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SUSTAINABLE UTILIZATION OF SURPLUS MONOFACIAL PV MODULES: AN EXPERIMENTAL PERFORMANCE OF AN INTEGRATED BIFACIAL CONFIGURATION

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ABSTRACT
To address the growing issue of photovoltaic (PV) waste and maximize energy generation in space-constrained areas, this study evaluates the experimental performance of a novel integrated bifacial PV configuration. The proposed system aims the sustainable utilization of surplus modules by attaching a secondary monofacial monocrystalline module directly to the rear of an identical front-facing panel. Experimental evaluations were conducted in Istanbul during the winter season. Electrical parameters and operating temperatures for each module were recorded independently, alongside simultaneous measurements of ambient temperature and tilted global solar irradiance. The findings indicate that the integrated bifacial setup significantly outperforms a standalone monofacial module, with the front and rear modules achieving weekly average electrical efficiencies of 15.86% and 10.79%, respectively. Operating temperatures significantly impacted performance; the front panel's efficiency ranged from a maximum of 17.18% (at 12.8°C) to a minimum of 14.88% (at 31.9°C), while the rear panel's efficiency varied between 5.02% and 14.69% based on environmental conditions. Furthermore, the contribution of the rear panel resulted in a weekly average bifacial gain of 7.98%, ranging from a minimum of 4.11% up to a maximum peak of 13.09%. Ultimately, repurposing surplus or older modules in this integrated design offers a highly sustainable

strategy to increase energy yields per unit area while giving otherwise obsolete panels a productive second life.
Keywords: Energy, Solar, bPV, Bifacial Photovoltaic, Sustainability, Renewable Energy

İHTİYAÇ FAZLASI TEK YÜZLÜ FV PANELLERİN SÜRDÜRÜLEBİLİR KULLANIMI: ENTEGRE ÇİFT YÜZLÜ FV DÜZENEĞİN DENEYSEL PERFORMANSI

ÖZET
Artan fotovoltaik (FV) atık sorununu ele almak ve kurulum alanı kısıtlı bölgelerde enerji üretimini en üst düzeye çıkarmak amacıyla, bu çalışmada, özgün bir entegre çift yüzlü (bifacial) FV konfigürasyonunun deneysel performansı değerlendirilmektedir. Önerilen sistem, tek yüzeyli monokristal bir FV panelin birebir aynı özelliklere sahip ön panelin arka kısmına doğrudan entegre edilmesiyle, ihtiyaç fazlası modüllerin sürdürülebilir kullanımını amaçlanmıştır. Deneyler kış mevsiminde İstanbul'da gerçekleştirilmiştir. Her bir modülün elektriksel parametreleri ve çalışma sıcaklıkları bağımsız olarak kaydedilirken, ortam sıcaklığı ve eğimli yüzeye gelen güneş radyasyonu eş zamanlı olarak ölçülmüştür. Deney verilerine göre, entegre çift yüzeyli kurulumun bağımsız bir tek yüzeyli modüle kıyasla önemli ölçüde daha yüksek performans gösterdiğini; ön ve arka modüllerin sırasıyla %15,86 ve %10,79 haftalık ortalama elektriksel verime ulaştığını ortaya koyulmuştur. Çalışma sıcaklıkları performansı belirgin şekilde etkilemiştir; ön panelin verimi günlük en yüksek %17,18 değerinden (12,8°C'de) günlük en düşük %14,88'e (31,9° C'de) düşerken, arka panelin verimi çevresel koşullara bağlı olarak %5,02 ile %14,69 arasında değişiklik göstermiştir. Ayrıca, arka panelin sisteme katkısı haftalık ortalama %7,98'lik kazançla (bifacial gain) sonuçlanmış olup, bu oran en düşük %4,11 ile en yüksek %13,09 arasında değişmiştir. Sonuç olarak, ihtiyaç fazlası veya eski modüllerin bu gibi entegre tasarımlar ile yeniden değerlendirilmesi, aksi takdirde atıl duruma düşecek panellere üretken ikinci bir kullanım ömrü kazandırırken, birim alan başına elde edilen enerji verimini artırmak için oldukça sürdürülebilir bir strateji sunmaktadır.
Anahtar kelimeler: Enerji, Güneş, ÇFV, Çift Yüzlü Fotovoltaik, Sürdürülebilirlik, Yenilenebilir Enerji

1. INTRODUCTION

The continuous growth of the global population and industrial production has led to an unprecedented increase in energy demand, requiring a reliable and uninterrupted electricity supply. Global energy demand reached its highest recorded level in 2023 (Keiner et al., 2023). At present, this demand is predominantly met by non-renewable energy resources, whose extensive use contributes significantly to greenhouse gas emissions and global warming. Consequently, many governments have promoted the adoption of renewable energy technologies, particularly photovoltaic (PV) systems, at both residential and utility scales to reduce environmental impacts and support sustainable energy production. As a result, the global deployment of photovoltaic systems has increased steadily in recent years (Bórawski et al., 2023; Ghosh and Yadav, 2021)

