First Solar

Energy Yield Simulations

Module Performance Comparison for Four Solar PV Module Technologies

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Executive Summary

Arup has been appointed by First Solar to carry out an independent module performance comparison between First Solar modules and three other module technologies. The energy yield assessment has been completed for a hypothetical PV power plant at three different locations in South Africa and for both a fixed-axis and single-axis tracking mounting system. The three locations are Upington, Bloemfontein and Vryburg, which are all located in high irradiation regions of the country.

The fundamental approach used in comparing the module performance of the four selected module technologies, listed in Table 1, was to keep the system design parameters constant as far as possible and to only consider variables which are pertinent to the specific module.

PV Modules Selected for Analysis				
	First Solar	**Module 1**	**Module 2**	**Module 3**
Model Range	First Solar Series 4™	Not disclosed	Not disclosed	Not disclosed
Model Number	FS-4112A-2			
Nominal Rated Power (STC) [Wp]	112.5	310	310	310
Technology	Thin-film	Poly-crystalline	Poly-crystalline	Mono-crystalline

Table 1 PV Modules selected for analysis

The simulations were performed using PVSyst v6.34 software and considered the P50 energy yield probability for the first year of production.

Table 2 shows the overall results for all module technologies at all the locations for fixed-axis and single-axis tracking systems. The results show that the selected First Solar modules were estimated to produce the highest energy yield in all scenarios.

Average annual performance during year 1								
				First Solar – Thin Film Base Case	**First Solar – Thin Film** Excl. Spectral Adjustment	**Module 1 – Poly c-Si**	**Module 2 – Poly c-Si**	**Module 3 – Mono c-Si**
Bloemfontein	Fixed Tilt	Energy Yield	kWh/kWp	2 033	2 035	1 972	1 967	2 021
		PR	%	84.2%	84.3%	81.7%	81.4%	83.7%
	Tracking	Energy Yield	kWh/kWp	2 373	2 376	2 298	2 292	2 349
		PR	%	81.0%	81.1%	78.4%	78.2%	80.2%
Upington	Fixed Tilt	Energy Yield	kWh/kWp	2 078	2 091	2 015	2 008	2 069
		PR	%	82.3%	82.8%	79.8%	79.5%	81.9%
	Tracking	Energy Yield	kWh/kWp	2 472	2 486	2 388	2 378	2 448
		PR	%	79.5%	80.0%	76.8%	76.5%	78.7%
Vryburg	Fixed Tilt	Energy Yield	kWh/kWp	2 021	2 011	1 945	1 939	1 995
		PR	%	84.2%	83.7%	81.0%	80.8%	83.1%
	Tracking	Energy Yield	kWh/kWp	2 384	2 374	2 293	2 286	2 345
		PR	%	80.9%	80.5%	77.8%	77.5%	79.5%

Table 2: Summary of average performance during the first year of operations

1 Introduction

Under the terms of our Technical Services Agreement with First Solar (the *Client*), Arup has been tasked by First Solar to carry out an independent module performance comparison between First Solar modules and three other module technologies (the make and model of these three modules is not disclosed in this report). The energy yield assessment has been completed for a hypothetical PV power plant in three different locations in South Africa and for both a fixed-axis and single-axis tracking mounting system.

This report summarises the methodology, assumptions, results and conclusions associated with the comparison.

2 Project Locations

The three locations considered in this analysis are Upington, Vryburg and Bloemfontein, which are situated in high irradiation regions within South Africa, as shown in Figure 1 below. These locations were identified by the Client and they represent a range of temperature conditions in peak irradiation areas.

