Uncertainty in energy yield estimation based on C-Si module roundrobin results.

UNCERTAINTY IN ENERGY YIELD ESTIMATION BASED ON C-SI MODULE ROUND-ROBIN RESULTS

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ABSTRACT

Results of the European FP7 Sophia project round-robin of c-Si module power measurements at STC and low irradiance and temperature coefficients were used to calculate annual energy yield at four sites. The deviation in the estimates solely due to the different measurement results is reported, neglecting the uncertainty in the meteorological data and losses unrelated to the performed measurements. While minimising the deviation in Pmax measurements remains the key challenge, the low irradiance and temperature coefficient contributions are shown to be significant. Propagating the measurement deviation in c-Si module measurements would suggest that expanded uncertainty in energy yield due to module characterization alone can be as high as ±3-4%.

1. INTRODUCTION

As part of the continuous effort to improve PV measurement practices in Europe, eleven laboratories took part in a c-Si module round-robin under the EU FP7 Sophia project. Alongside STC measurements, six partners measured at Low Irradiance Condition (LIC), i.e. 200Wm^{-2}, and seven measured the Temperature Coefficients (TC). The round-robin's purpose was to assess the uncertainty analyses of partners and to serve as the baseline for a subsequent thin film round-robin. There was a wide range of partners, both accredited and non-accredited laboratories, with different traceability chains, measurement facilities and procedures. Three module types were selected, representing a standard technology and high efficiency mono c-Si modules:

- Mono-crystalline silicon (Mono)
- Back contact mono-crystalline (BC)
- Mono-crystalline silicon/a-Si Heterojunction (HIT)

Pmax measurement deviation from the mean for the seven partners that measured TCs was within -2% and 3%. The Pmax TC deviation was within ±13%. The low irradiance measurements of a different subset of six partners were within ±4.5%. Detailed results are presented in [1]. In this paper, the impact of real measurement deviation on Energy Yield (EY) estimates is investigated for four arbitrarily selected sites:

- Kyoto, Japan
- Milan, Italy
- Penzance, United Kingdom
- El Paso, Texas, USA.

2. ENERGY YIELD ESTIMATION AND RESULTS

The annual EY was calculated based on hourly total in-plane irradiance and ambient temperature data for the four sites listed above for each of the three module technologies. For simplicity, losses due to spectral effects, reflection, shading, snow and soiling, degradation and the inverter were not included in the EY calculation. The irradiance and temperature data were obtained with the Meteonorm 7 software package. The module temperature was calculated empirically based on irradiance, back-of-module temperature and ambient temperature outdoor measurements at CREST, Loughborough, UK. A limitation of this approach is the difference in wind profile at the selected sites and the dataset used. Since Loughborough is a windy location, the estimates of the impact temperature coefficient measurements on the EY are conservative, especially for a location such as El Paso, Texas.

The EY estimates, normalized to the mean based on each of the seven partners' measurements, are illustrated in Fig. 1. The mean between partners is different for each set of site and module. Hence only data within the same set can be directly compared in the figure.