In parallel with this rapid deployment, research efforts have increasingly focused on improving the efficiency of photovoltaic technologies. Numerous studies have investigated new PV cell materials (Vimala et al., 2023), novel operating principles (Hossain et al., 2023) and advanced module configurations. Conventional photovoltaic modules, including monocrystalline, polycrystalline, and thin-film technologies, convert only the solar irradiance incident on their front surface into electrical energy. To overcome this limitation, recent research has increasingly focused on bifacial photovoltaic (bPV) modules, which can harvest solar irradiance from both the front and rear surfaces. This capability enables bPV systems to achieve higher energy yields than conventional monofacial PV modules under suitable operating conditions (Aksoz, 2025; Zhong et al., 2023).

Among the performance indicators used to evaluate bifacial photovoltaic systems, bifacial gain (BG) has been the most widely adopted. BG is defined as the ratio of the electrical power generated by the rear side of a bifacial module to that generated by its front side, and it is commonly used to quantify the additional energy contribution from the rear surface (Berrian and Linder, 2023; Garrod and Ghosh, 2023). Numerous experimental and numerical studies have demonstrated that BG is influenced by several environmental and installation parameters.

Weather conditions are among the most influential factors affecting bifacial gain. Experimental studies have consistently reported that BG is generally higher under cloudy conditions than under clear skies because diffuse solar radiation enhances the contribution of the rear surface. For example, one study reported higher BG values on cloudy days than on sunny days (Yu et al., 2016), while another observed average BG values of 28% and 15% under cloudy and sunny conditions, respectively(Ernst et al., 2024).

The geographical latitude of the installation site also plays a significant role in determining bifacial gain. An empirical investigation reported that the critical latitude varies between 30° and 50°, depending on the panel elevation and ground albedo (Sun et al., 2018). Similarly, another study concluded that bPV systems installed at latitudes above 40° are more economically advantageous than those located below 40° (Rodríguez-Gallegos et al., 2018). This behavior can be explained by the observed trend that BG increases approximately linearly from 0° to 40° latitude but rises exponentially beyond 40° (Khan et al., 2019). Supporting these findings, an experimental study conducted at a latitude of 37.5° reported BG values of 8.2%, 13.0%, and 18.1% for panel tilt angles of 10°, 20°, and 30°, respectively (Wang et al., 2022).

The installation geometry, particularly panel elevation and tilt angle, also substantially influences bifacial performance. A numerical study investigating these parameters under different ground albedo conditions found that increasing the module elevation above 0.7 m reduced BG because of the decreased intensity of ground-reflected irradiance reaching the rear surface. The same study further showed that tilt angles between 40° and 50° provided the maximum bifacial gain across different albedo values (Tao et al., 2021).

Ground albedo is another key parameter affecting the performance of bifacial photovoltaic systems (Alam et al., 2023; Ortega et al., 2024). Higher surface reflectivity increases the amount of irradiance incident on the rear side of the module, thereby improving BG. An experimental study compared five reflective surfaces placed beneath a bifacial module and reported BG values of 21.4%, 18.9%, 12.8%, 7.8%, and 4.8% for aluminum, white-painted material, cement, sand, and grass, respectively (Ganesan et al., 2023). Similar to conventional photovoltaic modules, soiling also affects the performance of bifacial PV systems (Raina and Sinha, 2023) reported that the front surface of bifacial modules accumulates dust approximately ten times faster than the rear surface. Consequently, the clean module exhibited a BG of 12.92%, whereas the soiled module showed a slightly higher BG of 13.98%. This increase was primarily attributed to the greater reduction in front-side irradiance caused by dust accumulation rather than an actual improvement in rear-side performance.

Several studies have also compared the performance of bifacial modules with conventional monocrystalline and polycrystalline photovoltaic technologies. Experimental results demonstrated that floating bifacial PV systems generated 6.75% more energy than floating monofacial systems. Similarly, under land-based operating conditions, the efficiencies of bifacial, monocrystalline, and polycrystalline modules were reported as 13.4%, 12.4%, and 12.0%, respectively (Widayat et al., 2020). Despite the extensive literature on bifacial photovoltaic systems, most previous studies (Castillo-Aguilella and Hauser, 2016) have evaluated front- and rear-side performance using the total electrical output of a commercially available bifacial module. Since these modules typically provide a single electrical output, separate measurements of the front- and rear-side power generation are not possible. Consequently, researchers have generally estimated the contribution of the front surface by assuming that it behaves similarly to a conventional monofacial monocrystalline module.

