The Atacama desert in Chile as a bifacial hotspot: yield modelling within the ATAMOSTEC project

Modelling | Alongside the recent rapid boom in bifacial solar deployment, extensive work has been underway to fine-tune the yield modelling of bifacial systems. Drawing on case studies from the ATAMOSTEC test site in Chile, researchers involved in the collaborative venture describe how it is helping improve understanding of bifacial yield and laying the foundations for a set of new rules to inform system design and installation

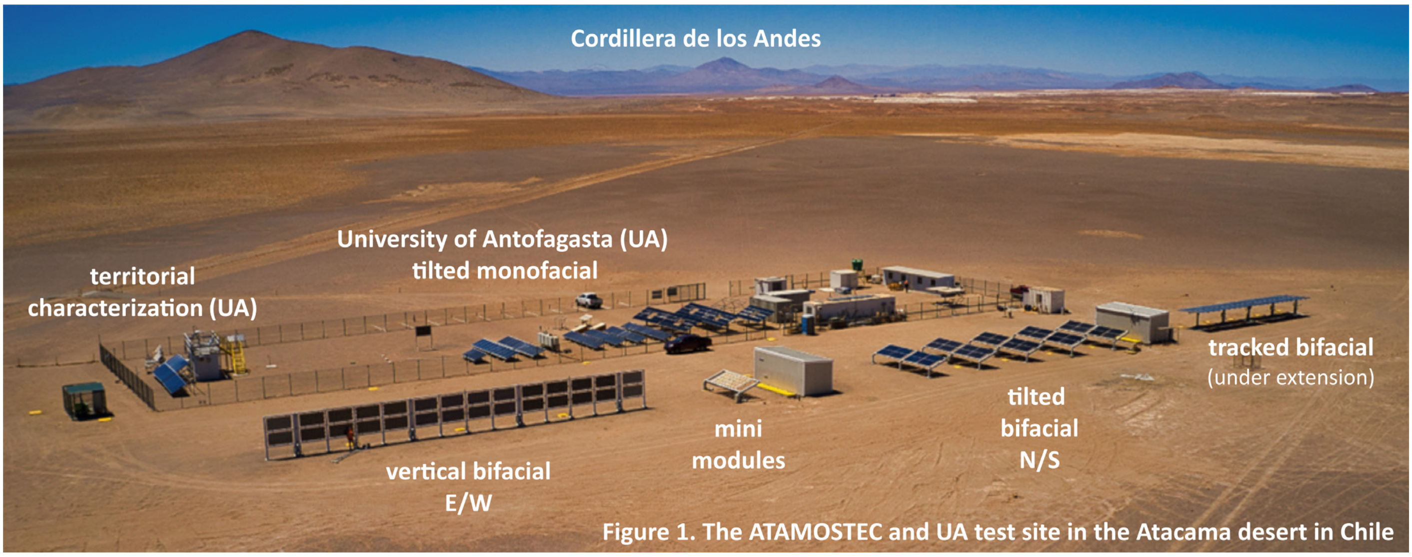


Figure 1. The ATAMOSTEC and UA test site in the Atacama desert in Chile

Bifacial solar technology was first developed back in the 1960s. Initially considered too costly, over some decades it remained dormant while the overall PV market boomed. However, with bifacial cells now becoming more or less a commodity within various cell technologies, the sleeping beauty of bifacial PV has finally awakened.

To accompany the rapid uptake of bifacial installations it is essential to provide practical guidelines for their configuration to optimise LCOE. Compared to monofacial installations the bifacial configuration concerns more parameters with complex interrelations and different geographical response. The ultimate goal of modelling is to turn the complexity of so many system parameters and with varying constraints into a manageable simplicity, offering reliable and simplifying solutions using straightforward input. This article summarises how the rapid progress made over recent years has improved understanding of design rules for bifacial PV. It also examines some case studies from within the ATAMOSTEC consortium operating in the Atacama Desert in Chile, as a collaborative effort between several institutional and industrial partners.

With the improved understanding of bifacial yield and the resulting best practices, bifacial PV shows strong signs of bloom in emerging markets such as Latin America, where companies such as Enel Green Power are turning to bifacial PV in order to power large-scale (200-600MW) solar projects in Chile, Brazil and Mexico. In addition, due to the recent exemption of bifacial panels from Section 201 import tariffs, US bifacial installations are expected to reach 2GW in 2020. [1]

Looking back: bifacial manufacturing, measurement and modelling

While the first bifacial cell patent was granted in 1960 and bifacial solar technology further developed in the late 1960s, it took surprisingly long – until the early 1980s – before the simple yet effective energy gain of the module backside was even considered for effective exploitation by collecting the ground albedo. Researchers at UPM Madrid reported bifacial energy gains of 35% in summer and over 50% in winter by using white painted walls and ground surfaces. [2] In 1986, the same group at UPM Madrid came up with a bifacial model based on a View-Factor approach that again estimated very high bifacial gains of up to

Five rules of thumb for bifacial installation design as found by modelling and as discussed in this article

A) 2D models give correct relative trends but underestimate absolute rear irradiance
B) The impact of the mounting structure cannot be neglected for bifacial gain diagnoses, forecast and yield.
C) The optimal tilt angle for bifacial systems is larger than for monofacial systems. This difference increases with ground albedo and latitude.
D) For vertical bifacial configurations, the bifaciality of the module (back-to-front ratio) strongly affects the energy yield and the LCOE of the system. This effect is independent of ground reflectivity.
E) The gain obtained by tracking is additive to the bifacial gain of a fixed-tilt system

