# Publishable Summary for 19ENG01 Metro-PV

**Metrology for emerging PV applications**

**Overview**

The aim of this project is to provide the necessary metrological infrastructure, techniques and guidance to accelerate time-to-market for emerging photovoltaic (PV) technologies, which have the potential to significantly reduce the cost of photovoltaic energy, the most important future energy source.

The next generation of solar devices with higher conversion efficiencies, compared to conventional single junction silicon solar cells, will be based on emerging PV technologies (e.g. perovskite-on-silicon tandem). In the field of Industry 4.0 applications the use of indoor-PV is gaining momentum. However, there is still a lack of measurement capabilities that realise performance measurements with low uncertainties for emerging PV applications. This project will reduce the reference solar cell calibration uncertainty that successively affects all subsequent calibrations and performance measurements in the traceability chain. In addition, international standards will be developed, including measurement procedures for emerging PV technologies. The uncertainty of the PV calibration chain will be reduced and thereby, in a wider perspective, the financial uncertainty of investments.

**Need**

According to current forecasts, the largest share of the entire future energy supply including electricity, heat, mobility and industrial processes will be based on solar power. The enormous investments required for this transition need to be metrologically underpinned by a corresponding expansion of the quality infrastructure (addressed by objective 1).

Perovskite-based cells have emerged as one efficient and low-cost option, which European organisations are seeking to rapidly scale-up and commercialise in applications such as PV integrated into buildings and vehicles and indoor energy-harvesting (addressed by objectives 1 and 4).

This project will improve the European metrology for emerging PV technologies such as perovskite-on-silicon tandem devices and indoor-PV devices to support this huge challenge (addressed by objectives 1 and 4).

The photovoltaic world market is worth about 100 billion Euros per year. New systems attract investment based on the estimated energy yield, which depends critically on the power rating under different conditions. Thus, every percent of measurement uncertainty leads to a financial uncertainty of 1 billion Euros. Studies predict a further increase in the market share of emerging PV that is required to preserve the high growth rates of PV. Therefore, lower measurement uncertainties as well as realistic standards are needed to reduce the financial uncertainty (addressed by objectives 1, 2 and 3).

**Objectives**

The project focuses on the traceable measurement and characterisation of emerging PV applications.

The specific objectives are:

1. To validate the suitability and reduce the uncertainty, associated with measuring the nominal power of PV devices, within the calibration chain according to the IEC 60904 standard series. This should include multi-junction PV devices and devices constructed from perovskite materials.
2. To determine the uncertainty sources related to the output power of PV modules. This should include development of models to quantify the uncertainty sources that are associated with measurement of the I-V curve in accordance with IEC 60904-1 and spectral irradiance and spectral response of PV devices in accordance with IEC 60904-8.
3. To define a quality metric for the behaviour of PV modules in shady locations such as urban areas in order to quantify the benefits of shade-tolerant module designs.
4. To prepare a classification of PV-based energy-harvesting devices for the Internet of Things (IoT) applications, by developing and validating traceable methods for evaluating their performance in low light (indoor) conditions and their sensitivity to influencing factors e.g. the pulse-width modulation of modern efficient light sources.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (accredited laboratories, instrumentation manufacturers), standards developing organisations (IEC, especially IEC TC82 and IEC TC113) and end users (e.g. photovoltaics industry). In addition, to contribute to revision of the IEC 60904 standard series.

**Progress beyond the state of the art and results**

This project will improve the accuracy of the measurements needed for the calibration of reference solar cells, by using the limitations of existing standards as a starting point in order to further reduce the lowest uncertainty in the world. Also, procedures for the evaluation of uncertainties will be established, i.e. brought to standardisation bodies. Furthermore, a metric will be developed to rate the shading sensitivity of PV modules. To improve the use of indoor-PV for the energy supply of IoT devices, the results of this project will contribute to international standardisation. As standardisation has thus far focused on outdoor applications, the development of new calibration facilities for indoor-PV with irradiance levels 100 to 1000 times lower than under standard outdoor conditions goes beyond the state of the art.

*Validation of suitable reference devices and measurement procedures*

The most accurate primary calibrations of WPVS type reference solar cells are performed by PTB. The “world record” lowest uncertainty is 0.4 %, using PTB’s Laser-DSR facility. As these calibrated solar cells act as references and thus as the starting point of the traceability chain for the performance rating of the solar cells and solar modules manufactured by industry, a reduction of this important quantity is crucial.

This project aims to reduce the expanded uncertainty to a value down to 0.35 %, or even below, to successively affect all following calibrations and performance measurements in the traceability chain. In addition, there is a rising demand for calibrations of emerging PV devices (e.g. for perovskite solar cells). Due to their properties (e.g. response time) it is challenging to measure and calibrate these devices with low uncertainties. The uncertainties will be reduced from 3 % to 2 %. The activities within this project will also allow a reduction of the lowest available uncertainty of emerging PV devices.

*Evaluation of uncertainty sources related to the output power and energy of PV modules*

The standards concerning measurement issues (the IEC 60904 standard series) describe procedures for the determination of *I-V* curves and of the spectral responsivity of PV devices, but they regularly lack documentation for determination of the uncertainty of the measurements. This determination of the uncertainty is often requested by the users of the standards.