To overcome this problem, the present study proposes an alternative experimental configuration in which two monocrystalline photovoltaic modules are integrated back-to-back to emulate a bifacial photovoltaic module. This configuration enables the electrical output of the front and rear modules to be measured independently as well as collectively, allowing a more detailed evaluation of their individual contributions. Furthermore, pyranometers were installed at the same tilt angle as the photovoltaic modules to measure the global tilted solar irradiance incident on each surface. This experimental arrangement provides more comprehensive insight into the front- and rear-side performance of bifacial photovoltaic systems than conventional single-output module measurements.

2. MATERIAL AND METHODS

The performance of the photovoltaic panels has been measured using various methods, such as electrical efficiency, thermal efficiency, and performance factor. In this study, a case-study approach was adopted to evaluate the efficiency of the PV panels. Experiments were conducted, and uncertainty about the results was given.

2.1. Experimental Setup and Procedure

The Sun-path diagram provided by Oregon University (DOI) was used to calculate the hour angle and solar azimuth angle to determine the orientation and direction of the panels . The setup is aligned in North-South and front panel looking South. The properties of panels used in this study given in Table 1.

Table 1. PV module characteristics

Parameter	Value
Model Type	TT100-36PM
Maximum Power (P_{max})	100 WP
Maximum Power Voltage (V_{max})	20.6
Maximum Power Current (I_{mp})	4.86
Open Circuit Voltage (V_{oc})	24.05
Short Circuit Current (I_{sc})	5.13
Number of Cells	36 (4 x 9)
Cell Size (mm)	158.75 x 79.375

Panel Size (mm)	680 x 790 x 20
Weight (kg)	5.87
Operating Temperature Range (°C)	-40 ~ +85

Experimental setup was built on a roof of in SantralIstanbul Campus located in Istanbul with the coordinates of 41°04'05.9" North and 28°56'47.2" and the measurements were recorded between March 7 and March 13, 2023. The experimental setup schematic can be seen in Fig. 1. Identical monocrystalline with a 100W at STC integrated such that their rear faces are in contact with no gap in between. Next, in order to calculate the electrical and thermal efficiencies of each panel, the ambient temperature of the surrounding air and the solar irradiance reaching the module surfaces were measured, along with the power production and temperature of each panel. The temperature of each PV panel was measured by placing thermocouples at the bottom, middle, and top of the rear surfaces of the modules. The final panel temperatures were then recorded by taking the average of these three measurements. The ambient temperature was measured in the shade to avoid direct sunlight. Similarly, solar irradiance incoming to the front surfaces of the PV modules were measured by placing solar irradiance measurement tools (pyranometers) on the bottom, center and top locations of the panels. To avoid the effect of shading of the apparatus, they are attached on the edge of the panel construction.

In the experiment, PV modules placed with a tilt angle of 23° and height of 50 cm, which is measured between the ground surface and the bottom edge of the panel. For the measurement of panel temperature and radiation values, PCE-SPM-1 pyranometers and PT100 RTD thermocouples were fixed to the top, center and bottom of the panels. Elitech Tlog 10EH was used to collect and log relative humidity (RH%) and temperature data. Meanwhile, P_{max}, I_{max}, V_{max}, I_{sc} and V_{oc} values of front and rear panels are separately collected with the help of HT Instruments I-V400W I-V curve tracker and Fluke 101 digital multimeter. The data stored in the datalogger is transferred to the computer hourly for 7 consecutive days for further analysis.