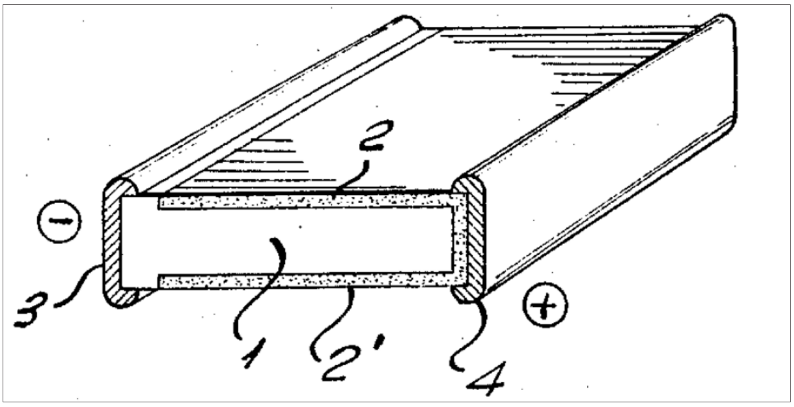


Figure 2. Double junction bifacial cell from a 1960 patent by H. Mori from Sharp (Japan). 1: n-type silicon, 2 and 2': p-type emitter regions


Credit: NASA

Figure 3. The International Space Station powered by bifacial PV

60% in winter. [3] Much more modest gains of around 20-25% were reported in 1993 by Martin Green at UNSW Sydney. [4]

The earliest appearance of bifacial PV in real-world applications, although somewhat out of this world, happened in Russian spacecrafts in the 1970s [5] and later on in the International Space Station, launched in 2000, where bifaciality offered increased sunlight collection from the Earth's albedo, which could avoid sun-tracking as required for monofacial modules. On the space station the module backside was found to produce about one third of the power of the module frontside. This in-orbit performance validated the results of a bifacial performance model that had been developed by NASA [6].

Whereas bifacial modules were deployed at the ISS because their doubled-sided light capture allowed the system to avoid sun tracking, recent years have seen a growing awareness of the benefits of using tracking on ground based bifacial systems. ENEL Green Power is operating such an innovative bifacial plant with horizontal single-axis tracking (HSAT) [7] at the site of La Silla in Northern Chile. Tracking of the modules and the resulting increase of tilt angles appears effective in reducing the effect of soiling in sandy climates like a desert [8,9]. Some modelling results on the La Silla plant will be discussed in the section on case studies.

Another bifacial configuration of increasing interest is illustrated in Figure 4. The use of vertical systems allows combined use of land for PV and agriculture ('agri-voltaics') [10]. Such a vertical configuration reduces soiling losses and saves on cleaning costs. It is also reported to give significantly lower operating temperatures due to optimised convection [11]. This not only gives a better performance ratio but may also lead to improved long-term reliability. When snow is involved a vertical bifacial installation even benefits due to the increased ground reflection (figure 4b).

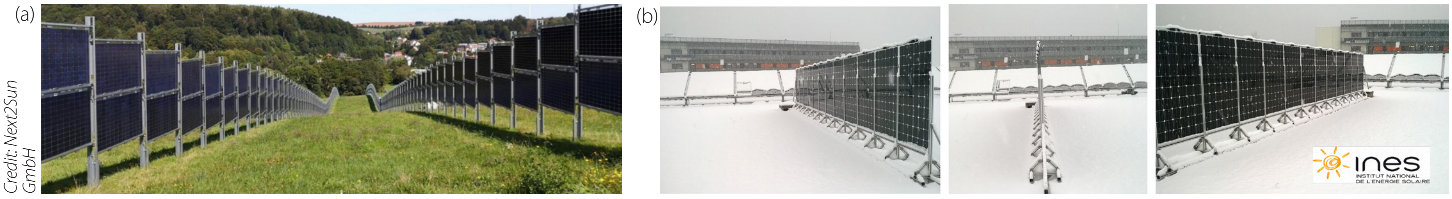
Modelling and measuring: intimate partners

The choices to be made for the design and financing of a bifacial installation are the result of a complex multi-criteria assessment where modelling can help to minimise lengthy trials and costly errors.

However, yield modelling is more than just predicting the exact value for the energy production of a bifacial PV plant. It can also help in the project definition by determining the most and least critical design parameters, related to the geometric configuration and geographical location. This can be done by a sensitivity analysis with varying parameter settings. In addition, measurements in the field do not have control over many of the 'intangible' parameters involved, such as meteorological events. This kind of 'noise' can only be filtered out by statistical methods which require lengthy data acquisition sequences, whereas modelling offers strict control over parameters and can pinpoint noise by taking it into account separately. The fact that modelling allows separation of the front and rear contributions enables identification of the most significant contributions to the energy yield and their design origin. Finally, modelling can help to build a common 'language' to define comparative test and measurement standards.

In general, the set of parameters taken into account for bifacial yield modelling consists of:

- Geographical location;



Credit: Next2Sun GmbH

Figure 4. (a) vertical bifacial configuration for agri-voltaics (left); (b) vertical test bench with bifacial heterojunction modules during winter at CEA-INES (Bourget-du-Lac, France)

- Local ground reflectivity;
- Local weather dataset (direct, diffuse irradiance, ambient temperature, wind speed, etc.);
- PV module specs, like efficiency, dimension, bifaciality, temperature coefficient, etc.;
- PV field design parameters: module tilt, module elevation above ground, row spacing, number of modules in a row, number of rows, module installation format (portrait/landscape), ground cover ratio (GCR).

