Techno-economic performance modelling of bifacial and tracking PV systems worldwide

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***Abstract*— Todays commercial and utility photovoltaic (PV) installations predominantly use monofacial PV-modules in a mounting structure with a fixed-tilt. In recent years, front and rear efficiencies of bifacial PV modules have improved and their cost has dropped, as has the cost for single-axis and dual-axis trackers. These advances make those two technologies interesting options to improve the yield of PV installations. In this work, we present a comparison of the calculated techno-economic performance of conventional installations and different combinations of bifacial and tracking configurations. We find that installations with bifacial modules and one-axis trackers provide the greatest techno-economic benefit over monofacial fixed-tilt installation by increasing yield by, on average 35%, and reducing LCOE on the vast majority of locations in the world by more than 10%. Dual axis trackers achieve even higher yields, yet the high cost for these trackers results in an overall higher LCOE. Sensitivity analyses reveal that our conclusions are robust in general, but the best configuration in a given location still requires analyzing local conditions in detail.**

Keywords*— bifacial modules; bifacial tracking; dual axis trackers; energy yield; levelized cost of electricity; monofacial modules; photovoltaic systems; single axis trackers

I. INTRODUCTION

Solar cell efficiency has traditionally been the biggest research driver for improvements in cost and performance of PV systems. Yet, two developments on the system level that increase yield without increasing standard testing condition efficiency could have the biggest impact on what commercial PV installations will look like and how they perform since the introduction of PERC cells. Most current PV installations today employ a fixed-tilt configuration and use monofacial crystalline silicon PV modules [1, 2]. Replacing fixed-tilt configurations by single-axis- and dual-axis tracking systems increase yield by adjusting module orientation to follow the sun's position. Replacing monofacial by bifacial modules unlocks collection of light from the rear. Both technologies can be combined into a bifacial-tracking system to improve yield even further. Neither of these ideas is new, but what has changed in recent year is the cost associated with their realization. Previously, bifaciality and particularly tracking came with considerably higher up-front investment costs. These cost increases would discourage investors and result in sparse deployment under very favorable conditions. Yet in the last years, tracking as well as bifacial modules have experienced a progressive cost-decrease [3-7]. By now, the benefits due to increased energy production outweigh the higher system cost.

In this study, we analyze how local climate climatic and economic factors influence the economic advantages of different combination of bifacial-tracking systems and we establish which combinations are favorable under which conditions.

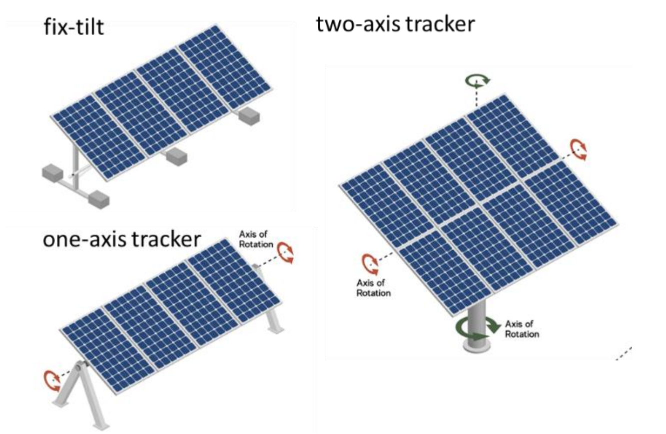

Figure 1. Different system configurations explored in this study. Figure repreinted from [8].

II. YIELD MODEL VALIDATION

Our yield calculation model is described in detail in [8]. We validated the model by simulating front and rear irradiance values and compared them to measured values from a setup operated by SANDIA National Laboratories and located in Albuquerque, USA at an altitude of 1657 m. Measurements were performed in blocks of five to eight weeks between September 2017 and March 2020. Measured parameters include GHI, DNI, DHI and module orientation over time, Sun position was estimated using the SPA algorithm [9]. From this data, irradiance at the front and the rear side of PV modules in different configurations were calculated. The results were then compared to the measured irradiance falling on either module plane. Results are shown in figure 2 exemplarily for one single-axis tracking configuration with horizontal tilt (HSAT). Relative errors (NRMSE) are larger for the rear side as a constant absolute uncertainty faces lower overall irradiance values and smallest for the combined measurement for the same reason. We also give the overall relative difference between measured and simulated overall insolation I_d, which is a proxy for the uncertainty in yield.

