark, "Forecasting Power Losses due to Potential-Induced Degradation (PID)", Poster 15.Österreichische PV Tagung, 13.-14.11.2017, Wien
53. A. Mihaljevic, G. Oreski, G. Eder, Y. Voronko, W. Müheisen, L. Neumaier, C. Hirschl, R. Ebner, G. Pinter, "Concept of optimized encapsulant composition for PV module reliability under different climatic conditions", 15. Österreichische PV Tagung, 13.-14.11.2017, Wien
54. S. Poetz, J. Scheurer, A. Rauschenbach, G. Oreski, "Glueing instead of soldering: Electrical conductive adhesives for application in PV", Poster 15.Österreichische PV Tagung, 13.-14.11.2017, Wien
55. M. Halwachs, K. A. Berger, M. Schwark, R. Ebner, L. Maul, L. Neumaier, "Descriptive statistics on power loss and failure modes of PV systems in different climate zones", Integrated PV Technical Conference - From Advanced Materials and Technologies to Multiscale Integration and Usages 2018 - PVTC, 2018, Cassis, Fance
56. R. Ebner, G. Ujvari, W. Mühleisen, CH. Hirschl, G.C. Eder, Y. Voronko, F. Vollmaier, "Importance of Power Stabilization of Crystalline PV Modules", Integrated PV Technical Conference - From Advanced Materials and Technologies to Multiscale Integration and Usages 2018 - PVTC, 2018, Cassis, Fance"
57. M. Halwachs, K.A. Berger, M. Schwark, R. Ebner, L. Maul, L. Neumaier, Y. Voronko, A. Omazic, N. Vollert, W. Mühleisen, Ch. Hirschl, "Trend Analysis of PV Module Failure Occurrence in Different Climate Zones", 34th European Photovoltaic Solar Energy Conference and Exhibition (34th EU PVSEC), 2018, Bussels, Belgium

58. R. Ebner, G. Ujvari, W. Mühleisen, CH. Hirschl, G.C. Eder, Y. Voronko, F. Vollmaier, "Importance of Power Stabilization of Crystalline PV Modules", 34th European Photovoltaic Solar Energy Conference and Exhibition (34th EU PVSEC), 2018, Bussels, Belgium"
59. M. Schwark, J. Slamberger, "Potential-induced degradation (PID) of n-type and p-type silicon solar cells", 34th European Photovoltaic Solar Energy Conference and Exhibition (34th EU PVSEC), 2018, Bussels, Belgium
60. Gabriele C. Eder, Yuliya Voronko, Simon Dimitriadis, Karl Knöbl, Gusztáv Újvári, Karl A. Berger, Lukas Neumaier, "Climate specific accelerated ageing tests & evaluation of ageing induced electrical, physical and chemical changes", 34th European Photovoltaic Solar Energy Conference and Exhibition (34th EU PVSEC), 2018, Bussels, Belgium
61. J. Zikulnig, L. Neumaier, W. Mühleisen, C. Hirschl, D. Holzmann, H. Heigl, “Development of a multichannel data logger for the measurement of microclimatic parameters within enclosures of (externally mounted) PV-inverters”, 34th European Photovoltaic Solar Energy Conference and Exhibition (34th EU PVSEC), 2018, Bussels, Belgium
62. L. Neumaier, D. Holzmann, W. Mühleisen, J. Zikulnig, C. Hirschl, „Determination of moisture ingress and diffusion path in encapsulation layers of standard PV Modules”, 34th European Photovoltaic Solar Energy Conference and Exhibition (34th EU PVSEC), 2018, Bussels, Belgium
63. A. Horn, W. Muehleisen, C. Hirschl, R. Ebner, G. Eder, M. Spielberger, H. Sonnleitner, „System Failure Analysis Tool for PV Plants – A Software Concept for Non-Specialists”, 34th European Photovoltaic Solar Energy Conference and Exhibition (34th EU PVSEC), 2018, Bussels, Belgium
64. W. Mühleisen, L. Neumaier, J. Scheurer, B. Stoesser, W. Pranger, A. Schuetz, F. Vollmaier, T. Fischer, R. Lorenz, M. Schwark, R. Ebner ,C. Hirschl, “Glued Solar Cells - A Sophisticated Technology for PV Modules”, 34th European Photovoltaic Solar Energy Conference and Exhibition (34th EU PVSEC), 2018, Bussels, Belgium
65. G. Oreski, A. Omazic, G. Eder, L. Neumaier, C. Hirschl, M. Edler, W. Krumlacher, R. Ebner, "PV materials and modules developed for certain climatic zones", 34th European Photovoltaic Solar Energy Conference and Exhibition (34th EU PVSEC), 2018, Bussels, Belgium
66. G. Oreski, S. Pötz, A. Omazic, G.C. Eder, Y. Voronko, L. Neumaier, C. Hirschl, R. Ebner, J. Scheurer, W. Pranger, "Reliability of Electrically Conductive Adhesives", 34th European Photovoltaic Solar Energy Conference and Exhibition (34th EU PVSEC), 2018, Bussels, Belgium
67. R. Ebner, G. Ujvari, W. Mühleisen, CH. Hirschl, G.C. Eder, Y. Voronko, F. Vollmaier, "Importance of Power Stabilization of Crystalline PV Modules", Poster 15.Österreichische PV Tagung, Krems, 2018
68. M. Halwachs, K.A. Berger, M. Schwark, R. Ebner, L. Maul, L. Neumaier, Y. Voronko, A. Omazic, N. Vollert, W. Mühleisen, Ch. Hirschl, "Trend Analysis of PV Module Failure Occurrence in Different Climate Zones", Poster 15.Österreichische PV Tagung, Krems, 2018
69. G. C. Eder, Y. Voronko, S. Dimitraiadis, K. Knöbl, G. Ujvari, K. A. Berger, M. Halwachs, L. Neumaier, Ch. Hirschl, "Influence of variable climate stress conditions on performance and material degradation of PV-modules", PV-Reliability Workshop, 2018
70. Gabriele C. Eder, Yuliya Voronko, Simon Dimitriadis, Karl Knöbl, Gusztáv Újvári, Karl A. Berger, Lukas Neumaier, Christina Hirschl, "Climate specific accelerated ageing tests & evaluation of ageing induced electrical, physical and chemical changes", Progress in Photovoltaics, 2018
71. A. Omazic, G.Oreski, G. Eder, C. Hirschl, M. Edler, G. Pinter, M. Erceg, "Weathering stability of newly developed polyolefin-based and PET-based backsheet", 34th European Photovoltaic Solar Energy Conference and Exhibition (34th EU PVSEC), 2018, Bussels, Belgium

