

Conference Highlights



Robert Kenny

European Commission Joint Research Centre

VIENNA | Great location



EXHIBITION | Meet

EXHIBITION

Connect and network

Around 70 exhibitors

NETWORKING Meet and share

NETWORKING



FACTS & FIGURES | Presentations



FACTS & FIGURES | Presentations

EU PVSEC Scientific Conference Programme -Distribution of Presentations per Topic



FACTS & FIGURES | Participants

EU PVSEC Programme – **Participants by Countries – Top 10**

No	Country I	Participants
1	Germany	456
2	Austria	144
3	Italy	109
4	France	104
5	South Korea	99
6	The Netherla	nds 85
7	Switzerland	83
8	Spain	76
9	Belgium	66
10	Japan	64





Plenary Session "Manufacturing"

A. Barin



N. Haegel

Moderated Panel Discussion "Solar Everywhere: Addressing the Challenges and Potential of Global PV Expansion"

OPENING | Monday, 23 Sept. 2024

Becquerel Prize Ceremony



Welcome Message, Opening Addresses & Keynote Speech











PANEL DISCUSSIONS | Four sessions

OPENING PANEL DISCUSSION

Solar Everywhere: Addressing the Challenges and Potential of Global PV Expansion

BO.13

Stable Perovskite Tandems: Hype or Hope?

CO.7

Social Acceptance of Ubiquitous-PV: The Era of Integrated Photovoltaics - Interactive Workshop

DO.13

Renewables 24/7: The challenges of integrating renewables into the future Electricity System

VISUAL SESSIONS | Poster Awards



PV ACADEMY | Sunday 22nd

Calibration of Tandem Solar Cells and Modules

Agri- and Floating PV Systems Recycling of PV Systems CALIBRATION OF TANDEM CL AUTHORS: DR. NIKOS KOPIDAKIS (NREL), DR. GERALD

Vienna, 22 Sep. 2024

THREE SESSIONS

HOFER

TOPIC 1: SILICON MATERIALS AND CELLS

Silicon solar cells continue to demonstrate efficiency improvements due to continued research. Nevertheless a focus of research is now on sliver replacement and CRM reduction (including Si). Process simplification also furthers the above aims, while at the same time reducing manufacturing costs. Silicon bottom cells are the basic building blocks of perovskite silicon tandem solar cells and much research is ongoing, including recombination junction assessment and optimization, for this application. There is an increased interest in silicon cells for space applications due to the deployment of low earth orbit communications satellite constellations.

TOPIC 2: THIN FILMS AND NEW CONCEPTS

Chalcogenides (Kesterite, CIGS) continue to demonstrate increased efficiencies. Perovskites and tandems with perovskites are an increasing area of research. Good progress on tandem and triple junction devices with perovskite-CIGS tandems (19.9% module), all-perovskite tandems (19.7% flexible tandem module), perovskite-Si tandems, perovskite-perovskite-Si (3V open circuit voltage) and all-perovskite triple junction tandems. Outdoor testing of perovskite devices are really important to detect failure mechanisms.

The design, manufacturing, and measurement and reliability of photovoltaic modules continues to be one of the larger areas of interest. Module manufacturing is improved through new encapsulants and interconnection techniques. Modules are increasingly being designed to facilitate recycling at their end of life an important sustainability objective. New technologies, such as perovskite materials are introducing new challenges in characterisation and standands.

TOPIC 3: PHOTOVOLTAIC MODULES AND BOS COMPONENTS

The field of systems and applications of PV is the largest at the conference, demonstrating the increasing maturity of the sector. PV systems O&M is increasingly employing nonintrusive methods such as daylight photoluminescence imaging. Machine learning is being used to monitor the performance. The wide range of applications of PV is rapidly developing, such as for agrivoltaics, with numerous studies looking at system performance and also impact on crop yield – which can also be positive for the case of arid climates. Floating PV, for example on reservoirs or onshore, is being field tested and showing great potential. In BIPV, a lot of work is looking into improving the integrating custom elements, such as coloured modules.

TOPIC 4: PV SYSTEMS ENGINEERING, INTEGRATED / APPLIED PV

An important objective is the achievement of a fully circular economy, and recycling techniques and several schemes for module recycling are studied. The integration of PV into energy systems is a major theme. Novel approaches to grid integration, storage and new electricity market designs were presented. The social dimension, is increasingly being studied to understand the needs of society and also to evaluate the social acceptance of PV. TOPIC 5: PV IN THE ENERGY TRANSITION

PLENARIES | Thematic

Manufacturing

PV Everywhere

Performance and Reliability | Thin Films and Tandems

FOUR SESSIONS

Sustainability

PARALLEL EVENTS | Varied programme

PARALLEL EVENTS

Some examples

Women in PV: A Platform for Dialogue and Networking

The Landscape of Agrivoltaics: In Between People and Technology

Unveiling the Future of Solar Energy with Perovskite PV

Roundtable-BIPV Opportunities in the Indian Marketplace

INDUSTRY SUMMIT | Debate

INDUSTRY

SUMMIT

Industry Stakeholders

European PV Manufacturing in stormy times – will we see the tide turning any time soon?