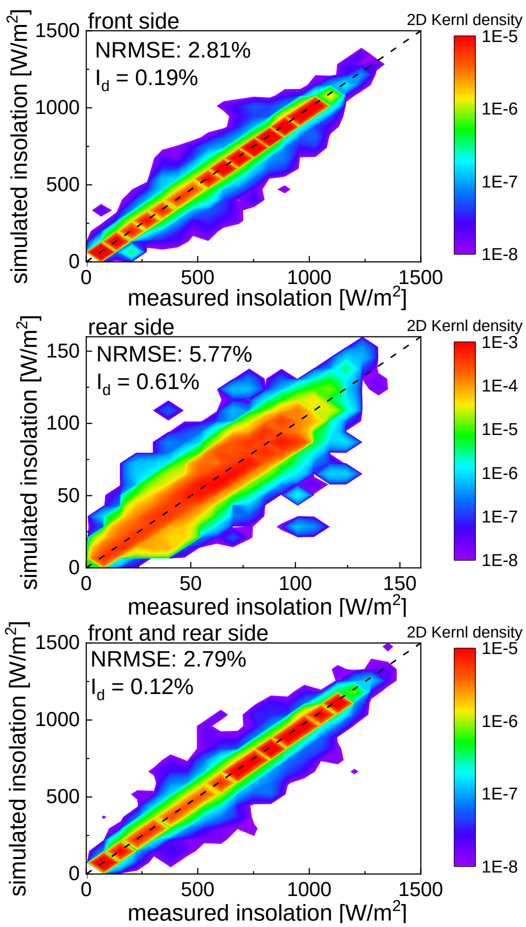

Figure 2.Comparison of simulated and measured irradiance at front, rear and for both planes simultaneously of a horizontal single axis tracking installation. Plotted are the 2D kernl densities of the comparisons.

III. TECHNO-ECONOMIC PERFORMANCE OF BIFACIAL TRACKING SYSTEMS

Following methods introduced in [8, 10], and using satellite measured meteorological parameters for the year 2015, global energy yield was calculated for different combinations of monofacial- and bifacial modules and fixed-tilt or tracking installations. Figure 3a shows the yield difference of the bifacial single-axis tracking system, and the monofacial fixed-tilt reference. The greatest yield advantage of the bifacial tracking system is found in high latitude regions. Here, the yield advantage can exceed 50%. The smallest advantage is found around the equator, where it still exceeds 25%. On average, the yield advantage amounts to 35%.

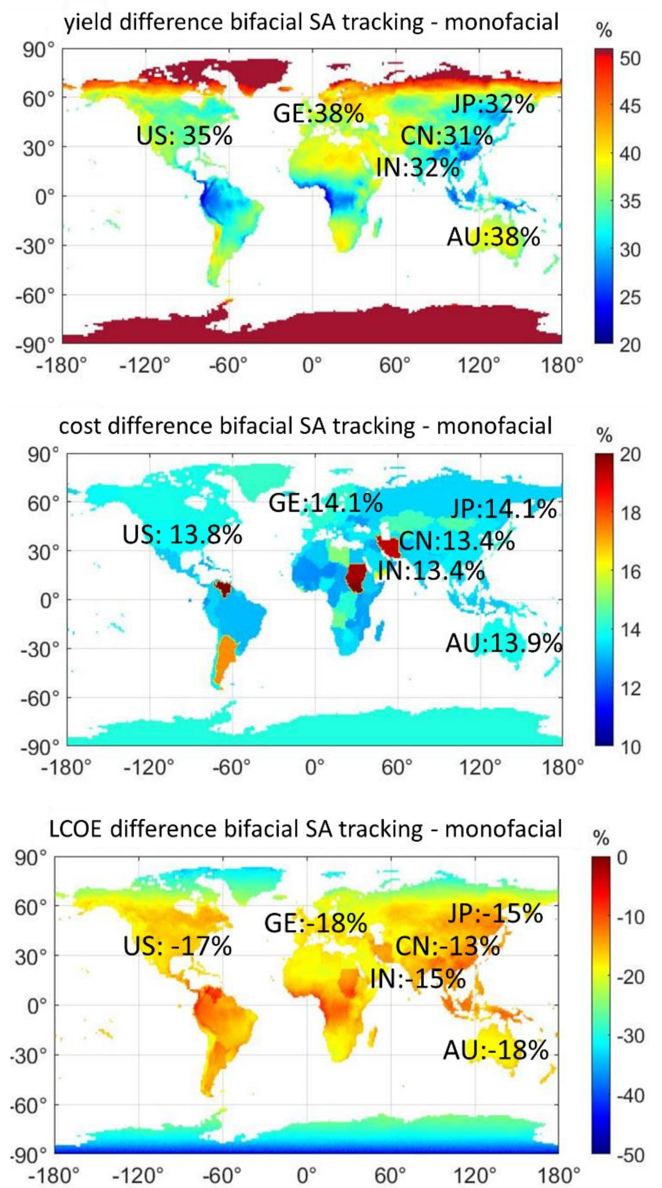

Figure 3. Comparison of techno-economic parameters (yield, overall system cost, LCOE) between a single-axis (SA) fixed tilt installation and a one-axis tracking installation with bifacial PV modules. Exemplary values are given for, west to east, the US, Germany (GE), India (IN), China (CN), Japan (JP) and Austraila (AU).