72. C. Hirschl W. Mühleisen, G. Brantegger, L. Neumaier, M. Spielberger, H. Sonnleitner, B. Kubicek, G. Ujvari, R.Ebner, M. Schwark, G.C. Eder, Y. Voronko, K. Knöbl, L. Stoicescu, "Scientific and economic comparison of outdoor characterization methods for photovoltaic power plants", PV-Reliability Workshop Ljubljana, Slowenia, 2018
73. J. Šlamberger, M. Schwark, B. B. Van Aken, P. Virtič, Comparison of potential-induced degradation (PID) of n-type and p-type silicon solar cells, Energy, Vol. 161, 2018, Pages 266-276, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2018.07.118.
74. G. Oreski, A. Omazic, G. Eder, L. Neumaier, C. Hirschl, M. Edler, W. Krumlacher, R. Ebner, "PV materials and modules developed for certain climatic zones", PV-Reliability Workshop Ljubljana, Slowenia, 2018
75. W. Mühleisen, C. Hirschl, G. Brantegger, L. Neumaier, M. Spielberger, H. Sonnleitner, B. Kubicek, G. Ujvari, R. Ebner, M. Schwark, G.C. Eder, Y. Voronko, K. Knöbl, L. Stoicescu, "Scientific and economic comparison of outdoor characterisation methods for photovoltaic power plants", Renewable Energy, 2018, ISSN 0960-1481, https://doi.org/10.1016/j.renene.2018.11.044.
76. Christina Hirschl, W. Mühleisen, G. Brantegger, L. Neumaier, M. Spielberger, H. Sonnleitner, R.Ebner, M. Schwark, G.C. Eder, Y. Voronko, K. Knöbl, L. Stoicescu, "Wissenschaftlicher und wirtschaftlicher Vergleich von Analysemethoden am Feld für Photovoltaik Module", Österr. PV Tagung Krems, 11-2018
77. Horn, W. Mühleisen, C. Hirschl, R. Ebner, M. Spielberger, H. Sonnleitner, "Einfache Systemfehleranalyse für PV Anlagen Ein Softwarekonzept für Nichtspezialisten",Österr. PV Tagung Krems, 11-2018
78. J. Zikulnig, L. Neumaier, W. Mühleisen, Ch. Hirschl, D. Holzmann und H. Heigl,"Entwicklung eines mehrkanaligen Datenloggers zur Messung mikroklimatischer Parameter innerhalb von PV-Wechselrichtern",Österr. PV Tagung Krems, 11-2018
79. Yuliya Voronko, Gabriele Eder, Simon Dimitriadis, Karl Knöbl, Gusztáv Újvári, Karl A. Berger , Christina Hirschl, Lukas Neumaier,"Klimaspezifische Alterungstests und Analyse von alterungsbedingten Veränderungen auf Modul- & Materialebene",Österr. PV Tagung Krems, 11-2018