Modelling challenges – opportunities and obstacles

Simulation of bifacial module performance involves the integration of optical, electrical and thermal models. Climatic parameters such as irradiance, ambient temperature and wind speed serve as input to the thermal and optical models that on their turn delver the input for the electrical model to obtain the projected energy output from the system. The main difference between monofacial and bifacial simulation is of course in the optical model. Currently, the most important available bifacial irradiance models are based on ray-tracing (RT) or view-factor (VF) methodologies.

A third, empirical, approach is based on fitting formula derived from simulations and measurements using geometrical system configuration and albedo as input parameters. These types of models vary a lot since the coefficients can be computed based on theoretical models, measurements, etc.

The main difference between 2D and 3D View-Factor models is the complexity of the equations. The 2D-VF approach assumes the PV module rows to be of infinite length, with PV arrays described as a two-dimensional cross-section of the rows. Consequently, analytical formulas can be used and calculations can be made within the order of seconds. This approximation is well suited for long regular rows such as in large-scale ground-mounted PV installations, or on flat rooftop commercial installations. However, it cannot be directly applied to smaller bifacial systems where the backside irradiance may vary drastically from the centre to the edge of the array. These edge effects can well be taken into account by 3D View-Factor models. But for these models there are no simple analytical formulas: integrals need to be solved and simulations can take from minutes to several hours, like for the simulation of a tracker system.

Ray-Tracing algorithms simulate the path of light rays and are capable of reproducing a highly detailed interaction between geometries of the modules and their supporting structure but at the expense of computational cost, typically days on a standard laptop. One of the best-known ray-tracing tools is 'bifacial_radiance' [12]. Table 2 lists some other open-source tools and commercial products, as well as some academic simulation tools [13].

Modelling case studies – modelling versus measurements

A - The discrepancy between bifacial gain as modeled by 2D-VF and ray-tracing methods

2D view-factor modelling may give the correct tendencies for parameter sensitivities but users need to be aware that they may underestimate the absolute value of the bifacial gain by a few percent compared to ray-tracing methods. Modelling of the front-side irradiance is nowadays fairly straightforward using commercial packages like PVsyst, which is a 2D view-factor model.

To compare the accuracy of rear-side irradiance of the different modelling approaches ISC Konstanz evaluated two open-source tools from NREL: 'Bifacial VF' (2D-VF) and 'Bifacial Radiance' (ray tracing) were applied for rear-side simulation whereas the front side was modelled using 2D view-factors [14]. For comparison, the same simulations were run using PVSyst for both front and rear side. As a case study the 1.7MW La Silla PV system in Chile was used, the first large PV system combining horizontal single-axis tracking (HSAT) and bifacial modules. In order to identify trends, a sensitivity study on the elevation of the modules above ground was made. Results are presented in Figure 5. Since this is a tracked system, module elevation is relatively high.

We can see that 'PVSyst' and the equivalent '2D-VF' approach from NREL give very similar results and trends, as expected. However, when comparing with the Ray-Tracing results, the rear-side results appear largely different. Both approaches give a similar trend, but the ray-tracing approach predicts a significantly (2-3%) larger bifacial gain (defined as the ratio of backside irradiance to total irradiance).

These modelling results were then compared to measurements from the La Silla site, as given in Table 3, which shows

	View-factor (VF)		Ray-tracing (RT)
Origin	From heat transfer studies		Rendering image method
PV System definition (the modules)	2D (infinite row hypothesis)	3D	3D
Modelling rear side inhomogeneity (edge effect)	No	Yes	Yes
Precise structure shading (racking)?	No (at best a global shading factor)		Yes
Reflection nature (scattering)	Isotropic only		All types of reflection (isotropic, specular, etc.)
Unconventional configurations: BIPV, curved surfaces etc.	No		Yes
Computation time to simulate yearly irradiance on a standard laptop	Seconds to minutes	Hours	Days
When to use?	Rules of thumb trends yield calculation	Yield calculation diagnostic and prevision	Diagnostic and prevision

Table 1. Comparison of ray-tracing (RT) and view-factor (VF) methods

**available in Python as open-source software*	2D view-factor	3D view-factor	Ray-tracing	Empirical
Open source	pvfactors* PUB model bifacial_vf*		bifacial_ radiance*	Prism Solar
Commercial	PVSyst Polysun		PVCase	Polysun
Research/academic		BIGEYE MoBiDiG TriFactors	MoBiDiG	

Table 2. Overview of most used bifacial simulation tools

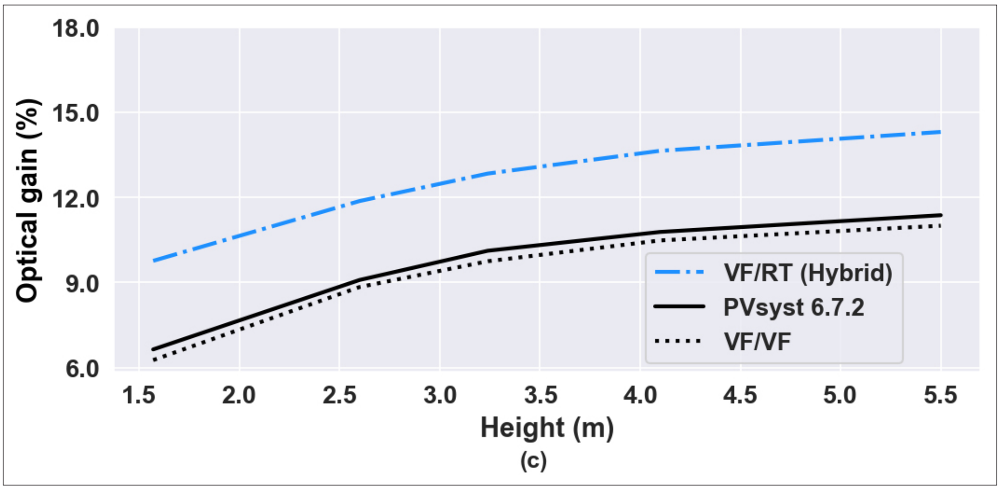


Figure 5. Simulated bifacial gain of the La Silla tracked bifacial plant in Chile, using PVSyst (with a 2D-VF approach) and MoBiDiG models. MoBiDiG is evaluated using two different approaches: 2D-VF for both front and rear side (dashed black) or 2D VF for the front side and RT for the rear side (dashed blue)