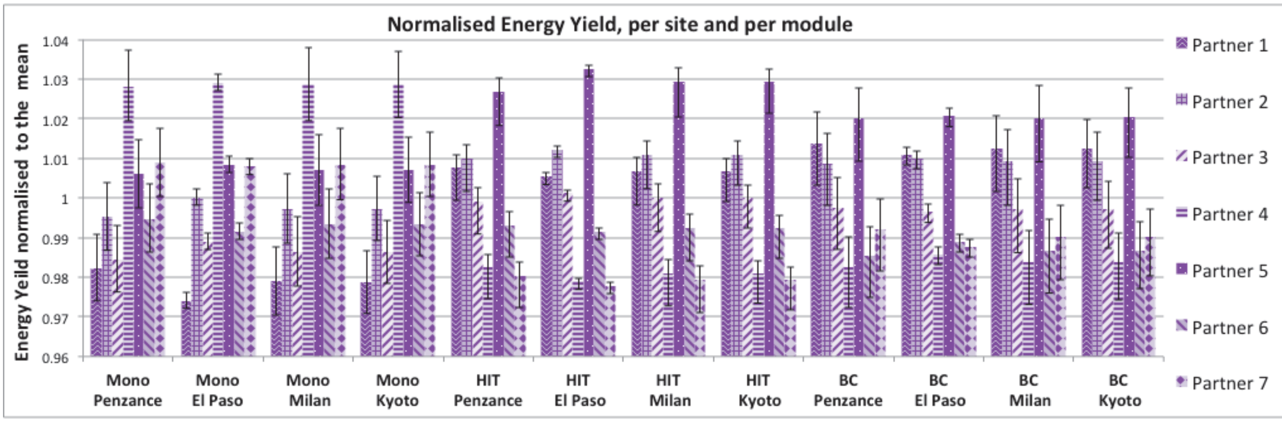

Fig 1. Energy Yield deviation normalized to the mean for each site and module. The error bars represent the best and worst case scenario in energy yield based on the LIC measurement deviations between the partners.

Due to the different subset of partners measuring TC and at LIC, the average of LIC measurements and typical irradiance vs. efficiency data for the three module types were used. The LIC measurement deviation between partners was used to calculate best and worst case scenarios. These are depicted as error bars in Fig. 1. The effect of the LIC deviation was within ±0.25% for El Paso, significantly lower compared to within ±1% for the other locations.

In Fig. 2 the deviations from the mean for Pmax measurements, EY estimates based on average LIC measurements and Pmax TC (δ) measurements for each module type are presented. The key contribution to the deviation in EY estimates was the deviation in Pmax, since EY estimates mostly follows the Pmax deviation. The effect of the temperature coefficients deviation was negligible in a place like Penzance ±0.1%, relatively small and almost identical for Kyoto and Milan ±0.4% and significant for El Paso, Texas ±0.9%.

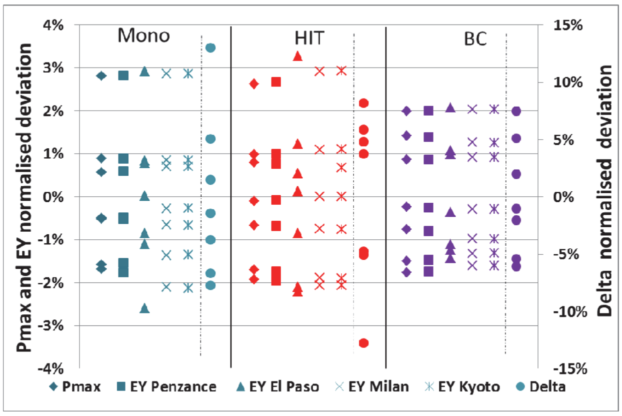

Fig 2. Pmax, EY and Delta deviation for each module.

Overall, the EY estimates for the Mono module were within -3% and +4%, for the HIT module within -3% and +3.3% and for the BC module within -2.8% and +3%. These results must be considered in the context of the limited number of samples, i.e. participating partners and modules measured.

3. CONCLUSION

In order to harmonise measurement practices in Europe, validate uncertainties and minimise measurement deviation a c-Si round-robin was carried out by eleven partners varying in their accreditation status, setup, traceability and procedures. A subset of the results were applied to an energy yield model indicating that while the majority of the effort should be focused on minimising the deviation in Pmax measurements at STC, the combined effect of TC and LIC measurement deviation can contribute approximately an additional ±1% deviation in EY estimates for the selected sites. Sites with a larger contribution due to the LIC have negligible TC contribution and vice versa. While some c-Si technologies can be more suitable for certain sites, because of their LIC or TC performance, the uncertainty in the energy yield can be estimated to be mostly the same (given the limited number of measurements) and within ±3-4% solely based on the module rating uncertainty.

4. ACKNOWLEDGEMENTS

B. Mihaylov would like to acknowledge his funding through the RCUK Supergen project ‘Supersolar’ (contract no: EP/J017361/1). This work has been funded by the European FP7 SOPHIA project, grant number: 262533.

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