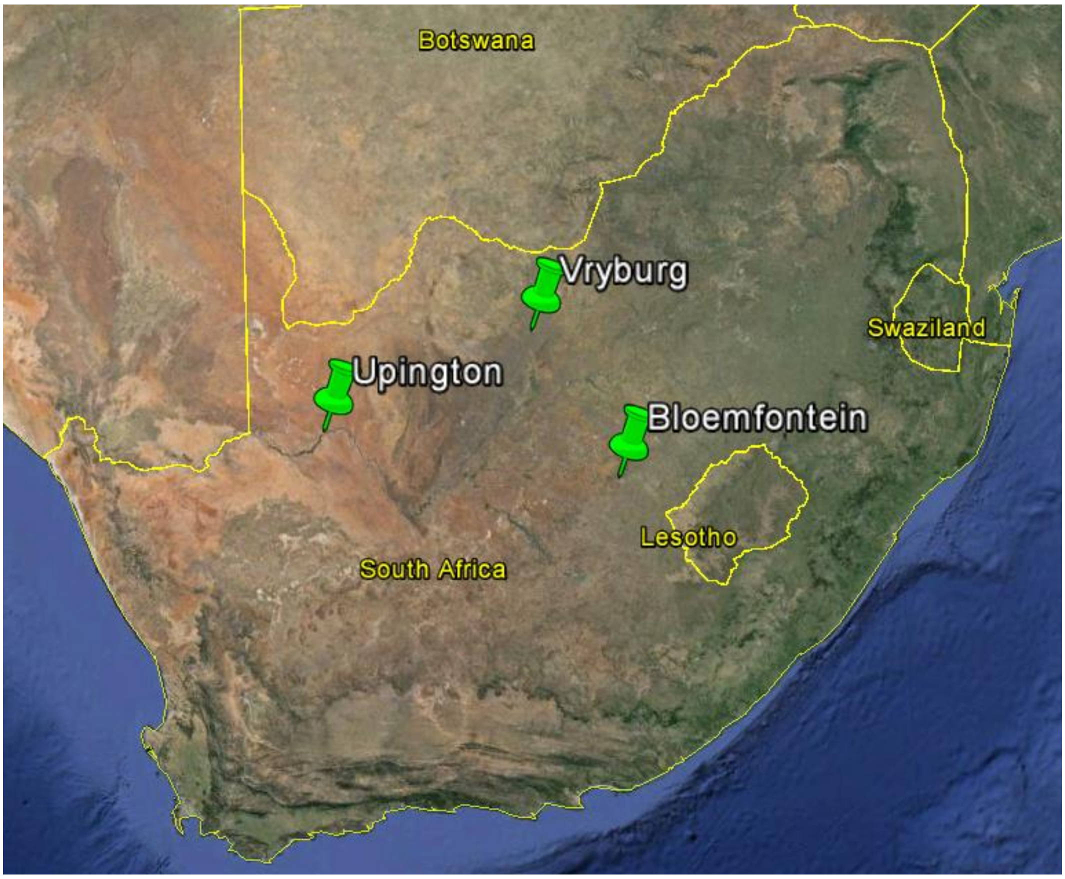


Figure 1: Three project locations considered in the analysis

3 Simulation Method

The analysis comprised of 24 energy yield simulations where the P50 energy yield probability for the first year of production was considered for examination.

The fundamental approach to comparing the module performance of the four selected module technologies was to keep the system design parameters constant as far as possible and to only consider variables which are pertinent to the specific module.

The detailed inputs and result for each simulation are included in Appendix B.

3.1 Simulation Software

The simulation process was undertaken by Arup using the industry standard PVSyst V6.34 software package. Figure 2 below describes the simulation process which is followed by PVSyst in order to calculate the expected energy generated by the PV facility.