	Bifacial electrical gain (%)
Measured data	10.4 – 12.4
MoBiDig with RayTracing for rearside	9.3
MoBiDiG with 2D-VF for rearside	6.5
PVSyst 6.7.2	6.8

Table 3. Measured data over four months on the HSAT bifacial PV System at La Silla (compared to their monofacial HSAT system) and simulation results using three approaches. Adapted from [8]

that MoBiDiG with ray tracing gives a bifacial gain close to the one measured in the La Silla PV plant. However, all the three simulation models (PVSyst, MoBiDiG with 2D-VF and MoBiDiG with ray tracing) underestimate the measured bifacial gain. This raises the question whether the measured value for the bifacial gain might be affected by an artefact such as a faster field degradation of the STC power for the monofacial (p-type) modules compared to the bifacial (n-type) modules.

Of course, it can be questioned if this 2-3% higher precision of the ray-tracing approach justifies a simulation time that explodes from minutes to days. However, it has to be kept in mind that other types of simulation, like for the loss diagnosis discussed in the next section, require smaller simulation time steps that will lead to discrepancies between 2D-VF and RT approaches that can go up to 10%.

B – The impact of the mounting structure on bifacial yield diagnosis and forecast.

To forecast bifacial energy production profiles over the day, accurate values of rear irradiance are necessary at a minute-wise resolution. The precision depends on the capability to reproduce the exact configuration of the PV system, including the mounting structure. The mounting structure (racking) will influence rear irradiance and its uniformity over the entire rear surface of the bifacial PV array. Non-uniformity of the rear irradiance can be a significant loss factor and has been found to increase with higher ground albedo, direct radiation from the sky and with lower tilt angle of the PV array [15].

The impact of racking was evaluated at the test bench of CEA-INES by comparing measured and simulated rear irradiance. As indicated in Figure 6 it was measured by reference cells facing ground at the plane of the array (POA) in positions E (edge) and C (centre). Using ray tracing, the test bench is simulated with the mounting structure as it is (Figure 6, bottom left) and without any structure, assuming free-floating panels (Figure 6, bottom right).

The mean absolute error ($MAE = 1/n\Sigma\Delta_i$) was used as an indicator of precision for the simulation. It was found that the influence of the mounting structure was largest at the edge position E and this position was evaluated in more detail to gain a better insight into the capability of the various simulation tools to deal with the effects of the mounting structure under either sunny or cloudy weather in both winter and summer. Figure 7 compares measurement with simulations using 2D-VF (pvfactors), 3D-VF (TriFactors) and RT models (bifacial_radiance, without and with racking).

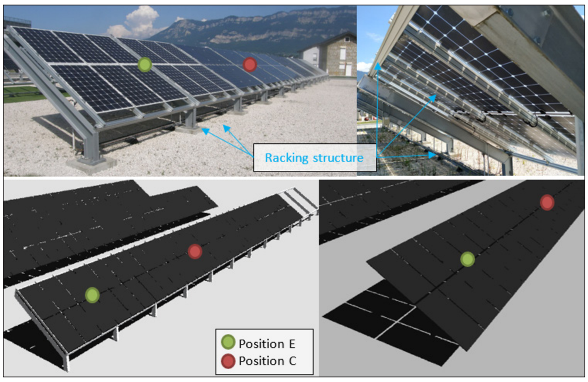


Figure 6. Bifacial PV test bench at CEA-INES, Le Bourget-du-Lac, France (top). 'Bifacial radiance' simulation with racking (bottom left) and without (bottom right)

From the numbers for the MAE between simulation and measurement it is concluded that:

- The VF models have a 50% higher error than the RT models (MAE of 15.1 versus 10.3)
- The error averaged over all four models is 50% higher in winter than in summer (10.5 vs. 14.9)
- On cloudy days this error is lower than on clear days: 26% in winter (12.6/17.1) and 13% in summer (9.8/11.2)
- Lowest error over the four sky conditions is obtained by the 'Radiance' model with racking (6.3)
- Highest error over all four sky conditions is obtained by the 'pvfactors' model (15.5)

C - Optimal tilt angle for bifacial systems is larger than for monofacial systems