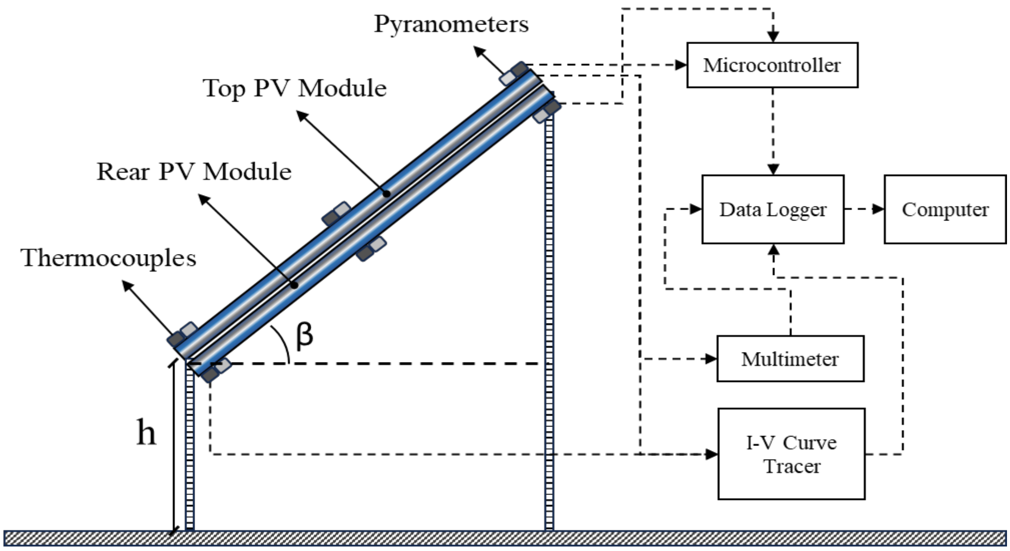

Figure 1. Schematic illustration of experimental setup

Table 2. Experiment Apparatus

Instrumentation	Model	Specification
Pyranometer	PCE-SPM 1	Measuring range 0 ~ 2000 W/m^2, Resolution 0.1 W/m^2, Accuracy ± 10 W/m^2 or ± 5%
Temperature Sensor	PT100 RTD	Measuring range -200 ~ 550 °C, Accuracy ± 0.5 °C
Temperature & Humidity sensor	Elitech Tlog 10EH	Measuring range -40 ~ 85 °C, Accuracy ± 0.5 °C, Resolution: 0.1 °C Relative Humidity Accuracy: ±3 %RH, Resolution: 0.1 %RH
I-V Curve Tracker	HT Instruments I-V400w	Max power 5 ~ 1000 W, Resolution 1 W, VDC Voltage 5 ~ 1000 V, Resolution 0.1 V, IDC Current 0.1 ~ 15 A, Resolution 0.01 A
Digital Multimeter	Fluke 101	AC range 0.6 ~ 600 V (1% accuracy), DC range 6 ~ 600 V (0.5% accuracy),

2.2. Performance Parameters

There are various methods proposed to assess the performance of bPV panels. The straightforward approach is to measure the power production of PV module at maximum power point (MPP). Another common method is electrical efficiency which is simply the ratio of power yield at MPP to the solar irradiance exerted on the panel surface. As a more realistic and proper method, the efficiency equation is written in Eq. 1 since tilted global solar irradiance preferred in this study instead of global solar irradiance.

$$\eta_{elec} = \frac{P_{max}}{TGI * A_m} = \frac{I_{max} * V_{max}}{TGI * A_m} \tag{1}$$

where Imax is the maximum current and Vmax is maximum voltage at maximum power point, Pmax is the maximum power output, Am is the net area of the PV module and TGI is the tilted global irradiance W/m^2. Apart from the parameters above, bifacial gain namely bifaciality frequently used to show the contribution of the rear side of the module to the bPV panel electricity production. Therefore, the bifacial gain can be expressing in percentage form as:

$$BG(\%) = \frac{P_{Rear\ max}}{P_{Front\ max}} * 100 \tag{2}$$

Where BG is the bifacial gain in this study expressed in percentage, $P_{Rear\ max}$ and $P_{Font\ max}$ are the MPP output of rear and front modules in Watt, respectively. Sometimes, to represent efficiency of a PV module, fill factor (FF) which demonstrates what portion of the theoretical maximum power output i.e. the product of open circuit voltage (V_{oc}) and short circuit current (I_{sc}), converted into electricity. Fill factor can be written in the form of:

$$FF = \frac{P_{max}}{V_{oc} * I_{sc}} \tag{3}$$

The parameters mentioned above may be significantly affected by panel type and orientation. Hence, optimum design parameter for each panel type and array arrangement must be developed. In the literature reviewed in this study some researchers attempted to optimize the design parameters of bPV to maximize the efficiency parameters.

3. RESULTS AND DISCUSSION

The average bifacial gain of the integrated bifacial photovoltaic (bPV) system is presented in Fig. 3. As shown, the integrated bPV module generated approximately 4–10% more power than the front-side-only panel throughout the day. Even during the early morning hours, the average bifacial gain was approximately 7%. During the following hour (09:30–10:30 a.m.), the maximum average bifacial gain of nearly 10% was observed.

Interestingly, the bifacial gain exhibited a decreasing trend until noon, despite the expectation of higher solar irradiance during midday. This unexpected reduction can be attributed to the prevailing weather conditions, particularly the sky clearness index, which reflects the extent of cloud cover. Increased cloud cover reduces direct solar irradiance while also decreasing the diffuse and ground-reflected components of solar radiation. Under such conditions, although the proportion of diffuse radiation in the global solar irradiance increases, the overall available solar radiation decreases, resulting in a lower bifacial gain.

From noon until approximately 15:30, the bifacial gain gradually increased, reaching about 9%, which represents the second-highest value observed during the day. This increase can be explained by three factors. First, during the morning and afternoon, the solar rays strike the ground at a more oblique angle, allowing the ground beneath the PV module to receive greater direct solar irradiance. Second, the reflected solar radiation from the ground is more likely to reach the rear side of the integrated bPV module under these geometric conditions. Third, the sky conditions became clearer compared with those observed around noon, increasing the available solar radiation.

