Modeling Agrivoltaic Land Productivity for Mobile vs. Fixed Tilt Bifacial Photovoltaic Panels

Hassan Imran[1], Muhammad Hussnain Riaz[1] and Nauman Zafar Butt[1]

[1] School of Science and Engineering, Lahore University of Management Sciences, Lahore 54792, Punjab, Pakistan.
Tel: +923457090801, hassan.imran.ee@gmail.com, hussnainriaz8@gmail.com, nauman.butt@lums.edu.pk

1. Abstract: The productivity of agrivoltaic systems (AV) has a critical dependence on the spatial and temporal sharing of sunlight between the solar panels and crops. Here we explore how the bifacial PV (bi-PV) technology can be optimized for various crops in fixed tilt and single-axis tracking AV systems. For the case of shade sensitive crops such as corn, we show that the fraction of the transmitted photosynthetically active radiation useful for the crop (PAR_u) is higher for East/West (*E/W*) faced bi-PV in fixed vertical and customized tracking (*CT*) schemes relative to that for North/South (*N/S*) faced fixed tilt scheme at identical PV array density. For shade tolerant crops such as lettuce, PAR_u for *E/W* vertical tilt scheme gets relatively lower. The energy yield for *N/S* fixed tilt bi-PV can be 20−30% higher relative to *E/W* vertical tilt and *E/W CT* schemes. The proposed framework can predict the best PV design based on the desired food-energy needs from the system.

2. Calculation of energy and crop yield: Fig. 1 shows the schematic diagram of *N/S* and *E/W* faced bi-PV AV farms. The *E/W* facing panels are either fixed or mobile around single-axis. Three different tracking schemes are implemented, termed as standard solar tracking (*ST*), reverse tracking (*RT*) and customized tracking (*CT*). In *RT*, panel face is kept parallel to direct beam throughout the day, whereas in *CT*, *ST* is implemented for n=4 hours with $n/2$ number of hours on either side of midday, while *RT* is implemented for rest of the day. For PV energy (I_{PV}) and transmitted irradiance to the ground, we use the detailed approach as reported in [1]. The integrated PAR_u harvested by the crop up to its light saturation point [2] is normalized to that for the open field [see Fig. 2] to get effective *PAR* yield $\left(Y_{\mathrm{Crop}}\right)$ for the crop. Similarly, PV energy yield factor (Y_{PV}) is computed by normalizing the PV energy produced by various PV schemes to that for standard *N/S* fixed tilt PV

$$Y_{\mathrm{PV}}=\frac{I_{\mathrm{PV}}\ (\mathrm{AV})}{I_{\mathrm{PV}}\ (\text{standard } N/S \text{ fixed tilt PV})} \qquad ; \qquad Y_{\mathrm{Crop}}=\frac{PAR_u\ (\mathrm{AV})}{PAR_u\ (\text{Open Field})}$$

3. Fixed-tilt vs. single-axis tracking: I_{PV} and Y_{PV} along with Y_{Crop} for different *N/S* and *E/W* panel densities are shown in Fig. 3 and Fig. 4 respectively. Y_{Crop} tends to saturate for $p/h \geq 3$ for lettuce, whereas for turnip and corn, it continues to increase with decreasing panel density albeit at the cost of Y_{PV}. To compare the relative performance of different single-axis *E/W* tracking schemes, Y_{PV} and Y_{Crop} are plotted in Fig. 5 and Fig. 6 respectively at $p/h = 2$. For lettuce, both *RT* and *CT* exhibit the same Y_{Crop}, which implies that *RT* would be over-irradiating lettuce at the cost of Y_{PV}. On the other hand, *ST* produces maximum Y_{PV} but at the cost of reduced Y_{Crop}.

4. Light productivity factor: We define light productivity factor ($LPF = Y_{\mathrm{PV}} + Y_{\mathrm{Crop}}$) plotted in Fig. 7 for different panel orientation at $p/h = 2$. Both *N/S* fixed tilt and *E/W ST* configurations exhibit highest *LPF* for all crops, whereas *E/W RT* configuration exhibits highest Y_{Crop} but at the cost of Y_{PV}. The Fig. 7 shows that optimal fixed/mobile panel orientation needs to be chosen depending upon the crop grown in AV farm.

5. Conclusion: In this paper, we have explored the potential of bifacial PV technology in fixed tilt *N/S* and *E/W* orientations and for different single-axis tracking schemes. We found that more than 80% of required PAR_u for different crops (*i.e.* Lettuce, Turnip and Corn) can be achieved by optimizing array design with energy yield between 50−100% depending on the crop's *PAR* needs. We conclude that light productivity can be significantly enhanced through crop-specific customized single-axis solar tracking schemes.

References: [1] R. Younas, *et al.*, arXiv preprint arXiv:1910.01076, 2019. [2] S. Tazawa, Japan Agricultural Research Quarterly, 33 (1999), 163-176. [3] G. B.-Gafford *et al.*, Nature Sustainability, 2, (2019), 848-55. [4] H. Marrou *et al.*, Agricultural and Forest Meteorology, 177 (2013), 117-32. [5] B. Valle *et al.*, Applied energy, 206, (2017), 1495-507.