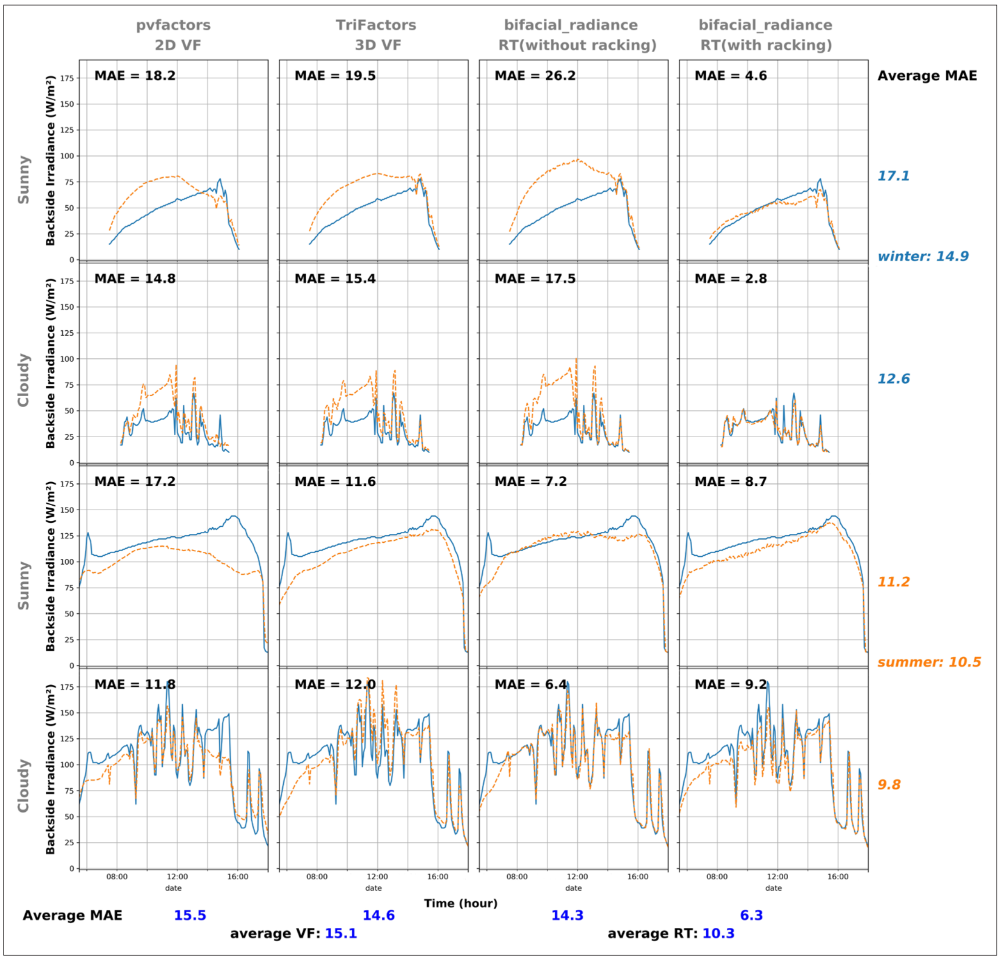
As can be intuitively anticipated the optimal tilt angle for bifacial systems will be slightly larger compared to that for monofacial systems, because higher angles favour the rear-side irradiance. Figure 8 illustrates this effect for two locations at 24.5° latitude (Atacama Desert, Chile) and 45° latitude (Chambéry, France) for two albedo values (0.3 and 0.6).

D – Vertical bifacial installation: the importance of the back-to-front ratio for energy yield and LCOE

The bifaciality of a module, also referred to as back-to-front ratio (BTFR), is crucial when calculating the LCOE of bifacial systems or when comparing monofacial to bifacial systems. It usually varies from 65% to 95%, depending on the cell technology. The rear-side energy production increases linearly with bifaciality.

Vertical installations with east-west orientation offer a production profile that is interesting because it has peaks in morning and afternoon and can help to tailor energy production over the day when mixed with equator-oriented modules. In addition, such a configuration helps to avoid soiling with associated losses that can easily reach 20%.

As stated before, 2D-VF models are well suited to indicate trends. Figure 9 indicates the trend of bifacial gain with increasing



◀ **Figure 7. Measured (blue) and simulated (brown) rear irradiance over the day (6am to 6pm) for four different sky conditions (winter and summer, cloudy and clear) by four different simulation approaches (2 VF and 2 RT, of which one without (nr) and one with racking taken into account) at edge position E of Figure 6. The numbers indicated are the mean absolute error (MAE) between measurement and simulation for the 16 different combinations**

bifaciality, for equator tilted and vertically mounted bifacial modules. Compared to the tilted bifacial installation, the BTFR sensitivity is 2-3 times stronger for the vertical installation.

Another way to present this sensitivity of vertical installations to module bifaciality in a geographic perspective is shown in Figure 10, which compares vertical EW-oriented modules to equator-tilted monofacial modules, taking into account satellite-based data for the ground albedo [16]. The green regions, where the vertical bifacial installation outperforms the monofacial installation by over 5% reduces rapidly when decreasing bifaciality from 100% to 90% and 80%. The overall benefit of vertical bifacial installations is expected to be larger than that depicted in Figure 10 as it does not consider soiling losses that can be severe (10-20%) for tilted modules and are largely reduced for vertical installation.

The bifaciality of a module is determined by the cell technology, with PERC cells at a typical value of 80% bifaciality whereas SHJ heterojunction cells achieve up to 95%. A study by Fraunhofer ISE [17] on the economic value of optimised bifaciality has shown that the higher bifaciality of heterojunction modules will give them a price margin of €0.1/Wp higher than PERC modules to still deliver the same LCOE (of €0.06/kWh). In other words, a higher modules price of up to €0.1/Wp still comes down to the same LCOE due to the increased bifaciality. This economically acceptable price margin for higher bifaciality scales with the target value of the LCOE.

E - The gain obtained by tracking is additive to the bifacial gain of fixed tilt systems

Similar monofacial, bifacial, fixed tilt and tracked systems have been compared with results summarised in Figure 11.