Global Perspectives on Solar PV Manufacturing: Time-to-market, Costs and Technology Transfer in USA, India, and Europe

Next era of European PV Manufacturing

Company Presentations & Round Tables

SESSIONS | In detail

The following sections provide further details of the presented works, session by session, based on the valuable feedback provided by the Session Chairs.

The sessions are ordered by topic, and include oral and visual session highlights. The session code and title are included for easy reference.

TOPIC 1 | Session by session highlights

1AP.1	Manufacturing	The presentation of Mr. Zhang showing the development of solar cell sizes and thickness and what were the drivers for this development was really good. Also he showed the measues/activities taken to improve the cell production pricess in respect to economics and ecology
1AO.4	Silicon Material for Solar Cells: Growth, Stability and Reuse	 Joshua Kamphues showed us that we can use Fe contamination as a proxy metric to assess the reproducibility in resistance and impurity concentration of recharged Ga Cz Si, including a correlation with LeTID. A creative method for monitoring industry critical Ga-doped melt recharged wafers. Guo Li presented results that show H as an important mitigator or healing agent that could enable improved stability Si for space applications, where H could heal the high radiation damage and improve the competitiveness of Si as a technology for space PV. The session also included many new insights on thermal defects in a range of silicon wafers and PV structures, as well as considerations for recycling silicon based on dopant type.
1AO.5	Processes for Highly Efficient Si Solar Cells	 Advances in leaner processes and passivation improvement for TOPCon and HJT solar cells Critical research in reducing silver consumption in HJT
1AO.6	Highly Efficient Si Solar Cells	TU Delft showed an IBC-tunnel SHJ solar cell with a MoOx/(n) a-Si based tunnel contact at the rear side and copper-plated metallization with a conversion efficiency of 23.1%. Fraunhofer ISE showed TOPCon solar cells fabricated on epitaxially grown Si wafers. They could demonstrate 24.4% and 24.7% conversion efficiency on n-type and p-type epi wafers, respectively (i.e., as good as on reference FZ silicon wafers). ISC Konstanz showed a poly-Zebra IBC solar cell with 24.12% efficiency and demonstrated it holds potential for 25% based on experimental-based simulations. ISFH showed POLO IBC solar cells with 23.9% efficiency.
1BO.1	Silicon Bottom Cells for Tandem Photovoltaics Dielectric Layer Related Defect Characterisation	Silicon bottom cells are the fundament of perovskite silicon tandem solar cells. TOPCon and HJT bottom cells have been presented in the session. Both technological progress (thinner wafers, improved voltage) and a better in-depth understanding were discussed in the excellent presentations. A special focus was set on different approaches for the interface to the perovskite top cell as tunnel junctions or recombination layers.
1BO.2	Advanced Silicon Solar Cell Characterisation in Laboratory and Production	The papers in this session highlighted ways in which large data sets from production lines can be collected and analyzed to understand the impact of specific variations in production parameters on final cell performance. In this regard, there was no single highlight contribution, but each presentation provided pieces of the puzzle to substantially improve solar cell manufacturing with big data analysis.
1BO.3	Optimised Processes for the Manufacturing of TOPCon Solar Cells	 Julian Reichle; RCT Solutions: review of emerging wafer sizes industry Lu Wang ; Jiangsu Xianghuan Technology: 1GW Cu platting tool for solar cell manufacturing Damian Brunner ; RENA : 37%USD Cost saving for alkaline batch edge isation tool compared to acidic solutions Eric Schneiderlochner ; Von Ardenne : Full PVD route for TOPCon including SiN, poly-Si and Silicon tunnel oxide Xutao Wang ; UNSW: laser assisted firing (LECO/JSIM) 0.6% abs efficiency gain compared to selective emitter Tadeo Schweigstill; FISE: Printing down to 8um with glass stencil
1BO.4	New Concepts for the Manufacturing of IBC and HJT Solar Cells	2 important European projects (BUSSARD and IBC4EU) were presented with relevant technical data from the material to the module, including cells, equipment and recycling tasks; and several process flow for simple and efficient IBC technologies were presented. This made the session really interresting with alternative and promising results paving the way to new industrial processes. Solutions for more simple and sustainable process have been presented, including metallization with reduced silver consumption and selective etching for patterning process.
1BV.5	Silicon Material: Growth, Defects and Recycling Manufacturing of Solar Cells and Related Tools & Processes	This session showed progress on the application of copper metallisation for high efficiency cell concepts like HJT and TOPCon with cell efficincies comparabel to Ag references.
1CV.2	Processing & Characterisation of Crystalline Si based Solar Cells Silicon Bottom Cells for Tandem Photovoltaics Advances in Silicon Solar Cells Characterisation and Simulation	A very rich session with many novelties going from processing to characterization and modelling. Award to the impactful poster on simple method to reduce Cu diffusion.