As expected, the average bifacial gain gradually decreased toward sunset as the incident solar irradiance on the tilted PV module declined. Consequently, the minimum bifacial gain was observed during the 17:30–18:30 time interval.

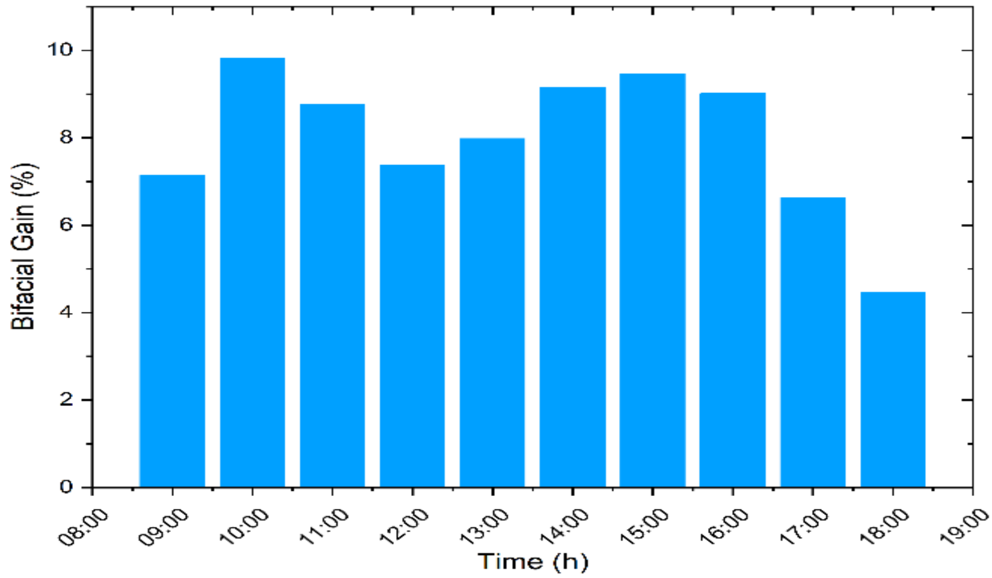

Figure 2. Weekly average bifacial gain during daylight hours (%)

