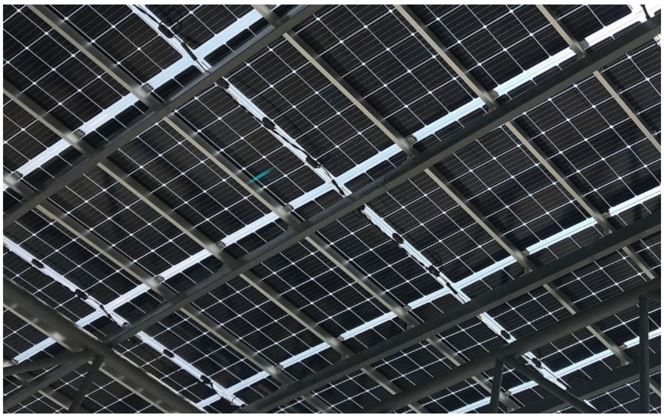
Jan 2019

Technical Briefing Note - Bifacial PV Technology



Introduction

This Technical Briefing Note provides an overview of bifacial PV technology, which produces power from both the front and rear surface. This technology is rapidly advancing in development and offers the potential for significant performance increases.

This note has been prepared to summarise the technology, explain advantages and disadvantages, discuss deployment issues, industry status, future trends, standardisation and performance.

In order to understand potential performance benefits a high-level energy yield and economic model was created by WSP to compare bifacial with conventional single sided (monofacial) PV technology.

Technology Introduction

Where conventional monofacial PV technology has an opaque backing, bifacial technology has a transparent back, usually glass, to allow the PV cells to benefit from diffused albedo light, thereby increasing performance. To make use of this additional light the PV cells are manufactured to increase the rear surface absorption, whilst also using a form of selective deposition to allow light between the rear contacts and onto the cell surface. This adds complexity and cost to the manufacturing process[i].

The first prototypes of bifacial PV technology were developed in the 1960s, but the high costs limited the viability of this technology[ii]. As the global PV market developed and manufacturing costs fell, circa 2010 the technology experienced a resurgence as manufacturers sought to differentiate their products and offer customers with higher performing products.

The majority of bifacial PV technology is currently offered in framed module format, though unframed laminates are also available. Bifacial modules prices have been falling rapidly and the gap between these and conventional monofacial, monocrystalline modules has narrowed, making them an attractive option to developers. Bifacial modules are now moving closer to the tipping point of commercial viability, moving from the early adopters to more widespread deployment.

Plant Layout

In order to maximise the benefits of bifacial technology, conventional plant layouts require adjustment as follows:

- Mounting structure heights should be raised to allow the rear surface to capture additional diffuse albedo light. A table height of up to 2 meters is common for bifacial, however heights between 1.0 - 1.5m have been seen to be optimum, with further increases offering diminishing returns[iii]. The increase in height also improves the homogeneity of the irradiance received on the rear surface, reducing mismatch losses[iv]. This increased height does, however, pose challenges for installation, cleaning, inspecting and replacements;
- The mounting structure and foundation also require new designs to reduce any obstruction to the rear surface, whilst also being strong enough to secure the heavier modules and greater wind loads expected;
- If using a fixed tilt mounting structure, a more aggressive tilt angle is common. This aggressive tilt angle aims to increase rear side exposure and promote diffuse albedo light; however, this will also increase the load experienced under high wind conditions and provide additional considerations for inter-row shading. Ultimately, true optimum tilt angle is project specific;
- Increasing the pitch (row to row spacing) also increases rear side exposure and promotes diffuse albedo by minimising inter-row shading.

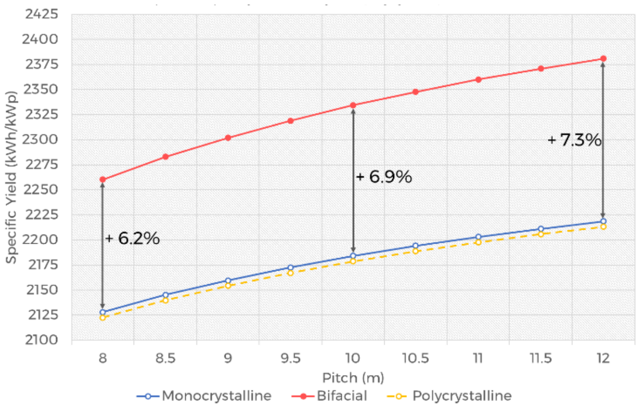


Figure 1 - Relationship between pitch and specific yield for identically modelled monofacial and bifacial indicative 25MW sites.