TOPIC 2 | Session by session highlights (1)

2CP.3	Performance and Reliability Thin Films and Tandems	CP.2.1 Increase in size and reduction of glass thickness to 2mm reduces strength and increases probability of failure; Longi announced to go back to 3.2mm front glass thickness. CP2.2 Watch out manufacturers, Daylight PL has become even more powerful. 9000 modules at once, 50 at once when resolution on cell level is needed. CP.2.3 Power optimizers don't deliver 30% perfomance increase of roof systems under partial shading conditions as advertized. CP.3.4 Outdoor testing of encapsulated perovskite modules (statistics) is crucial for better understanding of their performance and stability. CP.3.5 triumph project succesfully worked on triple junction and achieved 26% in the endeavor to make tandems/triple junctions great again. CP.3.6 Comeback of CIGS? New record efficiency of ~24% reported, in 4 terminal tandem with Perovskite: 29,9%
2AO.1	Inorganic and Organic Compound Solar Cells and Tandems	In session 2AO.1 about Inorganic and Organic Compound Solar Cells and Tandems, several novel contributions were presented. Two major highlights were on some new devices: Both IREC and UPC showed recent progress in kesterite development. The latter showed a kesterite device with Li doping and Ag alloying reaching 14.1%. A second highlight was on the rear surface passivation of CuIn(S,Se)2 by patterned Al2O3, presented by the University of British Columbia.
2AO.2	Solar Cells based on CIGS and its Alloys	Upsala University presented record efficiency CIGS solar cells alloyed with Ag and reaching 23,6% after a ligth soaking step. She gave an in-depth analysis on the evolution of the structural, chemical and electronics properties of the devices. Another highlight was from ZSW on transparent CIGS semitransparent cells for tandem devices. Results focused on the need to control the ITO/CGS interface by adding a thin Mo layer to prevent GaOx formation. Alternative TCO layers are also proposed to achieve back contacts combining both high transparency and good electrical behaviour.
2AO.3	III-V Solar Cells & Space PV	It seems silicon came back to space again, due to marked volume demand a lower cost. All space related presentations were talking (iii-v also) about Silicon.
2BO.10	New Modelling and Characterisation - Material Properties	Spatially resolved determination of implied open-circuit voltage and thickness of perovskites and perovskites silicon tandem solar cells.
2BO.8	Novel PV Material and Conversion Concepts	 * two talks could be highlighted for this session, namely 2BO8.1 and 2BO8.3, however the 2BO8.3 makes one step further in view of practical implementation of the contribution 2BO8.1. * it is practically applicable on an IBC solar cell and could potentially lead to 34% efficiency using 1 junction only * There might be doubt about additional effects due to band bending related to MoOx and heavy-doping induced BGN, but at least it sketches a way to practical implementation.
2BO.9	Advanced Materials for PV Devices	In this session, we saw a trend towards trying to improve the performance and manufacturability of emerging materials; in particular, we saw Sarallah Hamtaei from Imo-imomec (Hasselt University/imec) present results showing PV-grade WSe2 deposition, a transition metal dichalcogenide, on much larger areas (up to 6 inch wafers) using ALD than previously achieved using mechanical exfoliation.
2CO.1	Processing, Characterisation, and Modelling of Perovskite/Silicon Tandems	2CO.1.1: Oussama Er-raji from Fraunhofer ISE, student finalist, showed how incorporating the urea-treated perovskite absorber in a fully textured tandem cell passivation were improved and series resistance were reduced achieving over 31% stabilized PCE.
2CO.2	Triple Junctions and Advanced Concepts in Perovskite-based Tandems	Perovskite-CIGS mini-module with scalable processes with 19.9% and 24.5% on solar cell level. 3V Perovskite-Perovskite-Si Triple Junction Device. All-Perovskite Flexible Tandem Module with 19.7 efficiency.

TOPIC 2 | Session by session highlights (2)