First, we can see (Figure 11a) that the bifacial gain is lower for the tracking system than for the static one. In addition, the tracking gain is lower for bifacial than for monofacial systems (Figure 11b). This is

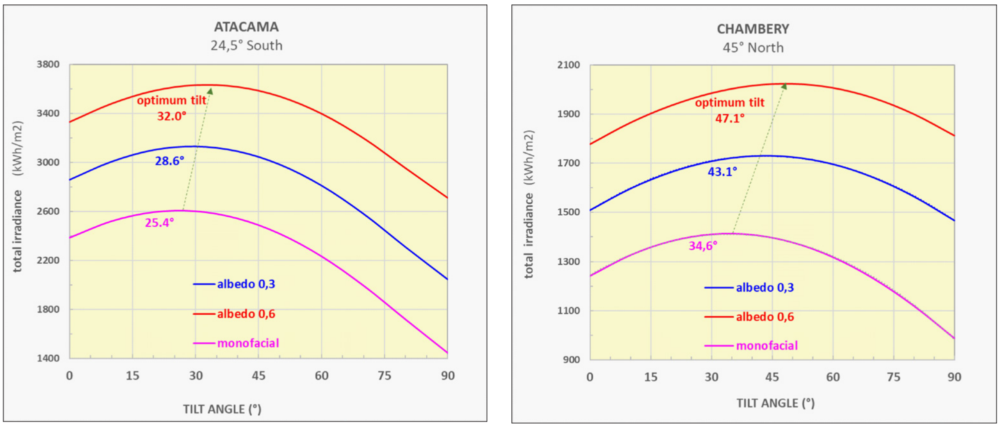


Figure 8: Simulated annual bifacial irradiance as a function of tilt angle and albedo for the Atacama Desert (Chile) and Bourget-du-Lac (France). The optimal bifacial tilt angle is seen to increase with albedo and latitude and is always higher that the optimal tilt angle for monofacial systems

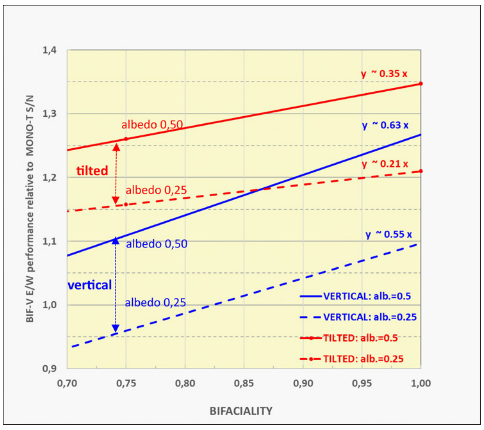


Figure 9. Annual performance, relative to south-oriented tilted monofacial, of bifacial modules in EW-vertical (in blue) and south-tilted configuration (in red) as function of their back-to-front ratio (module bifaciality), for albedo values of 0.25 (dotted line) and 0.50 (solid line). Simulated for the test site at CEA-INES, Le Bourget-du-Lac (France) using the PUB 2D-VF model from Purdue University

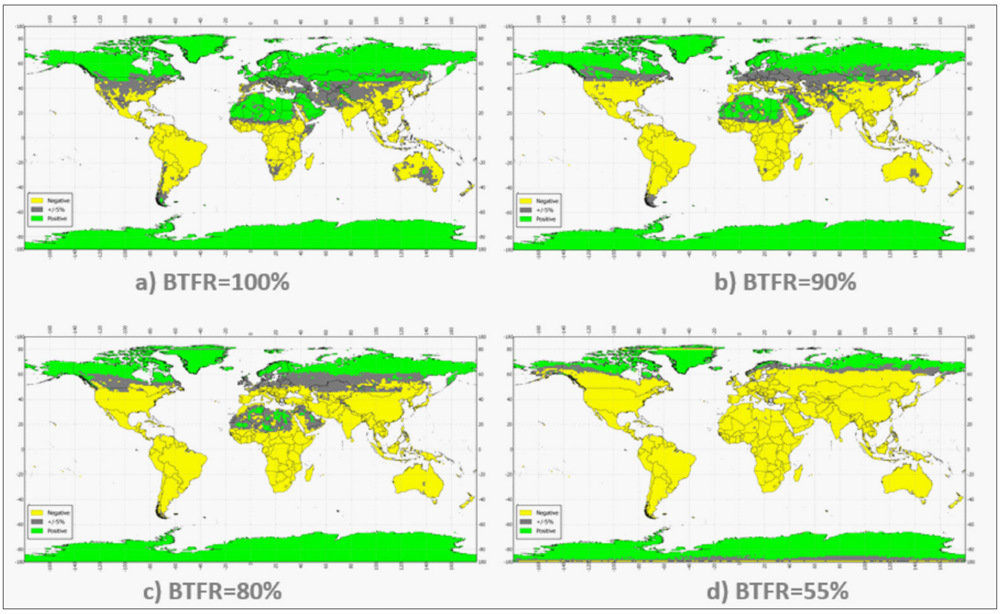


Figure 10. Effect of back-to-front ratio (BTFR) on the yield of vertical bifacial E/W oriented panels compared to monofacial equator-oriented tilted panels. The color is green when the gain is higher than 5%, yellow when the loss superior to -5% and grey otherwise

because tracking optimises the front-side irradiance and the relative contribution of the rear side is lower compared to the static case. A closer look on the different contributions to the energy gain, and the relation between them, is given in Table 4 that considers the case of a ground cover ratio (GCR) of 0.35 in Figure 11. It also gives the gain relative to the fixed tilt monofacial system.

There is no direct relation between the bifacial tracking gain (32.6%, in red) on one side, and the tracking gain of monofacial (23.5% in orange) and the bifacial gain on fixed tilt configuration (10.1% in green) on the other side. Nevertheless, it appears that the sum of the tracking gain of monofacial and the bifacial gain on fixed-tilt configuration gives a good approximation of the observed bifacial tracking gain. This observation has been verified for all GCR values and it has been confirmed by measurements performed at the ATAMOSTEC platform (see Figure 1), as shown in Table 5 for a tracked system with 44 modules. The tracking bifacial gain (44%) is almost equal to the gain of tilted bifacial (11%) plus the gain of the tracked monofacial (31%), both relative to tilted monofacial.