Marketing Publications:

Medium	*Title*	*Publ. date*
APA OTS	*Photovoltaik Systeme, die sich dem Klima anpassen – Österreichisches Leitprojekt forscht daran* *http://www.ots.at/presseaussendung/OTO_20151201_OTO0001/photovoltaik-systeme-die-sich-dem-klima-anpassen-oesterreichisches-leitprojekt-forscht-daran-bild*	01.12.2015
Kleine Zeitung	*Neue Generation der Photovoltaik*	01.12.2015
BMVIT Infothek	*Photovoltaik Systeme, die sich dem Klima anpassen*	01.12.2015
Informationsdienst Wissenschaft (IDW) (D)	*Photovoltaik Systeme, die sich dem Klima anpassen – Österreichisches Leitprojekt forscht daran*	01.12.2015
Informationsdienst Wissenschaft (IDW) (E)	*Photovoltaic systems that adapt to the climate – subject of Austrian lead project research*	01.12.2015
PV Magazine (D)	*Individuelle Photovoltaik-Systeme für jede Klimazone* *http://www.pv-magazine.de/nachrichten/details/beitrag/individuelle-photovoltaik-systeme-fr-jede-klimazone_100021352/*	02.12.2015

PV Magazine (E)	*Austrian scientists launch "climate adaptive PV project"*	02.12.2015
Market Watch	*PV-Systems, that adapt the clima*	03.12.2015
Solar Novus Today	*PV systems that adapt to the environment*	03.12.2015
Spotfolio.com	*PV-Systgeme, die sich dem Klima anpassen*	06.12.2015
Greentech News	*New Research Project: Solar power for all?*	03.12.2015
Ökonew.at	*PV-Systeme, die sich dem Klima anpassen*	09.12.2015
Medianet	*Photovoltaik, die sich dem Klima anpasst* *http://medianet.at/article/photovoltaik-die-sich-dem-klima-anpasst-7272.html*	10.12.2015
Solar Server	*Österreichische Forscher arbeietn an PV-Systemen, die sich dem Klima anpassen*	14.12.2015
Technische Bildung	*Photovoltaik Leitprojekt* *https://www.technischebildung.at/neuigkeiten/detail/?tx_ttnews%5Btt_news%5D=1281&cHash=a87a62ca7229b0a57e7b5cd123ed3a5a*	05.01.2016
New Business	*Anpassungsfähige Photovoltaik*	05.01.2016
Die Presse	*Weltweit die Sonne besser nützen*	28.01.2016
Die Presse online	*Weltweit die Sonne besser nützen* *http://diepresse.com/home/science/4915095/Weltweit-die-Sonne-besser-nutzen?from=suche.intern.portal*	29.01.2016
Der Standard	*Solarmodule für Alpen, Tropen und Wüsten*	07.02.2016
Der Standard online	*Solarmodule für Alpen, Tropen und Wüsten* *http://derstandard.at/2000030251719/Solarmodule-fuer-Alpen-Wuesten-und-Tropen*	08.02.2016
Magazin invent	*Österreichisches leitprojekt jorscht an flexiblen PV-Systemen*	01.03.2016
Der Standard	*Sonnenenergie wird bleifrei*	11.01.2017
BMVIT Website	*http://www.energy-innovation-austria.at/article/infinity/*	03.02.2017
CTR Jahresbericht	*http://www.ctr.at/fileadmin/user_upload/downloads/JB_2016_web.pdf*	30.03.2017
CTR Website	*Energy Globe Award Kärnten: Bleifreie Photovoltaik gewinnt* *http://www.ctr.at/news/news-presse/details/news/energy-globe-award-kaernten-bleifreie-photovoltaik-gewinnt/*	04.05.2017
Regionalmedien	*https://www.meinbezirk.at/land-kaernten/lokales/energy-globe-awards-2017-repair-cafe-villach-holt-den-gesamtsieg-d2111351.html*	04.05.2017
Energy Globe (A)	*http://www.energyglobe.at/kaernten/*	04.05.2017
High Tech Campus Villach (D)	*http://www.hightechcampus.at/en/news-events/news/news-detail/energy-globe-award-kaernten/*	08.05.2017
BMVIT Broschüre (D)	*Schlüsseltechnologie Photovoltaik - Innovationen aus Österreich für die Stromversorgung der Zukunft*	20.05.2017
BMVIT Broschüre (E)	*Photovoltaics - a key technology Innovations from Austria for tomorrow`s power supply*	20.05.2017
PV Magazine (E)	*https://www.pv-magazine.com/2017/05/22/teamtechnik-research-partners-develop-award-winning-lead-free-pv-system/*	22.05.2017
Solarnews (CH)	*http://www.ee-news.ch/de/solar/article/36071/teamtechnik-energy-globe-award-karnten-fur-bleifreie-photovoltaik*	23.05.2017
Teamtechnik (D)	*http://www.teamtechnik.com/en/news/teamtechnik-sets-trends-in-stringer-technology-lead-free-photovoltaics-cooperative-research-project-receives-energy-globe-award-in-austria/*	23.05.2017
Regionews	*http://www.regionews.at/newsdetail/%E2%80%9ERepair_Cafe_Villach%E2%80%9C_sichert_sich_Gesamtsieg_bei_Energy_Globe_Awards_2017-146213*	24.05.2017
CTR Jahresbericht	*https://www.ots.at/presseaussendung/OTS_20180508_OTS0100/ctr-forschungsbilanz-2017-bringt-zuwachs-und-weiterentwicklung-bild*	28.05.2018