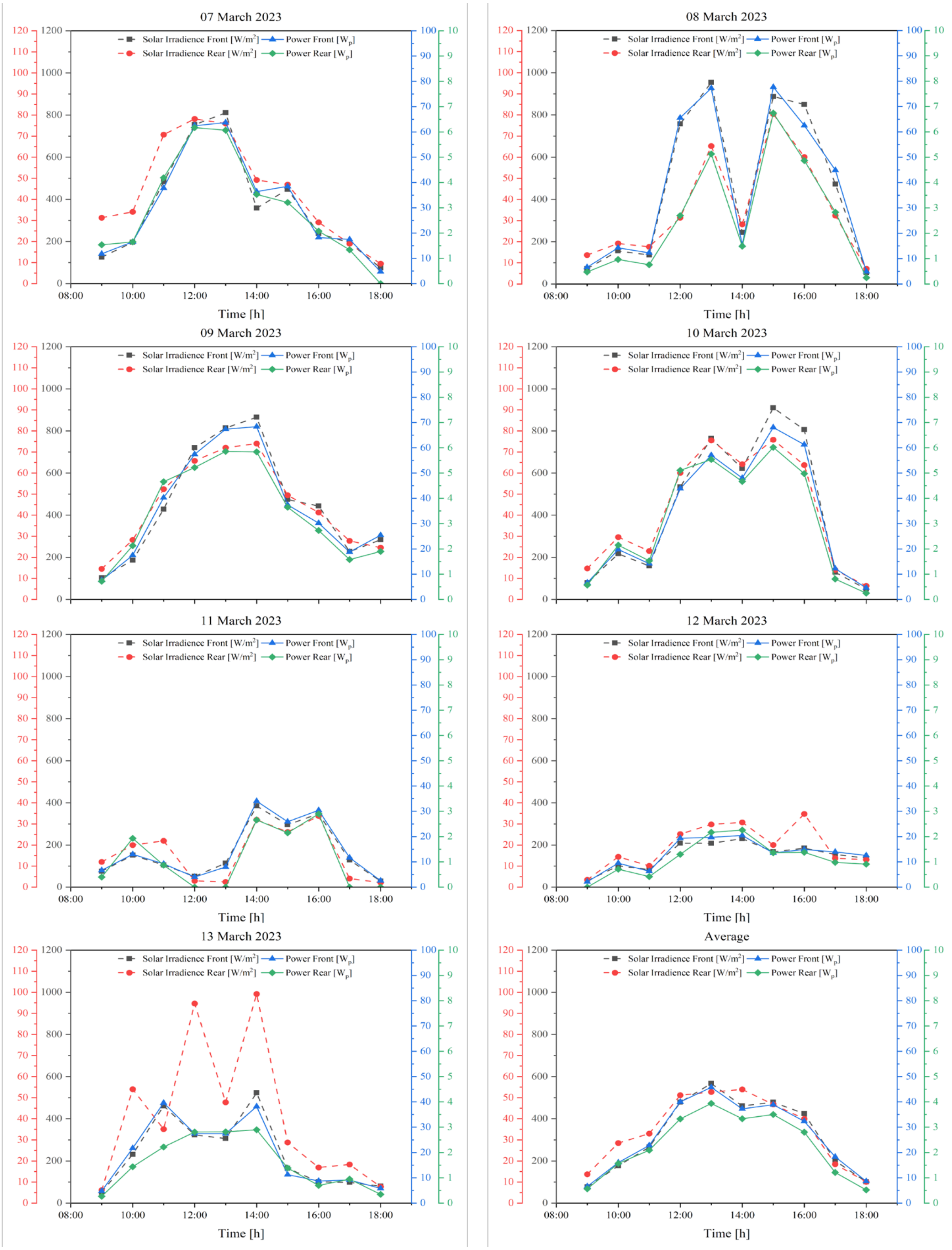

Figure 3. Daily solar irradiance and power production of the front and rear PV modules, along with their weekly averages