2CO.3	New Modelling and Characterisation - Device Performance	This session covered various aspects of modelling and characterization of perovskite solar cells solo or in tandems, as well as a bonus talk on thermophotovoltaics. We heard about the fundamentals of cell selective techniques to determine loss mechanisms, along with correlations between capacitance-based measurements and simulations identifying e.g. effects of ion migration and mobility. Outdoor testing of bifacial perovskite-silicon tandems were also investigated with a special focus on spectral and temperature effects. Modelling using machine learning techniques help to identify recovery mechanisms in perovskite solar cells. Finally we were educated about thermophotovoltaic systems and how to measure them.
2DO.18	Late News: Developments in High Efficiency Tandem Cells	HZB: Two main innovations in all-PVK tandems. The first is piperazinium iodide treatment to displace the contact between WBG PVK and C60. This results in better QFLS and Delta_Voc > 100 mV. The second innovation is a new SAM-based bilayer HTL for NBG PVK. This enables good transport while allowing crystallization of the Tin-based PVK absorber. Deploying these innovations, an all-PVK tandem with PCE ~ 30% and an all-PVK triple junction with Voc ~ 3 V are demonstrated. Jinko: Certified 33.24% 2T tandem based on PVK/TOPCon combination (certified at SIMIT, China). Key innovations are: high temperature ITO as RJ; double side textured TOPCon (boron diffusion at the rear side), one step coating process for the top cell with buried interface in the absorber as well as novel additive to quench hysteretic behavior and new surface treatment. Oxford PV: Focus of the company in on high PCE to push down the LCOE. Main market for them is not necessarily rooftop but rather power plants. Their module is sturdy anyway against partial shading and passed IEC 61215 (draft certification). Datasheet value is 545 Wp with 15 year warranty. Right now, full area module PCE is 25% (certified at Fraunhofer). Polytechnic University of Turin: Preparation of 3T PVK/SHJ in 3T hybrid bipolar junction configuration (PNP in terms of front/back contacted PVK onto front/back contacted SHJ). Technical challenges have been overcome to extract the common terminal in the middle of the 3T HBT.
2DO.6	Towards Improved Understanding of Perovskite Solar Cell Device Physics	2DO.6.5: Enhancing crystallinity of perovskite materials through rapid microwave annealing. The innovative modification of perovskite annealing, and the implications for upscalability were impressive.
2DO.7	Process Innovations for Perovskite Devices	Stronger focus on a combination of industrialization (scale up, higher throughput) and stability of perovskite solar cells and modules. The relatively low fracture energy in PSM compared to cSi solar modules can be largely compensated by a laser scribe strategy. In this approach the POE bonds to the substrate and bares the mechanical load.
2DO.8	Scalability of Perovskite Solar Modules	The session impressively demonstrated how the perovskite technology is maturing and moving towards industrialization. UNSW showed in 2DO.8.1 a new metrology approaches for mass production whilst the other talks demonstrated the increasing number of high-level pilot lines for supporting industrial ramp-up. Scaling is happening right now!
2DO.9	Lifetime and Reliability of Perovskite Devices	Extended dataset on small and large (28x28 cm2) perovskite modules outdoors in 4 locations up to 3 years [2DO.9.1] as well as 20 months-long testing of 4T perovskite/Si tandems in Cyprus [2DO.9.5].
2BV.1	Advances in Novel Materials, Devices and Concepts New Modelling and Characterisation Techniques	The session showcased a wide variety of new concepts and characterization techniques in different stages of development. It was very interesting to learn about the new materials, device designs and methods for predicting the performance of new device technologies.
2BV.2	Compound and Organic Semiconductors	The poster session 2BV2 included thin film CIGS, kesterite and CdTe solar cells as well as III-V materials and solar cells for space. For the CIGS solar cells, the poster by Arivazhagan Valluvar Oli et al from University of Luxembourg with a 15.7 % efficient high bandgap Cu(In,Ga)S2 device was nominated to the poster award. Both the results and the presentation were excellent. Kesterite solar cells with Cd-free buffer layers were presented by IREC, Spain (Yudania Sanchez et al) and show good promise for the future of this material. Novel architectures with bottom-up grown CISe micro-cells had potential for high efficiency concentrator cells with selective growth, presented by (Lucassen et al from University of Duisburg-Essen, Germany). The jury was also impressed by the poster presented by Jennifer Teixeira from INL (Portugal) on modeling of passivation of Ultrathin CIGSe solar cells. For the III-V, remote-plasma process gave good results for growing high quality thin films. The poster was presented by IPVF, France (Lise Watrin et al).
2CV.3	Perovskite-based Multijunctions Perovskite Photovoltaics	Highlight of the session was a all vacuum-based approach to form perovskite layers on planar substrates and textured silicon via an evaporation + CVD sequential deposition. Their innovative approach shows a process sequence by scalable techniques, including for the organic precursor deposition, which typically is a critical step. (posters 2CV3.63 and 2CV3.24 by CSIRO, Australia)

TOPIC 3 | Session by session highlights (1)

3BO.11	Reliability of PV Modules: The Impact of Solar Cell Technology	Our session covered different cell technologies from TOPCon over HJT to Perovskites and poked at various degradation mechanisms. A common theme of all presentation was the importance to have a well designed Vom in order to keep degradation limited.
3BO.12	Reliability of PV Modules: The Impact of Polymers	The importance of studying the reliability studies of the backsheet materials that are mostly used today in production, namely PET with fluoropolymer coating was highlighted. First results of combined stress on this type of backsheets were presented (NIST). The session was focused on investigating the reliability and long-term performance of new encapsulating materials and backsheets. Initial results on the reliability of fluoro-coated backsheets were presented, which is very critical for the field but still unsufficiently studied.
3BO.14	Failure Modes and Degradation Mechanisms in PV Modules	The talks highlighted a variety of microstructure failure modes for new cell technologies and provided insights into mitigation strategies.
3BO.15	Reliability of PV Modules: Testing and Modelling Approaches	An innovative approach for reliability testing of PV modules, tailored for hot desert climates. Authors from four different continents presented results from outdoor testing on degradation rates and failure modes and effect analysis (FMEA). Slide #6 as a nice example-reference.
3CO.10	Materials and Processes for PV Modules	 Very interesting session with material topics covering: > overview encapsulation materials with recommended selection for next generation cells (e.g. for perovskite based tandem cells), > presentation of alternative encapsulation material, > new developments for multilayer ARC for solar glasses, some of which could be also implemented on other substrates like sensitive cells (e.g. customized multilayer ARC applied on perovskites to improve their stability by reducing their exposure to certain wavelength) And module manufacturing processes topics covering: > review advantages of double side heated laminators > proposal to avoid thickness decrease (and mechancal stress) at glass-glass laminates with membrane laminators (partial cross-linking in edge region).
3CO.11	Emerging Interconnection Technologies	3 CO.11.3 - neccessary step towards lowT interconnection - hopefully relevant study, need to developed towards industrially relevant cycle times. 3 CO.11.5 - nice to see new concepts being featured in presentaions; very interesting for niche applications where shading is hard to avoid.
3DO.12	Low Environmental Impact Module Design and Technologies	 3DO.12.1 Steps Towards a 100% Renewable Material Solar Module: Evaluating Material Substitutions for Encapsulation and Interconnection, Ringo Koepge: Full PV-module produced with recycled backsheet and biodegradable encapsulant, recycled frame. 3DO.12.2 New Encapsulant for PV Modules Designed for Recycle: A Lab Scale Prototype, Timea Bejat: New innovative silicone based vitrimer developed for recycling purposes with easy lamination and delamination approach, it promote repair and reuse in the future. 3DO.12.3 Laser-Assisted Ablation for Silicon Solar Panels Recycling, Remi Aninat: Solution with NIR laser for ablation and separation of silicon and encapsulation interface, fabrication and decomposition are both show for samples in a clean process. 3DO.12.4 Innovative Design-for-Recycle for Critical Material-Free Interconnection, Antoine Perelman: Assembly of a module with a liquid instead of polymeric encapsulation with led to full decomposition of the stack with recovery of the material, it also showed satisfying stability under TCT 350. 3DO.12.5 Bifacial Lightweight Solution without Glass, Alicia Buceta: Light weight module with reinforced composites and UV protection film was tested for hail impact, damp heat and UV, it showed positive results for hail test. 3DO.12.6 Development of Novel Protective Coatings to Increase the Durability and Reliability of Glass-Free Lightweight PV Modules, Yuliya Voronkon: Comparison of UV-curable coatings developed for PET-foil protection with good results of accelerated aged samples in characterisation of optical transmission
3DO.16	PV Module Assessment and Classification	Noted interest in also monitoring potential Pb leaking from Pk-Si tandem, reported by Atse Louwen (EURAC research) from Nexus project. Brendan Wright (UNSW) reported on significant improvements in luminescence imaging (together with contributions), in particular also in machine learning methods to implement this automatically on a large scale.