Kronen Zeitung	*https://www.krone.at/1740001*	15.07.2018
APA OTS	*https://www.ctr.at/news/news-presse/details/news/photovoltaik-systeme-die-sich-dem-klima-anpassen-oesterreichisches-leitprojekt-erfolgreich-abgesch/*	21.11.2018
APA OTS	*https://www.ctr.at/en/news/news-press/details/news/photovoltaik-systeme-die-sich-dem-klima-anpassen-oesterreichisches-leitprojekt-erfolgreich-abgesch/*	21.11.2018
FHTW Homepage	*https://www.technikum-wien.at/newsroom/news/photovoltaik-systeme-die-sich-dem-klima-anpassen-oesterreichisches-leitprojekt-mit-fhtw-beteiligung-erfolgreich-abgeschlossen/*	29.11.2018

7 Contact Details

Dr. Christina Hirschl
Area Manager Smart Systems
CTR Carinthian Tech Research AG
Europastraße 12
Technologiepark Villach
A - 9524 Villach / St. Magdalen
Tel: +43 (0) 4242 56300 - 260
Fax:+43 (0) 4242 56300 – 400
Email: christina.hirschl@ctr.at
Web: http://www.ctr.at
Web INFINITY: https://www.ctr.at/fe-kompetenz/fe-projekte/ffg-programme/infinity/

Rita Ebner, AIT Austrian Institute of Technology GmbH (A)
Robin Hirschl, ENcome Energy Performance GmbH (A)
Karl Knöbl, FH Technikum Wien (A)
Hannes Heigl, Fronius International GmbH (A)
Herbert Pairitsch, Infineon Technologies Austria AG (A)
Michael Edler, Isovoltaic SOLINEX GmbH (A)
Karl Kürbisch, PV Products GmbH (A)
Gabriele Eder, OFI Technologie & Innovation GmbH (A)
Gernot Oreski, PCCL Polymer Competence Center Leoben GmbH (A)
Archim Wießler, Polytec PT GmbH (D)
Ingram Eusch, PVI GmbH (A)
Markus Spielberger, PVSV e.U. (A)
Wolfgang Pranger, Ulbrich of Austria GmbH (A)