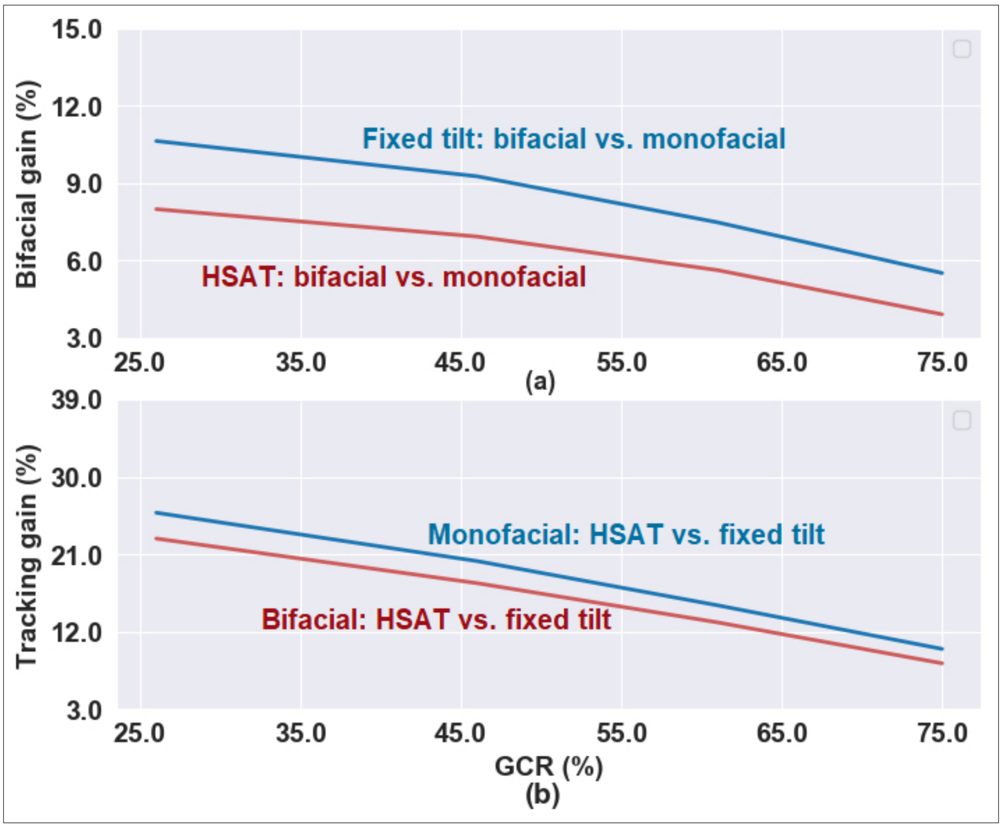


Figure 11. (a) Simulated bifacial gain of fixed-tilt and HSAT system as a function of ground cover ratio (GCR); (b) tracking gain for monofacial and bifacial systems. Gains obtained for a full year simulation with MoBiDig (2D-VF for the frontside and RT for the rearside)

Looking forward – what is next?

LCOE calculations

Coupling opto-electrical and LCOE models is quite a challenge. As a good example, SERIS Singapore used a Monte-Carlo approach on weather, module and cost parameters to compare the LCOE of fixed tilt, single-axis and dual-axis installations with either monofacial or bifacial modules. For single-axis tracking they considered both standard horizontal single-axis tracking (HAST) and tilted single-axis tracking (TSAT). For TSAT, the axis of rotation is tilted (usually at 30°) offering a better angle of incidence, mainly during winters, at higher geographical latitudes. SERIS' study showed that the lowest LCOE for 90% of all locations around the world is offered by bifacial-1T installations, as summarised in Table 6.

The table shows an LCOE reduction of 3% when using bifacial systems with respect to their monofacial counterparts. One-axis tracker systems achieve an average reduction on LCOE of about 14% compared with fixed-tilt systems, while double-axis systems suffer an increase of LCOE by 8%. The table also shows that yield gains from bifacial and tracking are cumulative. No soiling was considered in these simulations, nor in the vertical bifacial configuration that is a straightforward way to strongly reduce soiling.

Evolution of existing simulation tools

It is common practice in comparing PV test and measurement methods to do round-robin comparisons between different laboratories and different equipment and methodologies. This concept is currently applied, by comparing the numerous bifacial simulation models that have been developed within institutes and industries, within the IEA-PVPS-task 13: Bifacial PV Modeling Comparison. Some of these tools are already available as open source ('bifacial_radiance', 'bifacial_vf', 'pvfactors', 'PUB' model).

A common framework would facilitate the combined use of these tools by the PV community. The PV-LIB library [20] offers a