TOPIC 3 | Session by session highlights (2)

3DO.17	Outdoor Performance and Energy Yield Estimation	Both presentations on degradation rates highlight the need to analyse more technologies for longer timeframes, the importance of bill of materials and the re- definition of main stressors in extreme weather conditions. The other 3 presentations, on energy rating standards highlighted that the scientific community is still working on their improvement, by validating them through outdoor performance data and round robins between laboratories to validate the parameters extraction. The results are promising and will be implemented in new versions.
3DO.19	Modelling Techniques for PV Modules	Blind PV Performance modelling comparison of commercial software (3DO.19.6). The paper reveal critical shortcomings of currently used modules and provided valuable feedback for the PV community which will help improve the accuracy of energy yield simulation.
3DO.20	Shading and Soiling on PV Modules	 SHADING: A methodology for shading resistance classifictaion of PV modules have been presented by Richelmann (PTB) 3DO.20.3. The metholody has been proved to be simple to carry out and reproducible across different labs. A proposal for a new standard about shading resistance has been suggested. SOILING: Different type of dust has been observed and analyzed in desert environment. Correlation with Isc losses have been presented. (3DO.20.5). PV cleaning effect has been shown to be important in desert environment. Standardize evaluation of cleaning procedures has been proposed (3DO.20.6).
3EO.1	In Field Characterisation of PV Modules BoS Components in Operation	The session covered various topics of outdoor module performance testing and optimization. Visual inspection was shown to be a useful screening tool for low performing modules that might require further testing. Different encapsulant compositions degrade very differently. A new UVF and NIRA technique allows for a more informative inspection. Variations between similar BOM modules were also shown. A mobile module testing lab including a A+A+A+ simulator with an EL capability was also shown that can test a large amount of modules. It has been applied both to initial pre-installation inspections and to already fielded modules. Lower performance than Pnom was demonstrated in initial tests that correlates to manufacturer and, seemingly, not to the specific technology of the module. Reduction of uncertainty components arising from irradiance and temperature variations in fielded modules was also shown. A couple module types were used as test cases, fielded in different locations and different mounting configurations. Combined expanded (k=2) uncertainty of Pmax was found to range between 3.3 and 5.7%, which could be improved further. A power electronics device was demonstrated and fully integrated to a module package to produce an AC module. This included connectivity between the modules. The structure avoids multiple connections by integrating everything to the module package itself in a larger "junction-box" that has been shown to be durable and operate safely. Typical commercial DC power optimizers were tested to evaluate the algorithm for finding maximum power. This seems reasonable for avoiding bypass diode activation and possible hotspot problems, however it does not conform with the specifications provided by the manufacturer. A 1-axis tracker algorithm optimization effort was shown that aims to find optimized tracker angles for diffuse conditions. A neural network was trained and initially validated using lab data. The next step is for further application and validation on an outdoor system.
3AV.1	PV Module Design and Manufacturing BoS Components. Operation and Aging	Shingling with soldering technology: process optimisation, reliability testing and perspectives for further optimisation. Detailed encapsulant formulation, coloring optimisation through design of experiments.
3AV.2	PV Modules Reliability: Components, Failure Mechanisms, Testing & Modelling	We are witnessing an increasing interest and research activity on failures assessment, testing and modelling approaches related to glass, as critical component of current and future PV module technologies.
3AV.3	PV Modules Performance: Testing, Modelling Techniques and Outdoor Performance	Characterization remains a topic of ongoing research, with the need to establish clear measurement methods, in particular for bifacial measurements. There is also concern about underperforming new technologies, both in performance and reliability.