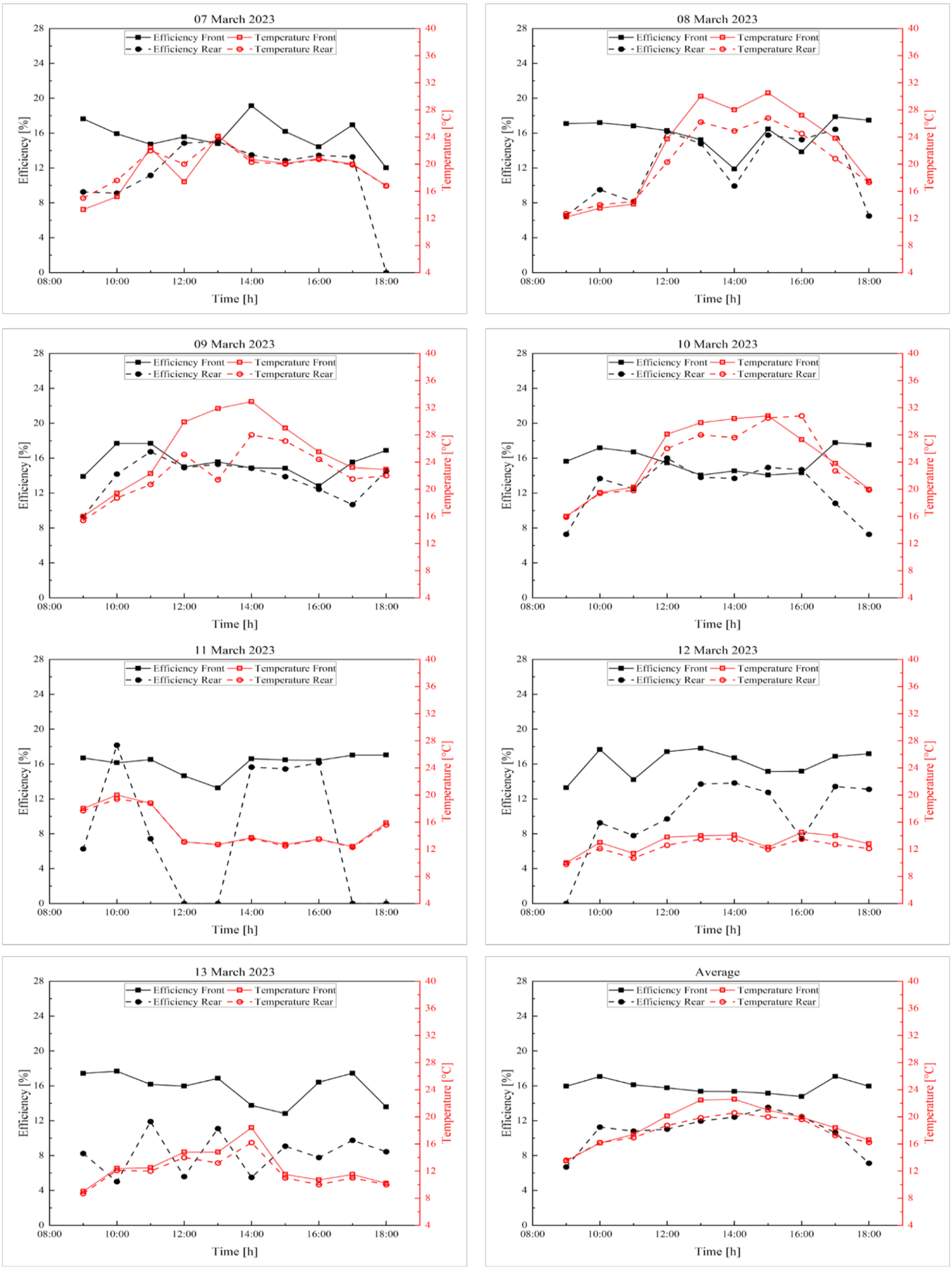

Figure 4. Daily efficiency and temperature of the front and rear PV modules, along with their weekly averages

The results indicated that the integrated bifacial PV modules achieved a higher overall efficiency and a bifacial gain of up to 13% compared to single-module power production. The weekly average efficiencies of the individual front and rear panels were 15.86% and 10.79%, respectively. Furthermore, the weekly average total bifacial gain relative to the front panel was determined to be 7.98%. Excluding zero-gain periods, the maximum bifacial gain reached 13.09% on the first day of the experiment and 4.11% at noon on the second day. This variation is attributed to the higher levels of diffuse and reflected solar radiation present at lower hour angles.

Regarding thermal performance, the front panel exhibited an efficiency of 14.88% at its peak temperature of 31.9 °C, which increased to 17.18% at its lowest temperature of 12.8 °C. While these specific values do not represent the absolute maximum and minimum efficiencies of the module due to the influence of other environmental parameters, the trend of increasing efficiency with decreasing operating temperatures is clearly demonstrated. In comparison, the rear panel showed an efficiency of 14.69% at a temperature of 30.8 °C. At its lowest temperature of 8.7 °C, the corresponding efficiency dropped to only 5.02%, which is attributed to the low diffuse and reflected solar radiation during the first hour of daylight.

4. CONCLUSIONS

This study experimentally demonstrated that integrating two identical monofacial photovoltaic modules in a back-to-back configuration provides a practical and sustainable alternative for utilizing surplus or aging PV modules while increasing energy production per unit area. The proposed configuration enabled independent evaluation of the front and rear modules, revealing weekly average electrical efficiencies of 15.86% and 10.79%, respectively, with an average bifacial gain of 7.98% and a peak value of 13.09%. The results also confirmed the significant influence of operating temperature and environmental conditions on system performance, particularly the contribution of diffuse and reflected solar radiation to rear side power generation. Overall, the integrated configuration offers a simple and cost-effective approach to enhancing photovoltaic energy yield without requiring commercially manufactured bifacial modules, while simultaneously extending the service life of existing PV panels and contributing to more sustainable photovoltaic waste management. Future studies should investigate the long-term performance of the proposed system under different climatic conditions, panel orientations, installation heights, and ground reflectivity levels to further optimize its energy and economic performance.

REFERENCES

Aksoz, Z.Y., 2025. Impacts of reflector positioning on horizontal bifacial photovoltaic module performance: an experimental case study. Sustainable Energy Technologies and Assessments 83, 104578. https://doi.org/10.1016/j.seta.2025.104578

Alam, M., Gul, M.S., Muneer, T., 2023. Performance analysis and comparison between bifacial and monofacial solar photovoltaic at various ground albedo conditions. Renewable Energy Focus 44, 295–316. https://doi.org/10.1016/j.ref.2023.01.005

Berrian, D., Linder, J., 2023. Enhanced Bifacial Gain with Optimized Mountings in Photovoltaic Systems. Solar RRL 7, 2300474. https://doi.org/10.1002/solr.202300474

Bórawski, P., Holden, L., Bełdycka-Bórawska, A., 2023. Perspectives of photovoltaic energy market development in the european union. Energy 270, 126804. https://doi.org/10.1016/j.energy.2023.126804

Castillo-Aguilella, J.E., Hauser, P.S., 2016. Multi-Variable Bifacial Photovoltaic Module Test Results and Best-Fit Annual Bifacial Energy Yield Model. IEEE Access 4, 498–506. https://doi.org/10.1109/ACCESS.2016.2518399

Ernst, M., Liu, X., Asselineau, C.-A., Chen, D., Huang, C., Lennon, A., 2024. Accurate modelling of the bifacial gain potential of rooftop solar photovoltaic systems. Energy Conversion and Management 300, 117947. https://doi.org/10.1016/j.enconman.2023.117947

Ganesan, K., Winston, D.P., Sugumar, S., Jegan, S., 2023. Performance analysis of n-type PERT bifacial solar PV module under diverse albedo conditions. Solar Energy 252, 81–90. https://doi.org/10.1016/j.solener.2023.01.020