Figure 1 above illustrates the specific yield, which can be expected for an equivalent 370Wp mono/polycrystalline and bifacial PV module deployed in the same environment per annum. The increases in performance can be observed for the two technology types; as the pitch increases so do the relative gains in performance. A pitch of 10 meters provides a practical balance between performance and an increased plant footprint. Increasing the pitch beyond this distance creates spatial challenges for constrained sites and increases the Capital Expenditure (CAPEX) due to cabling, access roads, etc. beyond acceptable levels.

The greatest performance benefits for bifacial technology are seen when it is deployed in tracking systems. For Single Axis Tracking (SAT) systems, bifacial has been shown to provide superior production over monofacial, as this not only increases the front face production (the same as for monofacial), but also increases the rear side production as shading is reduced.

A comparison of the specific yield for bifacial technology in different environments was undertaken. Three sites were modelled (using industry standard simulation software PVSyst) for sites in the UK, Kenya, and Zambia. Figure 2 demonstrates that bifacial will likely benefit any project.

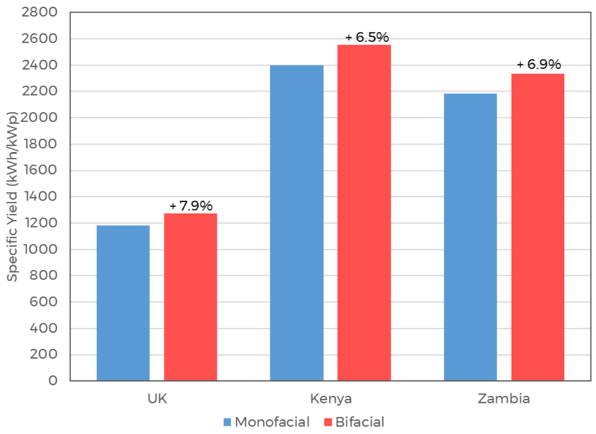


Figure 2 – Comparison of specific yield between monofacial monocrystalline & polycrystalline and bifacial

Albedo

Since albedo is such an influential factor when considering bifacial modules, measurement and characterisation of albedo is equally important. Albedo is defined as the ratio of reflected irradiance from a surface to total global irradiance received on a surface. It is dimensionless and expressed as a number between 0 and 1 (total absorption and total reflectance respectively). Typical albedo figures for various surfaces are shown in Figure *3*.

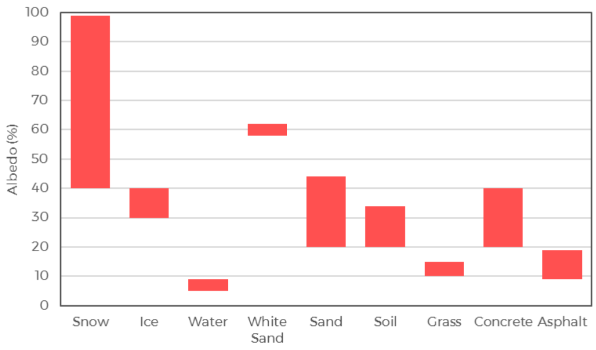


Figure 3 – Albedo value range for various common ground conditions

There are currently no international standards for the measurement of albedo, and hence there may be discrepancies in the values determined for a site (albedo is considered to have a negligible impact on monofacial modules and hence there was previously little importance placed on correctly accounting for it).

It is considered good industry practice to use an albedometer to measure albedo at a site. This consists of two pyranometers with one facing upwards (measuring horizontal global irradiance) and one facing downwards (measuring diffuse albedo light), with the data gathered providing an albedo ratio between 0 and 1. An important consideration is that albedo is a temporal value: it changes throughout the seasons and even throughout the day. Errors in assuming albedo values can result in significant errors (~5%) in real world bifacial gain[v]. This places greater necessity to gather granular site albedo data over an appropriate period of time (+1 year).

Conducting initial development stage Energy Yield Assessments (EYAs) using an appropriate value taken from Figure *3* is considered reasonable, however given that a small change to albedo (or even high uncertainty in the values used) can have a significant impact on plant performance, it is advisable to collect site-specific data.

Using the model simulations for the 3 sites, the albedo assumption value was incrementally increased to analyse the effect on bifacial modules. The percentage gain over the initial 0.3 albedo value for the 3 sites is shown in Figure 4.

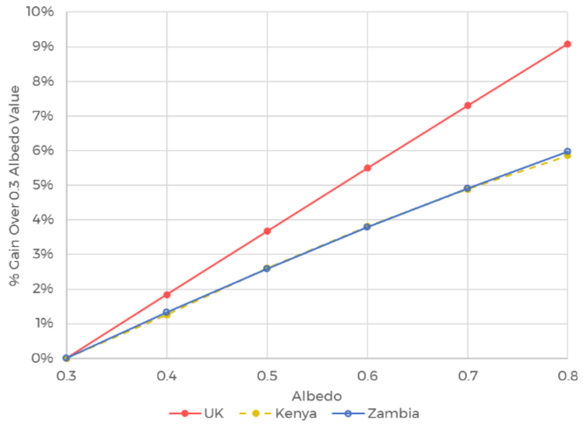


Figure 4 – Comparison of energy production percentage gain of increased albedo over a baseline of 0.3 for UK, Kenya, and Zambia sites using bi-facial PV modules.