TOPIC 4 | Session by session highlights (1)

4CP.1	PV Everywhere	With 15 years research data on over 30 implemented projects in Southern France, Sun'Agri demonstrated that dynamic agrivoltaics proves to be very effective for improving the crops performance, supporting a better response of plants to mitigated extreme climatic effects. Shading offered from PV modules is a clear advantage for the crops, and helps in saving the crops in case of adverse seasons, reducing the water demand around 30%-40%. JRC through an extensive and detailed analysis of the potential for agrivoltaics in Europe demonstrated that the land consumption is not the issue. Countries like Italy, Spain, Germany and France demonstrate the highest potential for agrivoltaics in Europe. Still important challenges need to be faced: Regulatory framework, Social acceptance; Impact on agricultural yield. Christophe Ballif gave a very comprehensive overview of the 'history of colored PV'. His talk included all the different techniques to apply color, the major breakthroughs, efficiency ranges, and even euro/m2 best estimates. Colored BIPV is entering a new era in which the reliability of the color becomes important. That requires a new color measurement methodology and maybe even a new chapter 'color reliability/stability' in the IEC BIPV-standard (although that was not explicitly mentioned by Christophe). Minne de Jong gave a nice comprehensive overview of the 'rise of Floating PV'. Without running into confidentiality issues, he showed quite open all the challenges in the field of FPV. He summarized all important issues in the Wave Category (WC) 1 systems. And he gave a first glimpse of what aspects will be very important research (and development) topics for the more challenging WC2,3 or even WC4 (off-shore) FPV: 'Birds have a preference of soiling the more horizontal systems'.
4AO.7	Advanced O&M Strategies and Methods	Several Data driven Modells were presented for PV System failure prediction Even with Integrated Human in the Loop Maschine learning Concept, Deeplearning fault detection based on Artificial and convolutinal Network And diagnostics Hybrid Modell. The last one could Report on 89% accuracy fault detection for each measurement.
4AO.8	PV Plant Performance, Analysis, Monitoring and Fault Detection in Inverters	There is an increased need for PV performance diagnostics on inverter level and common failure syntax. For example: 8.2 by Stephanie and Malik on failure diagnostics and curtailment and 8.5 by Bernhard Kubicek a common syntax and georeferencing.
4AO.9	The Impact of Soiling on PV Systems	We see more models addressing soiling estimation in large regions; assumptions related to rain cleaning were revisited and updated and an interesting paper with soiling chambers to generate soiling more quickly.
4BO.16	Technology, Performance and Economics of PV in/on Buildings	Transparent Pv for windows and IGU; Shading effect and energy management; Policy at EU level; Architect as a new stakeholder; Agri-BIPV.
4BO.17	Characterisation, Reliability and Safety of PV in/on Buildings	The session presented progress in bipv characterizations and reliability assessment: new approaches and experiments to assess the impact of color and air gaps in BiPv facade together with the use of lightweight substrate have been presented. Fire is a concern for researchers to find the proper material but in the Netherlands out of 10000 fire occurred in buildings only 152 had Pv system.and 0,005% of total fire events. PVROOF IN EU27 has a potential of 2,4TWh/y based on a new open access model developed by JRC.
4BO.5	Design and Coloring Techniques of PV for Buildings	This session explored innovative approaches to integrating photovoltaic (PV) systems into buildings, focusing on colored modules. Experts discussed techniques to enhance architectural aesthetics while maintaining efficiency and durability, with key topics including methods to assess the visual and functional impact of these solutions. Marie Courtant from EPFL presented a significant contribution as a finalist of students award—a novel colorimetry tool designed for building-integrated PV (BIPV) applications, addressing current market limitations. The research's relevance extends to an alternative methodology, based on a measurement tool, offering further insights into optimizing the visual appeal and functionality of PV modules for greater acceptance in architectural design.
4BO.6	Performance and Degradation of PV Systems	Analysis of five PV systems with more than 30 years operation in Switzerland showed that degradation rates were lowest at higher elevations (due to lower temperatures?) and in general lower than degradation rates from comparable studies. Author: Hugo Quest, 3S Swiss Solar Solutions.
4BO.7	Data Driven Field Inspection based on Imaging	The section had a very wide variation of imaging techniques and specialties within the field, what enriched largely the quality of the session. Relatively new imaging techniques for field inspections such as electro- and photoluminescence, and ultraviolet fluorescence are upscaled and fault detection better understood. More highly accurate imaging inspection techniques are available to be performed during daylight, what maximizes the trust in the available data for PV plant diagnostics. Finally, automatic AI tools for imaging analysis and fault classification are shown to make utility power plant diagnostics possible.
4CO.8	Solar Resource Assesment	Absolute Highlight was the talk 4CO.8.1 'The Fourth Edition of the Best Practices Handbook for Solar Resource Data: An Introduction' - given by Jan Remund (Meteotest, Berne, Switzerland). The Solar Resources Handbook is truly exceptional, offering essential insights into all aspects of energy meteorology while also documenting the current state of research. It is a collaborative work authored by many globally renowned experts, freely accessible to the public, and is expected to be published soon after the conference.