The project will remedy the deficiency of the IEC 60904 standard series by writing technical reports on how to calculate the measurement uncertainties.

*Definition of a quality metric for the sensitivity of PV modules power output in shady locations*

State of the art energy rating procedures are currently not applicable to the emerging technologies (e.g. perovskite-on-silicon tandem). The existing methods and calculations do not consider the non-uniformity of irradiance in shady urban areas.

In this project a metric will be developed to rate the shading sensitivity of PV modules. This metric will improve the accuracy of energy yield determination.

*Characterisation and classification of PV-based energy-harvesting devices for Internet of Things (IoT) applications*

In the area of indoor-PV, standardisation has just started recently. Indoor PV is used for autarkic energy supply of energy harvesting Internet of Things applications, e.g. for communication and sensor issues. No standards are currently available, although they are important for Industry 4.0 applications.

The research activities within this project will contribute significantly to the ongoing standardisation processes by providing input to the standardisation.

**Impact**

*Impact on industrial and other user communities*

This project directly supports the PV community, i.e. PV manufacturers and suppliers, with new and improved measurement capabilities for emerging PV technologies and applications. In addition to the PV industry, the defined measurement procedures for indoor-PV could be utilised by all industries that are using self-sustaining Internet of Things devices with a PV power supply. Industry 4.0 concepts using wireless sensor technologies from the Internet of Things ecosystem will benefit from the project due to the more accurate determination of the device efficiency in a realistic indoor lighting environment.

Hence, this project will support the penetration of these emerging PV products (perovskite-on-silicon tandem solar cells/modules and indoor-PV) into the PV market. This will enable cost reductions in PV applications.

*Impact on the metrology and scientific communities*

The development of reference PV devices for emerging PV technologies and procedures for their calibration, sets an important basis for the metrology and scientific PV community. The improved facilities and procedures elaborated within this project will allow NMIs, calibration laboratories, and research institutes to gain competence in the field of emerging PV and it will enable traceable measurements to be conducted with the lowest possible uncertainties (2 % instead of 3 %).

*Impact on relevant standards*

The project will enable the extension of existing standards (e.g. IEC 61853) to a more precise estimation of the energy output of a PV installation, thereby reducing the financial risk to investors and leading to higher investment in this type of renewable energy. Technical reports on the measurement uncertainties of the most important measurement standards (IEC 60904-1 and the IEC 60904-8) will be produced. These will complement the existing standards by providing a detailed uncertainty assessment, whilst removing their current significant limitation. In addition, this project will contribute to developments of new standards for indoor-PV.

*Longer-term economic, social and environmental impacts*

The photovoltaic world market is worth about 100 billion Euros per year. New systems attract investment based on the estimated energy yield, which depends critically on the power rating under different conditions. Thus, every percent of measurement uncertainty leads to a financial uncertainty of 1 billion Euros. Studies predict a further increase in the market share of emerging PV and this is required to preserve the high growth rates of PV.

The harmonised measurement methods for new technologies together with reduced measurement uncertainties will contribute to a clear reduction of the investment risk. It will empower consumers by enhancing a metric for PV efficiency based on energy output under European climate conditions by adding uncertainty evaluations to it and considering shading effects. This will allow a risk assessment of these predictions that is currently less precise, and thus it will enable system planners and financial institutions to optimise their services. Some decisions on how to invest public (government) and private (industry/consumers) money in PV are being made based on power and efficiency numbers that do not correlate with the energy output under operational conditions and give limited indication of the risks involved. These risks are related to the financial pay back expectation, and for systems consisting of tandem modules, the physical properties may lead to operation under conditions which result in significantly lower outputs than expected. Better understanding and harmonised characterisation of the effects on the energy generation of emerging PV technologies will significantly mitigate the investment risks for end users.

Based on the project’s outputs, industry will be able to optimise their emerging products for more realistic operating conditions. This will increase the competitiveness of PV industries where Europe holds a leading position.

Foreseeable impacts of the project are:

* Fair and impartial assessment of emerging technologies. This reduces deployment risk and accelerates time to market. For SMEs especially, it is important to show their achievements in a timely manner. Delays affect the R&D development and potential market impact of EU technology.
* Local certification of PV efficiency. This avoids IP-leakage that has been reported especially in the certification of some thin-film devices.
* The development of a high-quality traceable measurement technique will protect European enterprises and end-users against cheap, but low-grade photovoltaic products.
* Support for sustainable and renewable European energy generation.
* The typically decentralised energy generation pattern of photovoltaic systems supports local employment policy and thus improves the socioeconomics in Europe.
* The dissemination of good metrology practice and novel PV measurement methodologies to European industry will enhance productivity by the improvement of quality control and hence reduced wastage.
* Appropriate PV metrology, based on the characteristics, will enable photovoltaic systems to thrive in an even more competitive power market, potentially enabling PV systems to bid subsidy-free into the free power market.

This project will meet the essential requirements for reducing the investment risk associated with initiating new large-scale PV installations, for removing barriers to entering the marketplace and thus it will accelerate the overall cost reduction of photovoltaics by delivering key enabling metrological research.

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| Project start date and duration: | | 01 September 2020, 36 months | |
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