These values demonstrate the significance of albedo in bifacial sites. If a site exhibits a naturally high albedo, or if cost-effective measures can be taken to increase it, then this should be done to maximise site yield. The graph also shows that sites further from the equator appear to experience higher albedo gains, which is presumed to be due to lower altitude of the sun and increased module tilt versus equatorial sites.

Model Simulation

WSP produced two EYAs for the purpose of comparing monofacial and bifacial plants. The EYAs were produced for an anonymised site in the MENA region with all the parameters the same, except for pitch (a 12m pitch would be suitable for bifacial, but would not be appropriate for a monofacial site layout).

Key site assumptions and inputs are shown in Table *1* below:

Input	Value	Unit
Plant Capacity AC	45	MWac
Plant Capacity DC	50	MWdc
DC:AC Ratio	1.1	
Mounting Technology	Single Axis Tracking	
Pitch (Row Spacing)	8 (monofacial) 12 (bifacial)	Metres
Yield Case	P50	
Module Degradation	0.45	% per year
Albedo	0.3	
Operating Life	25	Years

Table 1 – Key plant simulation inputs and assumptions

The specific yield in year 1 for the monofacial plant was estimated to be 2,128 MWh/MWp, and for bifacial, 2,381 MWh/MWp. This is an improvement of 11.9%. The results are shown in Table *2*:

Input	Mono.	Bi.	Unit
Year 1 Specific Yield	2,128	2,381	MWh/MWp
Specific Capacity Per Hectare (Ha)	143.97	106.13	MWp/MWh
Ground Cover Ratio (GCR)	50.0	33.3	%

Table 2 – key results from simulation of monofacial and bifacial sites

The ground-cover ratio referenced in Table *2* determines the percentage of the ground which is occupied, which is higher for monofacial as the rows are located closer together.

The modelling of bifacial technology in EYAs has limitations both in PVSyst and any other yield modelling software. These limitations are mostly due to the unproven performance of the technology, with insufficient data available to validate the models. The added complexity of accurately modelling diffuse albedo light can significantly affect the modelled performance. Reliance on data provided by manufacturers for incorporation into models also adds risk, as there is no universally accepted benchmark for comparison at the time of writing.

Economic Analysis

A simple economic model was created using the anonymised site to compare monofacial and bifacial PV plants. Standard assumptions are shown in Table *3* below:

Input	Value	Unit
Discount rate	7 %	
Tariff	45.00	USD/MWh
Annual OPEX escalation	2.0 %	
Debt to Equity	70 / 30	
Interest rate	7 %	
Debt repayment period	12	years
Total CAPEX Monofacial	690,000	USD per MWP
Total CAPEX Bifacial	726,000	USD per MWP

Table 3 – Key model inputs and assumptions for economic model

A simple site with an inexpensive grid connection and without significant constraints was assumed, for deployment in Q1-2 2019 and with export commencing at the end Q3 2019.

The inputs given are based on WSP market data gathered in Q4 2018, from comparable Tier 1 PV tender exercises at similar deployment timeframes.

Result	Mono.	Bi.	%
IRR	7.1%	9.0%	26.9
Payback (Years)	13	12	-7.7
Net generation (year 1) (MWh/yr)	106,400	119,050	11.9
LCOE (cents/kWh)	6.46	5.92	-8.4

Table 4 – Key economic model results for monofacial and bifacial sites, showing difference between

The economic model results are shown in Table 4. The CAPEX increase is attributed to the higher cost of bifacial modules, though a small increase in mounting structure and cable costs is also included. The increased generation from the bifacial plant results in higher revenue and hence a higher Internal Rate of Return (IRR). As a result, despite the higher CAPEX, the Levelised Cost of Electricity (LCOE) is lower for bifacial, meaning the site can be more competitive when negotiating a Power Purchase Agreement (PPA) tariff.

It is important to note that as bifacial technology emerges and establishes in the market, costs are likely to fall further, which will have significant impacts on future financial models.

International Standards

Bifacial modules are currently qualified under IEC 61215:2016, though this standard does not account for rear side generation. A test procedure for bifacial is currently being developed in IEC 60904-1-2, this standard proposes the procedure for the measurement of I-V characteristics of bifacial modules in natural or simulated sunlight. Until this standard and benchmarking process is set, making comparisons between products is difficult and performance claims require cautious scrutiny.

