VIPERLAB

FULLY CONNECTED **VI**RTUAL AND **P**HYSICAL P**ER**OVSKITE PHOTOVOLTAICS **LAB**

D4.7 Harmonization/ standardization outcomes to IEC and ISOS

DELIVERABLE REPORT

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FULLY CONNECTED VIRTUAL AND PHISICAL PEROVSKITE PHOTOVOLTAICS LAB VIPERLAB

DELIVERABLE

D4.7 HARMONIZATION/ STANDARDIZATION OUTCOMES TO IEC AND ISOS

Project References

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DISCLAIMER

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EXECUTIVE SUMMARY

This deliverable outlines the key activities and recommendations that emerged from VIPERLAB's efforts to engage with international standardization bodies and research communities such as the International Electrotechnical Commission (IEC) and the International Summit on Organic and Hybrid Photovoltaics Stability (ISOS).

The project's networking activities have been instrumental in addressing critical gaps in measurement accuracy, data consistency, and scalability. Through workshops, roundtables, and collaborations, VIPERLAB identified and addressed challenges in device characterization, aging protocols, and processing methods. Workshops held in Vienna, Karlsruhe, and Brussels brought together stakeholders from academia and industry, resulting in actionable recommendations for standardization. These activities also facilitated the development of harmonized testing protocols that align with established standards while catering to the unique properties of perovskite PV, such as material-specific degradation mechanisms and emerging device architectures like tandem perovskite-silicon PVs.

In parallel, VIPERLAB contributed to the refinement of testing methodologies through its Round Robin testing campaigns, which improved reproducibility across laboratories. Guidelines were developed to enhance the precision of performance measurements, ensuring compliance with standards like IEC 60904-1. These efforts included specific protocols for tandem and single-junction cells, addressing critical parameters such as quantum efficiency and stability under various environmental conditions.

To address broader challenges, VIPERLAB proposed tailored testing standards for emerging applications, including vehicle-integrated photovoltaics (VIPV) and building-integrated photovoltaics (BIPV). Recommendations focused on harmonized efficiency measurement methods, stability testing under operational conditions, and scalable manufacturing processes like roll-to-roll coating. Environmental sustainability was also emphasized, with strategies for managing lead usage and recycling perovskite modules, alongside research into non-toxic alternatives.

VIPERLAB engaged actively with ISOS to disseminate these findings and foster alignment with standardization efforts. Discussions during the ISOS-15 conference highlighted the need for new protocols tailored to perovskite-based technologies, particularly tandem devices, and VIPERLAB contributed insights from its research to inform ongoing IEC projects. Recommendations included nominating experts to participate directly in IEC working groups and supporting future standardization initiatives through continued collaboration.

The conclusions of this report underscore the importance of a comprehensive strategy for harmonization and standardization to ensure the scalability, reliability, and sustainability of perovskite PV technologies. By addressing technical and environmental challenges and aligning efforts with international standards, VIPERLAB has positioned Europe as a leader in renewable energy innovation, paving the way for the widespread adoption of perovskite PV in the clean energy transition.

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1. INTRODUCTION

VIPERLAB is an infrastructure project that aims to create a European environment where various infrastructures from 13 VIPERLAB partners can be accessed by different users from Europe and abroad. VIPERLAB objectives for Transnational and Virtual Access Activities (TA/VA) are to:

- Offer state-of-the-art and cutting-edge key infrastructure that covers the whole innovation/value chain: from material preparation to characterization of perovskite devices and modules
- Support, widen, and facilitate the access for the emerging / starting scientific perovskite PV community as well as for users from industry/SMEs

The task of this deliverable is to disseminate the main harmonization/standardization challenges that need to be solved to accelerate largescale industrialization of perovskite PV technologies to the International Electrotechnical Commission (IEC) and the International Summit on Organic and Hybrid Photovoltaics Stability (ISOS) community.

2. SUMMARY OF (NETWORKING) ACTIVITIES IN WP4-NA1 and WP9

WP4 established a foundation for harmonizing and standardizing test protocols for perovskite photovoltaics (PV). These activities aimed to address challenges in measurement accuracy, data consistency, and technology scalability to facilitate broad industry adoption. Early efforts included the development of guidelines for measurement procedures, standardized data formats, and intellectual property considerations (D4.1).