Garrod, A., Ghosh, A., 2023. A review of bifacial solar photovoltaic applications. Front. Energy 17, 704–726. https://doi.org/10.1007/s11708-023-0903-7

Ghosh, S., Yadav, R., 2021. Future of photovoltaic technologies: A comprehensive review. Sustainable Energy Technologies and Assessments 47, 101410. https://doi.org/10.1016/j.seta.2021.101410

Hossain, M.K., Mohammed, M.K.A., Pandey, R., Arnab, A.A., Rubel, M.H.K., Hossain, K.M., Ali, M.H., Rahman, Md.F., Bencherif, H., Madan, J., Islam, Md.R., Samajdar, D.P., Bhattarai, S., 2023. Numerical Analysis in DFT and SCAPS-1D on the Influence of Different Charge Transport Layers of $CsPbBr_3$ Perovskite Solar Cells. Energy Fuels 37, 6078–6098. https://doi.org/10.1021/acs.energyfuels.3c00035

Keiner, D., Gulagi, A., Breyer, C., 2023. Energy demand estimation using a pre-processing macro-economic modelling tool for 21st century transition analyses. Energy 272, 127199. https://doi.org/10.1016/j.energy.2023.127199

Khan, M.R., Sakr, E., Sun, X., Bermel, P., Alam, M.A., 2019. Ground sculpting to enhance energy yield of vertical bifacial solar farms. Applied Energy 241, 592–598. https://doi.org/10.1016/j.apenergy.2019.01.168

Ortega, E., Suarez, S., Jimeno, J.C., Gutierrez, J.R., Fano, V., Otaegi, A., Rivas, J.M., Navas, G., Fernandez, I., Rodriguez-Conde, S., 2024. An statistical model for the short-term albedo estimation applied to PV bifacial modules. Renewable Energy 221, 119777. https://doi.org/10.1016/j.renene.2023.119777

Raina, G., Sinha, S., 2023. Experimental investigations of front and rear side soiling on bifacial PV module under different installations and environmental conditions. Energy for Sustainable Development 72, 301–313. https://doi.org/10.1016/j.esd.2023.01.001

Rodríguez-Gallegos, C.D., Bieri, M., Gandhi, O., Singh, J.P., Reindl, T., Panda, S.K., 2018. Monofacial vs bifacial Si-based PV modules: Which one is more cost-effective? Solar Energy 176, 412–438. https://doi.org/10.1016/j.solener.2018.10.012

Sun, X., Khan, M.R., Deline, C., Alam, M.A., 2018. Optimization and performance of bifacial solar modules: A global perspective. Applied Energy 212, 1601–1610. https://doi.org/10.1016/j.apenergy.2017.12.041

Tao, Y., Bai, J., Pachauri, R.K., Wang, Y., Li, J., Attaher, H.K., 2021. Parameterizing mismatch loss in bifacial photovoltaic modules with global deployment: A comprehensive study. Applied Energy 303, 117636. https://doi.org/10.1016/j.apenergy.2021.117636

Vimala, M., Ramadas, G., Perarasi, M., Manokar, A.M., Sathyamurthy, R., 2023. A Review of Different Types of Solar Cell Materials Employed in Bifacial Solar Photovoltaic Panel. Energies 16, 3605. https://doi.org/10.3390/en16083605

Wang, S., Shen, Y., Zhou, J., Li, C., Ma, L., 2022. Efficiency Enhancement of Tilted Bifacial Photovoltaic Modules with Horizontal Single-Axis Tracker—The Bifacial Companion Method. Energies 15, 1262. https://doi.org/10.3390/en15041262

Widayat, A.A., Ma'arif, S., Syahindra, K.D., Fauzi, A.F., Setiawan, E.A., 2020. Comparison and Optimization of Floating Bifacial and Monofacial Solar PV System in a Tropical Region, in: 2020 9th International Conference on Power Science and Engineering (ICPSE). Presented at the 2020 9th International Conference on Power Science and Engineering (ICPSE), IEEE, London, United Kingdom, pp. 66–70. https://doi.org/10.1109/ICPSE51196.2020.9354374

Yu, B., Song, D., Sun, Z., Liu, K., Zhang, Y., Rong, D., Liu, L., 2016. A study on electrical performance of N-type bifacial PV modules. Solar Energy 137, 129–133. https://doi.org/10.1016/j.solener.2016.08.011

Zhong, J., Zhang, W., Xie, L., Zhao, O., Wu, X., Zeng, X., Guo, J., 2023. Development and challenges of bifacial photovoltaic technology and application in buildings: A review. Renewable and Sustainable Energy Reviews 187, 113706. https://doi.org/10.1016/j.rser.2023.113706