TOPIC 4 | Session by session highlights (2)

4CO.9 Solar Forecasting	Machine learning based method to do satellite based solar forecasts using Unit architecture show significant improvements from current state of the art. Cloud index based prediction better than cloud motion vector based method. GHI forecasts also demonstrate similar improvements. Hybrid model provides better forecast for longer lead time. Presentation on optimal data usage to reduce the number of training samples. Shows that skills driven sampling strategy can result in 30% of data being eliminated with no impact on data driven sky imager based forecasts. Deep learning model vs video processing method with regression (generative models) for solar ramp forecasting shows that the generative models are much better at forecasting ramps as they do not smooth the forecasts. XGBoost using infrared data from satellite can improve fog detection with a Probability of detection of 80%.
4DO.1 PV System Design and Optimisation	The session presented impressive work on optimizing the design plan of PV systems and PV plants often based on elaborated simulation techniques. The studies addressed not just optimal power performance but total delivered energy and LCOE taking in account degradation and soiling besides other impacts. An especially interesting presentation was given by Dr. Hesan Ziar of Delft University of Technology on a software tool for the allocation of irradiance sensors in PV plants. Starting from the purpose of the irradiance monitoring, it determines the minimum number of irradiance sensors and their optimal placement based on the plant layout and the topography of the site and its surroundings. (4.DO.1.5 A Matlab-Based Software Solution for Irradiance Sensor Allocation in European Solar PV Farms).
4DO.2 The Integrated Agrivoltaic Performance: Approaches, Modelling, Experiences	Some of the highlights and key learnings from the session were: * Very detailed modelling of agrivoltaics systems is possible, which include both the PV generator (and its yield) and the plants based on a 3-dimensional crop model. This allows to predict the expected photosynthesis active radiation (PAR) for different plants and the crop yield. * Important to distinguish between "food for humans" and "food for animals" (= food for animal husbandry). Crop used for "food for humans" tend to be more suitable for Agrivoltaics and hence should be addressed first. Experiments showed different optimisations for crops in arid conditions, where some plants (e.g. beans) grow better under PV and even under 50% less irrigation needs. * New use case for agrivoltaics: Agromining = phytoextraction of metals from hyper-accumulating plants, which were found to also work well under PV systems. * Sophisticated modelling platform and method is presented for optimizing solar tracker position boosting synergies for crop growth in agrivoltaics systems which support societal acceptance of these projects- validation in Germany follows soon. * Detailed irradiance validation is presented in greenhouses fitted with 30% and 50% cover ratio of PV panels in a checkered patterns in Spain. First results show expected crop yield reductions, large variance in sugar content and that number of fruits increase towards end of crop cycle.
4DO.3 The Integrated Agrivoltaic Performance: Different Climatic Conditions, Crops and Technologies	4DO.3.2 Reducing wind speeds in vertical PV farms is shown to have a generally positive effect on the agricultural yield, offsetting the reduction of light in Nordic countries as shown by Erlend Honningdalsnes from IFE, Norway. 4DO3.5 Alex Katsikogiannis on modelling of 3D apple trees in orchard, shading by PV panels brings the light conditions to near optimal for photosynthesis. 4DO3.6 innovative product for PV in greenhouses by Jacques Levrat, CSEM, already at TRL8 and 1 hectare installation. Growth of tomatoes shows no reduction, even in Netherlands conditions, but insects are less attracted by the plants as they appear less green.
4DO.4 Vehicle Integrated PV	New record 33.7 % efficiency of a module based on triple junction III-V on Silicon (InGaP/GaAs/Si) with high potential for VIPV. Toyota Prius equipped with a III-V 860 Wp module demonstrated a driving range up to 26.6 km/day without heating/air conditioning and 17.7 km/day with air conditioning and 100% energy self-sufficient ratio of for driving scenarios of 15km/day.
4EO.2 Planning of PV Systems Digital PV	Very diverse session, addressing key aspects of PV integration into the digital energy system. The diversity of issues and problem solving methodologies presented in this session is a sign that the PV community reaches a good level of maturity and understanding of their place and impact on the renewable energy transition. - Energy yields and yield disparities for energy transition modelling - Effects of large scale extreme weather events on a national power supply system with significant shares of PV - Solutions to address privacy issues with PV generation data.

TOPIC 4 | Session by session highlights (3)

4BV.3	Operation, Performance and Maintenance of PV Systems	Posters in session 4BV.3 highlighted many innovations that are improving the efficiency and scalability of PV O&M and reliability monitoring such as AI-powered analyses, drone-based monitoring, robotic automation, as well as many new monitoring methods that can extract new information from existing data streams. The most promising results combine the needs from industry with the creative innovation from research institutes and universities and are able to scale to fleets of systems.
4BV.4	Photovoltaic in/on Buildings	How to optimize color in BIPV is a challange for many cases. New techniques are proposed. A new texture is proposed to improve the angle dipendence of BIPV. Optimization of community PV has been simulated considering different surfaces, costs and co2 emission, Still to early to integrate batteries.
4CV.1	Solar Resource and Forecasting	More and more machine learning methods are used, compared and validated for forecasts, data assimilation, updated irradiance databases and all-sky imaging. Also physics-based and physics-informed models are employed, which enhances understanding of the various results, especially regarding to forecasting.
4DV.1	Dual Use (Floating PV, Agrivoltaics, VIPV) and other Innovative PV Applications	The PV community has a better understanding of the limitations and specific requirements of integrated PV applications such as agrivoltaics, floating PV, and low-energy PV. Several posters addressed design conditions, performance, and economics from the point of view of the end application and not just the PV part, which is a (good) sign that these industries are becoming more mature.
4DV.4	PV System Engineering Control and Systems for Power Systems with Renewables Integration	Battery Systems sizing in combination with PV Grid Integration to optimise the electricity price; Assessing Potential gain of bifacial modules in different Applications using albedo enhancing material in arid climate and alpine locations.