Three workshops on harmonization/ standardization challenged (D4.2, D4.4, D4.5) were pivotal in gathering insights from industry stakeholders, academic experts, and consortium partners to identify key standardization needs. These events featured discussions on device characterization, aging protocols, and processing methods, culminating in actionable recommendations for harmonized practices. For instance, the second workshop organized in cooperation with WP6 (WS on SRIA) introduced "harmonization road mapping," where working groups focused on device processing, characterization, and specific applications, producing insights on trends, influential topics, and areas requiring immediate standardization efforts. The third strategic workshop, co-organized with the "EERA PV BECOME PV" workshop in Brussels, drew diverse participants from academia and industry, fostering cross-disciplinary discussions on stability, reliability, and circularity in perovskite PV. It featured presentations on key findings from VIPERLAB's Round Robins, highlighting harmonized measurement and aging protocols, as well as insights into validation requirements for specific applications like vehicle-integrated photovoltaics (VIPV). The integration of VIPERLAB into a larger event enabled impactful exchanges between stakeholders, addressing challenges such as scalability, environmental sustainability, and commercial readiness.

In parallel, WP4 delivered **harmonized test protocols (D4.3, D4.6)**, integrating results from the initial Round Robin testing campaigns of **WP9**, which helped to improve reproducibility across

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multiple laboratories and refine testing methodologies. These drafts reviewed existing protocols from established entities such as IEC, NREL, and ESTI, aligning them with emerging perovskite-specific needs. The resulting framework defined baseline requirements for sample preparation, technical parameters for measurement systems, and reporting formats for critical performance metrics like efficiency and quantum efficiency (EQE). The protocols were actively shared with stakeholders and standardization bodies, further promoting their adoption within the community.

Finally, the public report **"D9.9 Guidelines for electrical performance measurement of perovskite PV technology – main outcomes and final conclusions"**, elaborated withing **WP9**, presents the results of the Round Robin testing campaigns of WP9 and provide guidelines to improve the accuracy of performance measurements for perovskite PV technologies. These guidelines align with IEC 60904-1 and IEC 60904-1-1 standards for photovoltaic device measurements and include specific recommendations for single-junction and tandem cells, electrical contact reliability, measurement mask positioning, and temperature control.

3. MAIN HARMONIZATION/STANDARDIZATION CHALLENGES AND RELATED RECOMMENDATIONS

3.1 Development of Tailored Testing Standards

Perovskite PVs exhibit distinct properties such as ionic conductivity and environmental sensitivity, which existing silicon-based standards, like IEC 61215, fail to adequately address. To ensure reliable evaluation, testing protocols should account for:

- Material-specific degradation: Mechanisms such as ion migration, delamination, and photochemical instability require unique stress tests under controlled humidity, temperature, and UV light exposure.
- New device architectures: Tandem perovskite-silicon PVs and other emerging designs necessitate revised testing frameworks to accurately measure performance and stability.
- Specialized or new applications: Perovskite-based PV technologies exhibit high potential for specific applications like vehicle-integrated photovoltaics (VIPV), consumer applications or product-integrated PV (PIPV) or building-integrated PV (BIPV) that may need adapted or even specific validation requirements.

3.2 Harmonization of Measurement Protocols

A critical bottleneck in perovskite PV research and commercialization is the lack of consistent measurement and reporting protocols. Divergent practices lead to variability in reported data, hampering comparability across studies and creating market uncertainty. VIPERLAB's recommends to:

- Establish uniform efficiency measurement methods tailored to tandem cells, such as spectral matching and multi-lamp sun simulation for accurate current-voltage (I-V) assessments.
- Use streamlined formats for reporting key metrics like open-circuit voltage (Voc), short-circuit current (Isc), and power conversion efficiency (PCE), beyond the raw I-V curves traditionally used.

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3.3 Stability and Durability Testing

Perovskite PV cells and modules face unique stability challenges, including degradation from environmental exposure to moisture, oxygen, and temperature cycling. To enhance product durability and market confidence, VIPERLAB recommends:

- Developing aging protocols that simulate long-term operational conditions in diverse climates.
- Investigating novel encapsulation materials and techniques to protect perovskites without compromising performance.

3.4. Scaling Manufacturing Processes

The scalability of perovskite PVs remains a major challenge as current laboratory processes must transition to industrial-scale manufacturing. Issues include:

- Reproducibility: Ensuring uniform material quality and consistent device performance across large device geometries (modules) and/ or production batches.
- Manufacturing methods: Adapting scalable techniques like roll-to-roll coating and inkjet printing to perovskite fabrication while maintaining high efficiency.
- Environmental sustainability: Mitigating concerns about lead usage through recycling frameworks and exploring non-toxic alternatives.
- Collaboration: between research, industry stakeholders and standardization bodies to integrate scalable solutions into the standardization landscape.