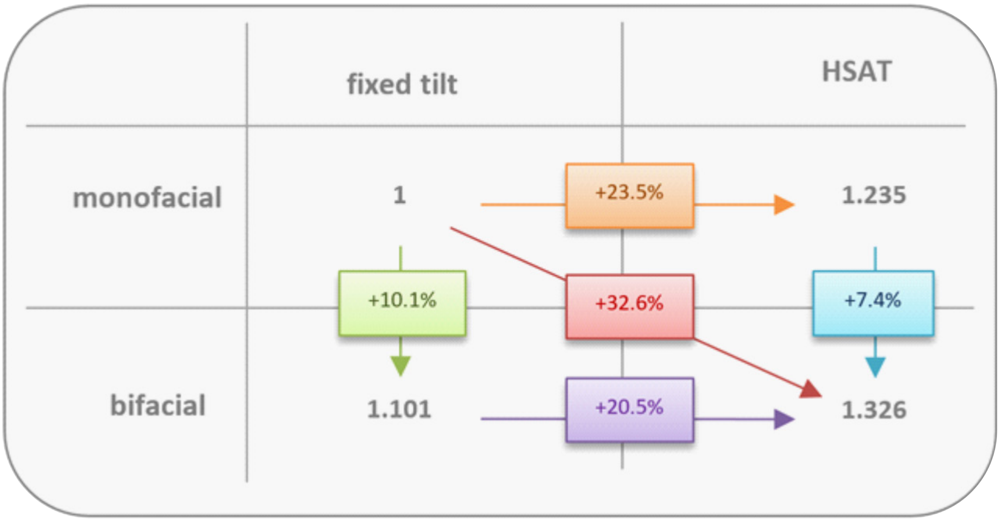


Table 4. Simulated comparison of normalised energy production of different configurations and the corresponding gains. Normalisation has been made (in grey) relative to the fixed tilt monofacial system from figure 11 with GCR = 0.35 (in colours)

Compared to equator-tilted monofacial	Gain
Equator tilted bifacial	11%
Tracking monofacial	30-31%
Tracking bifacial	44%

Table 5: Comparison of bifacial gain, tracking gain and bifacial tracking gain based on measurement data at the ATAMOSTEC platform [18]. The tracked system is a stand-alone tracker with 44 modules

Energy *LCOE*	Monofacial fixed-tilt	Bifacial Fixed-tilt	Monofacial 1-T	Bifacial 1-T	Monofacial 2-T	Bifacial 2-T
Monofacial Fixed-tilt	1 *1*	1.07 *0.97*	1.26 *0.86*	1.35 *0.84*	1.31 *1.08*	1.40 *1.04*
Bifacial Fixed-tilt	0.94 *1.03*	1 *1*	1.18 *0.89*	1.26 *0.87*	1.23 *1.11*	1.31 *1.08*
Monofacial 1-T	0.79 *1.16*	0.85 *1.12*	1 *1*	1.07 *0.97*	1.04 *1.25*	1.11 *1.21*
Bifacial 1-T	0.74 *1.19*	0.79 *1.16*	0.94 *1.03*	1 *1*	0.98 *1.28*	1.04 *1.24*
Monofacial 2-T	0.76 *0.93*	0.82 *0.91*	0.96 *0.81*	1.03 *0.78*	1 *1*	1.07 *0.97*
Bifacial 2-T	0.71 *0.96*	0.76 *0.93*	0.90 *0.83*	0.96 *0.81*	0.94 *1.03*	1 *1*

Table 6. Modelled comparison of energy yield (in blue) and LCOE (in red) of monofacial and bifacial systems at fixed-tilt, single-axis and double-axis tracking. The ratios compare the system in the column to the system in the row. Results for single-axis tracker installations refer to either horizontal (HSAT) or tilted (TSAT) configuration depending on which configuration gives highest energy yield in each particular location (adapted from [19])

set of functions and classes for simulating the performance of photovoltaic energy systems, including bifacial ones, and could be a solid basis for such initiative. Together with the standardisation of the variable names [21], initiated by SANDIA Labs, the convergence of existing bifacial tools would help accelerate bifacial installations by reducing yield prediction uncertainties. Finally, whereas VF and RT models have so far been the two main methods to model rear irradiance, new approaches are appearing that could become game changers for bifacial modelling. An example is the 'ray-casting' approach [22] that could offer both the precision of ray tracing and the short computation time of view factor-based modelling.

The future of bifacial PV systems

The majority of existing bifacial tools are not capable of simulating tilted single-axis tracker systems. TSAT systems produce more energy and may have a better LCOE than horizontal single-axis trackers at higher latitudes. Therefore, models predicting the behaviour of such systems are necessary to justify the acceptance of TSAT system configurations.

Module bifaciality is important, even more so for vertical installation. As SHJ modules (95%) and nPERT/TopCon modules (90%) offer significantly higher bifaciality than current PERC modules (80%) the higher €/Wp of SHJ and nPERT/TopCon modules in the end leads to a lower LCOE for vertical installation. Bifacial modelling tools are essential to determine what technology fits best to a certain location and system configuration.

Finally, some physical phenomena such as soiling, ageing due to UV, etc. still need to be investigated, both experimentally and numerically (using machine learning). Because energy yield modelling does not take into account soiling, the comparison with real data will give an indication of the relative losses induced by soiling and compare these losses to associated cleaning costs. The same holds true for other degradation mechanisms such as UV ageing along the years.

All these aspects are studied within the ATAMOSTEC project. The Atacama Desert presents some very specific conditions and is a perfect test field for soiling and UV degradation of bifacial systems of various configuration (vertical E/W, fixed tilt, tracking) and cell technologies (including SHJ). The outdoor facilities located in the Atacama Desert have already given promising results, with a 44% production gain with a tracking bifacial system compared to a fixed tilt monofacial one. This also allows validating bifacial modelling in a wide diversity of climatic conditions.

Conclusions

Bifacial technology and the estimation of its energy gain are rapidly evolving through improved modelling and measurement methodologies. The latter include the accurate measurement of site conditions, notably ground albedo. Ultimately modelling strategies will also allow staying on the same page with respect to measurement and test protocols as well as to reduce or understand uncertainties that affect bifacial project financing risks, in order to assure that these are at the same level as for monofacial projects.

Acknowledgements

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Turn to p.29 for insights into how inconsistencies in bifacial module technology are being tackled

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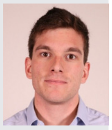

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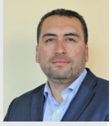

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