Overall system costs include all costs occurring over the lifetime of the system, and the calculation considers local differences in such factors as local cost of labor, bank interest rates and inflation. Regions with unstable values such as Venezuela of the Sudan show comparably high costs for this reason. Figure 3b shows the overall cost differences between the bifacial single-axis tracking system, and the monofacial fixed-tilt reference. Due to the higher cost of tracking installations (costs for bifacial and monofacial modules are very similar), bifacial tracking systems are more expensive everywhere, but the cost difference is generally below 20%. The comparison between yield and cost already indicates the overall economic superiority of bifacial tracking systems compared to monofacial fixed-tilt.

The economic metric that compounds yield and overall system costs is the levelized cost of electricity (LCOE). LCOE defines at which cost the installation is capable of delivering electricity. Differences in LCOE between the bifacial single-axis tracking system and the monofacial fixed-tilt reference are shown in Figure 3c. Bifacial tracking systems, according to our analysis, have a superior performance compared to monofacial fixed tilt systems anywhere on the planet. On average, LCOE is 11.3% lower for bifacial single axis tracking systems than for monofacial fixed-tilt systems. Even compared to other options, this configuration is the best performing one for 93% of all land mass. In areas close to the poles, bifacial two-axis tracking systems are preferable. In countries with high inflation rates, single-axis trackers with monofacial modules are sometimes preferable.

IV. Stability of the Presented Results

All results shown here were obtained using a set of assumptions about costs and performance of monofacial and bifacial PV modules. Details about these assumptions are found in [8]. To explore how sensitive our results are to these assumptions, we performed a stability analysis. Exemplary results of this analysis are shown in Figure 4. We color-coded the system configuration with lowest LCOE as a function of module cost (x-axis) and cost of the mounting structure (y-axis). We used two locations as exemplars, Zhongba in China as a location with comparably low installation costs, and Yuma in the US as one with comparably high costs. These citiess were chosen for their high insolation values. For Yuma, we find that the bifacial one-axis tracker (b-1T) is the preferred solution over a wide range of costs. Only if the costs of the mounting structure would drop by 80% another configuration (b-2T) becomes preferable. We find similar results for Europe, Japan or Australia. In Zhongba, we observe that a ~35% reduction in cost for modules and mounting structure simultaneously would result in the monofacial one-axis tracker system to become preferable.

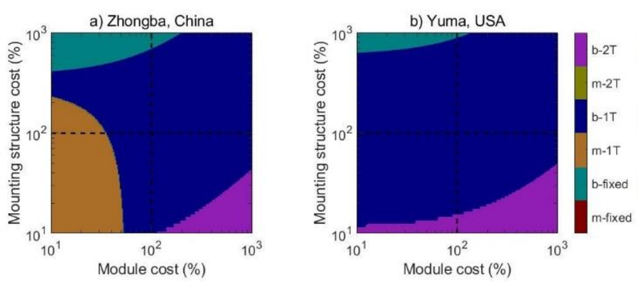

Figure 4.Stability of the results exemplarily calculated for one location in China (Zhongba) and the US (Yuma), exemplarily. The plot shows in color which system configuration is preferable as a function of module cost and mounting structure cost.

V. Conclusions

In this work, we presented an analysis of the techno-economic performance of different PV system configurations with monofacial and bifacial modules, and fixed tilt and tracking mounting structures. Our analysis reveals that bifacial modules with a one axis tracking system is the best performing configuration overall, and provides a techno-economic advantage over fixed tilt monofacial systems anywhere in the world: a yield increase of 35% stands against lifetime costs that are about 20% higher, resulting in a 11.2% lower LCOE, on average. A sensitivity analysis furthermore shows that module cost and mounting structure cost would have to fall substantially for another configuration to become superior. Looking at China and the US as two examples for locations with different installation costs, we find that in China reductions of about 35% in module costs and mounting structure cost would make monofacial systems preferable to bifacial ones, whereas in the US cost reductions in the mounting structure by up to 80% would not make a difference.

Bifacial tracking systems are coming. We already observe a change in the layout of PV installations in the US, Europe and Asia. Fixed tilt installations give way to one axis tracking systems, and we expect an increasing fraction of ~~the~~ them to be mounted with bifacial modules.

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