3.5 Toxicity and Environmental Impact

The presence of lead in many perovskite formulations raises environmental and health concerns, which may need to be addressed to align with global sustainability goals. Depending on lead leaking concerns or (adapted) regulations, VIPERLAB advocates for:

- Development of recycling and waste management protocols for perovskite modules.
- Research into lead-free perovskite materials and their performance optimization.

4. COMMUNICATION TOWARDS ISOS AND IEC

4.1 ISOS

Several steps have been taken and/ or initiated. On one hand, the **ISOS-15 conference** was organized by VIPERLAB coordinator HZB from 30th of September until 2nd of October 2024 in Berlin. VIPERLAB Roundtables were moderated by experts in the field covering 5 different topics, as shown in figure 1. All these topics more or less depend on or impact harmonization and standardization. For example, the discussions on the ISOS protocols per se identified similarities as in the VIPERLAB project, such as the need for module-related protocols, EQE-measurements for tandem devices, improved (IEC-based) reporting standards, special testing conditions for perovskites, i.e. light-/illumination-based, MPP-tracking, or reasonable scan rates, need of increased outdoor testing, etc. Moreover, most discussions showed that tandem devices need new tests since they are a different technology than Si, especially perovskite-based tandems that are not covered

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by ISOS tests. VIPERLAB also addressed these measurement challenges, amongst others, with a workshop and a follow-up webinar on precise measurement on perovskite silicon tandem solar cells.

VIPERLAB recommends continuing this work in the upcoming ISOS-16… conference(s) and a possible VIPERLAB follow-up project.

Figure 1. VIPERLAB Roundtables at ISOS-15 conference in Berlin.

4.2 IEC

Regarding the communication towards IEC, two relevant Technical committees (TC) have been identified: TC 113 (Nanotechnology for electrotechnical products and systems) and TC 82 (Solar photovoltaic energy systems), wherein TC 82 seems most appropriate and its working group 2 (WG2, project lead: Mr Masahide KAWARAYA) is currently working on the standard IEC TS 60904-1-4 ED1 (Photovoltaic devices- Part 1-4: Guidelines for current-voltage measurements of metastable photovoltaic devices), that should be published end of 2025.

Hence, VIPERLAB recommends supporting IEC TC82 with the above summarized results and findings from the project, if possible, by direct nomination of an expert for the IEC standardization project within a possible VIPERLAB follow-up project, which could provide the budget for such an expert as a part of its activities. It will be evaluated to nominate an expert (possibly Stephan Abermann himself) for the discussed TC 82 IEC standardization project, working at the moment on the committee draft CD, by the respective national mirror committee (i.e. Austrian OVE in case of Stephan Abermann). Also information about VIPERLAB should be sent to the IEC project leader Mr. Masashide Kawaraya (final public report), and direct contact should be established. This guarantees a smooth future interaction when a funding would allow for more intensive collaboration.

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5. CONCLUSIONS

The VIPERLAB D4.7 report provides a comprehensive analysis of the harmonization and standardization challenges critical to advancing the industrial adoption of perovskite photovoltaic (PV) technology. Accordingly, this report suggests a communication strategy based on dedicated next steps to forward this information to the International Electrotechnical Commission (IEC) and the International Summit on Organic and Hybrid Photovoltaics Stability (ISOS) community. This approach ensures that perovskite PV technology development is supported by a robust framework that promotes consistency, reliability, and sustainability at every stage of its lifecycle.

Through the identification of tailored testing standards, harmonized measurement protocols, and strategies for stability, scalability, and sustainability, the report highlights actionable solutions to the unique challenges posed by perovskite PV. Key recommendations address gaps in existing standards, propose scalable manufacturing processes, and outline environmental safeguards such as recycling strategies and the development of lead-free alternatives.

By addressing these challenges, VIPERLAB not only advances the technical and industrial maturity of perovskite PV but also positions Europe as a global leader in renewable energy innovation. The recommendations within this report, when implemented in the SRIA, will serve as a roadmap for fostering industrial-scale adoption and ensuring that perovskite PV contributes significantly to Europe’s clean energy transition.

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