TOPIC 5 | Session by session highlights (1)

5CO.4	PV Module Recycling	The number of attendess: 140-150 demonstrates the growing interest in the topic. New methods to measure the layer thickness of different PV module components were discussed. Innovative approaches to separate the polymers were presented. High value recycling of perowskites is demonstrated. Cost reduction models for the collection of PV models were presented. Innovative approach for generating energy in the form of heat and hydrogen from waste to create new products.
5CO.5	End-of-Life PV Modules & Ecology	We can see that there is a growing interest in sustainability for PV but some challenges remain. Presentations on PV sustainability on multiple perspectives: Test recycling solutions for novel PV technologies (PK) Develop metrics to evaluate circularity Identify challenges on lack of transparency on PV module material composition Ensure safe and transparent labeling for re-used modules with soon to be published IEC technical report Design of bifacial modules to improve ecosystems services Monitor microenvironnement for development of nature positive PV through bio and physical perspective models.
5CO.6	Life Cycle Assessment of PV	Developments in the field of LCA have made very good progress. - Low carbon solar panel for technology choice Good news from the PhD student Lu Wang - she introduced a methology to simplify LCA's by focus on key parameters. CI should not reduce for reliability. Fraunhofer ISE delivered new results (climate specific degradation) can be used for optimized PV deployment strategies.
5DO.10	Manufacturing PV in Europe Social Aspects of PV	Crowdfunding as a way to commit people to public engagement of RES as done at the University of Aarhus in Denmark as presented by Marta Victoria.

TOPIC 5 | Session by session highlights (2)

5DO.11	Value and Competitiveness of PV in the Growing Market	 5DO.11.1 G. Masson: Task1 IEA PVPS gave an overview of Global PV Market 2023 Global PV installed capacity reached 1.6TW. China is the largest supplyer and consumert of PV modules. Supply and demand gap causes lower prices stimulating the growth of the market. 5DO.11.2 U. Jahn give a presentation titled "Driving the Quest for Reliable and Bankable PV in Europe - Status and Targets in 2030" Key items of Strategic Research and Innovation Agenda (SRIA) related to reliability and bankability were introduced. Enhancement of lifetime, reliability, and sustainability of PV technology are focused. Predective mentenance, field inspection, lifetime modelling are picked up. 5DO.11.3 Dr. E Shiraz Is The Value of (BI)PV Increasing or Decreasing over Time? East and west facade PV value is promising option in comparison with South faced PV. Decline of the valu-factor is slower. 5DO.11.4 The Role of Flexible Demand in Reducing Utility-Scale PV Integration - Costs: An Italian Case Study, Elisa Veronese, EURAC Important topic 5DO.11.5 Wholesale Electricity Market Prices Forecast Considering Building Conditions Using Price Sensitivity J. Hirota JPEX, Japnese Electricity market forecast 5DO.11.6 Cost Analysis for Small scale hybrid Hydorgen based PV Energy System - Marius Möller, Univ. Paderborn, showed that depending on the further cost development of all the relevant system components and different locations in Europa, such systems can be in the upcoming years become more cost effective the electricity from the grid. Moreover, costs might not be the only reason for deciding for such systems, independency from public grids might be another factor, which makes this analysis very valuable in order to discuss the further needs and the financing of public electricity grids.
5DO.14	Energy System Integration with Storage	PV modules indirectly connected to electrolyzers improve the H2 conversion efficiency, relative to direct PV-electrolyzer connection. When using batteries to balance solar PV participating in the grid: if the settlement time (flexibility market) is shorter, the battery degrades faster. Power-heat-Power storage using thermo-photovoltaic for discharging can be used, together with Lithium-ion, to supply electricity and heat to buildings. Sandia is considering combining PV, battery, CSP and thermal energy storage to supply 100% renewable energy to facilities with loads more than 50 MW. Thermal energy storage is key for the extreme days in the year.
5DO.15	Resilience and Security of Supply	Grid supporting powerplants on 100% energy from PV and wind (Gerhard Mütter) - overcapacity (with reference to the nominal grid capacity)) of wind and PV at one grid connection point combined with a battery (4h - 8h) result in very high RE share in the grid with low losseses due to curtailment.
5DV.2	Energy System Integration; Resilience and Security of Supply; Solar Fuels, Storage PV Sustainability	Storage for PV now includes not only Lithium-Ion batteries but also redox-flow batteries. Energy communities with many PV installations are getting better in forecasting PV generation and demand and giving information to members of the communities regarding when to consume or not to electricity to maximize self-consumption.
5DV.3	PV Diversification Upstream and Downstream - from Industry to Applications Costs, Economics, Finance and Markets The Revolution of PV	The session highlighted the importance of supply chain economics, engaging communities, and training programmes for the industry.

SESSIONS | In detail

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