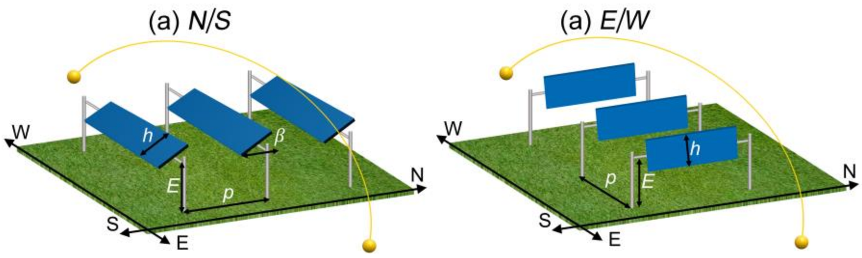

Fig. 1 Schematic diagram of modeled AV system for *N/S* and *E/W* faced PV farm.

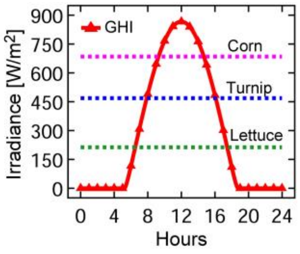

Fig. 2 Solar irradiance and PAR required by crops at their light saturation point.

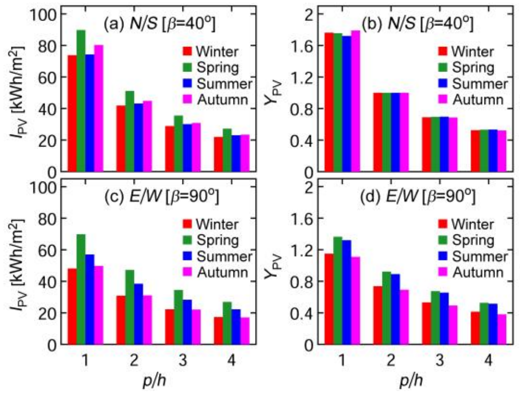

Fig. 3 Seasonal I_{PV} and Y_{PV} for *N/S* and *E/W* faced fixed tilt PV farms as a function of panel density.

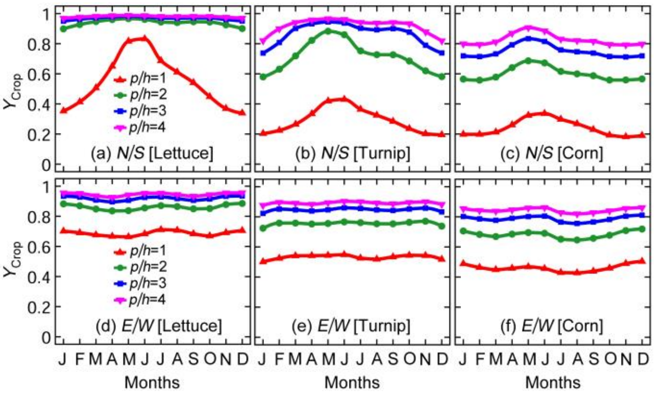

Fig. 4 Monthly Y_{Crop} for different crops for *N/S* and *E/W* faced fixed tilt PV farms at different panel densities.

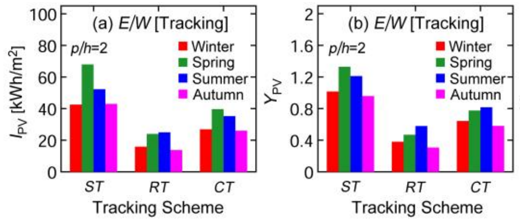

Fig. 5 Seasonal I_{PV} and Y_{PV} for different *E/W* signle-axis tracking schemes at $p/h = 2$.

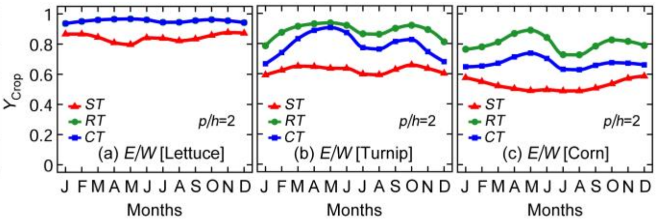

Fig. 6 Monthly Y_{Crop} for different crops for different *E/W* signle-axis tracking schemes at $p/h = 2$.

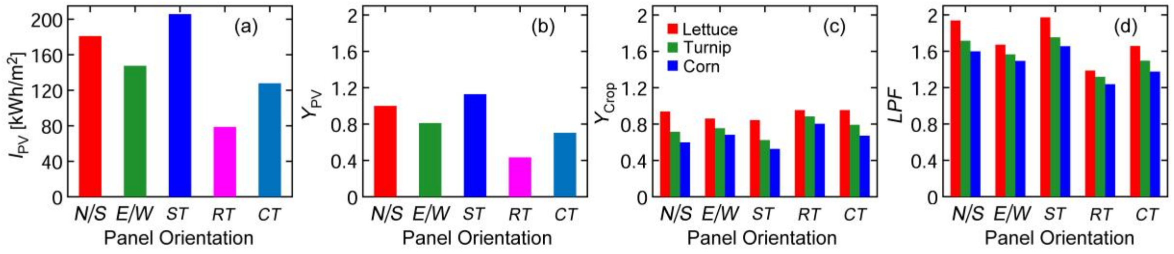

Fig. 7 Annual (a) I_{PV}, (b) Y_{PV}, (c) Y_{Crop} and (d) *LPF* for different panel (fixed and mobile) orientations at $p/h = 2$.