Future Trends and Applications

Future trends for bifacial include a very likely fall in price as the market develops and demand increases. This may also correspond to further reductions in monofacial pricing as existing manufacturers without bifacial capability look to maintain competitiveness and hold market share.

Bifacial manufacturers are already offering longer warranties (30 years) and reduced degradation rates, with this trend likely to continue.

Aside from locating bifacial technology in high albedo desert or snow type situations, applications may include flat rooftop installations with white reflective surfaces, car port roofs with reflective parking, floating solar power plants and combined agriculture situations allowing crop growth underneath.

In the second half of 2018 WSP has seen a rapid shift in developers proposing bifacial technology for future projects, with a number of open tenders in the Middle East and North Africa (MENA) region having been won with bifacial technology. These winning tenders have been at tariff levels far below the levels expected and far below conventional solar PV generation.

Caution is required, as the technology is still unproven over the longer term and deployment has not yet been at scale. Until this takes place, and validates performance and economic models, conservative investors and lenders appear to be holding back. In the meantime, some larger developers and manufacturers are taking a more optimistic approach, factoring in the risks and proceeding on the back of their balance sheets.

As a reminder that expectations should be managed, in 2018, a bid price of 1.78 cents/kWh for a 300MWp project in the Middle East with bifacial modules was rejected. The justification for this has not been released but it was widely reported that off-taker concerns over the unproven nature of the technology is likely[vi].

Advantages and Risks

The advantages and disadvantages of bifacial modules are summarised below:

Advantages	• Increased energy gain between 6 – 15% versus monofacial PV modules[vii] depending on the site location and local albedo; • Reduced quantity of modules required for the same rated power; • Glass backing has a lower permeability to moisture than monofacial backing materials, which reduces risk from Potential-Induced Degradation (PID); • Glass backing also increases the rigidity of the modules, offering better mechanical properties in wind and snow; • During morning and evening periods where direct irradiance on the module surface is low, the rear absorption of diffuse albedo light can increase performance[viii]. This also applies for cloudy days; • Favourable warranties compared to monofacial: 30 year lifetime warranty and 0.5% annual degradation are common; • As a result of the higher power production and falling costs, the Levelized Cost of Electricity (LCOE) may be lower than standard mono-facial designs.
Risks	• No plants have been operating for long enough to provide data for modelling validation and bankability metrics as of end of 2018[ix]; • Modules are heavier than monofacial, requiring a stronger mounting structure; • A more complex and higher mounting structure and cable layout is required to minimise rear-side shading; • Site selection is critical due to ground surface type and the corresponding albedo; • Bifacial require more spacing between rows, increasing plant footprint and subsequently increasing cable lengths. This contributes to a lower ground-cover ratio (GCR), which can be a crucial factor where land is expensive or limited. This can hurt a competitive PPA if considerable DC capacity must be removed to be able to fit the required capacity at a limited area; • Higher table heights required may result in difficulty in cleaning and maintenance, resulting in higher associated operational costs. There will also be additional costs to consider for cleaning the rear side of the module. Higher table also mean higher CAPEX cost for mounting structures and foundations; • Albedometers are to be installed with standard pyranometers throughout the facility to fulfil performance ratio (PR) guarantees. • Although the manufacturer's warranty is more favourable, it may be unclear how the degradation factors are calculated for bifacial since there are 2 absorption surfaces.

Table 5 – Advantages and disadvantages

If interested in discussing the above topics further, please contact:

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[i] Electric Power Research Institute, Bifacial Solar Photovoltaic Modules (2016)
[ii] https://solarprofessional.com/articles/design-installation/bifacial-pv-systems#.W9cXvGj7SM9
[iii] http://bifipv-workshop.com/fileadmin/layout/images/Konstanz-2017/9__C.Deline_NREL__bifi_modeling.pdf
[iv] http://bifipv-workshop.com/fileadmin/images/bifi/denver/presentations/5__Bailey-_simplified_method_to_approximate_mismatch_losses_bifiPV2018.pdf
[v] http://bifipv-workshop.com/fileadmin/images/bifi/denver/presentations/5__Bourne-_Albedo_measurements_bifiPV2018.pdf
[vi] https://www.pv-tech.org/editors-blog/bifacial-technology-was-likely-reason-worlds-lowest-ever-solar-bid-was-reje
[vii] https://solar-energy.energycioinsights.com/cxo-insights/bifacial-solar-modules-the-future-s-bright-but-how-bright-nwid-303.html
[viii] Webinar: Bifacial modules: Technology, application and field data. https://www.youtube.com/watch?v=XNsQGbYzihY
[ix] https://www.pv-tech.org/editors-blog/bifacial-bankability-metrics-need-to-shift-from-module-maker-to-mounting-pr