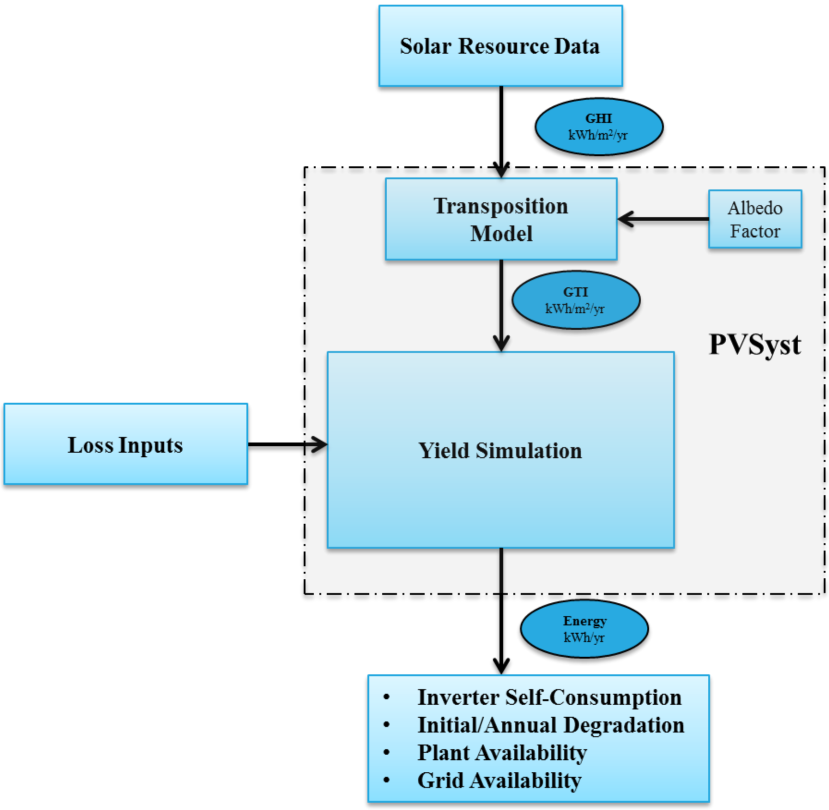


Figure 2: PVSyst simulation process

3.2 Meteorological Data

Arup has used Meteonorm version 7 to derive hourly irradiation and temperature readings for each site.

The Meteonorm data has been compared to the solar resource values from NASA-SSE, PVGIS-Helioclim and PVGIS-SAF databases in order to verify that the dataset is applicable to each site. Meteonorm data is gathered by interpolating results from records of the nearest weather stations, and using satellite data where weather station records are not available. NASA-SSE, PVGIS-Helioclim and PVGIS-SAF data is sourced from satellite records.

The periods over which solar weather data has been gathered for each source is as follows:

- Meteonorm: 1986 - 2005
- NASA-SSE: 1983 – 2005
- PVGIS-Helioclim: 1985 – 2004
- PVGIS-SAF: 1998-2005 and 2006-2010

All module technology simulations at each location utilised the same meteorological data file for consistency.

3.2.1 Global Horizontal Irradiation

The Global Horizontal Irradiation comparison between the three locations and four data resources is shown in the Table 3 below.

Annual Global Horizontal Irradiation (kWh/m²/)							
	Meteonorm 7	PVGIS-SAF	Diff (%)	NASA SSE	Diff (%)	PVGIS-HC	Diff (%)
Upington	2,283	2,290	0.3%	2,140	-6.2%	2,159	-5.4%
Vryburg	2,194	2,188	-0.3%	2,097	-4.4%	2,162	-1.4%
Bloemfontein	2,170	2,122	-2.2%	2,067	-4.7%	2,155	-0.7%

Table 3: Comparison of Meteonorm, PVGIS-SAF, NASA-SSE and PVGIS – Helioclim annual global horizontal irradiation data

The value for the annual global horizontal irradiation provided by Meteonorm for all locations is within 2.2% of PVGIS-SAF, 6.2% of NASA-SSE, and 5.4% of PVGIS-Helioclim data. These differences are within a reasonable range and the Meteonorm data is thus considered appropriate to be used for the yield simulation.

Arup have chosen to use the Meteonorm data for each yield simulation as it is considered to be a more robust data source, and the uncertainty associated with the global horizontal irradiation is considered to be less than for the other three data sources.

Figure 3 below shows the close correlation between Meteonorm 7 data and the other three sources for each location.

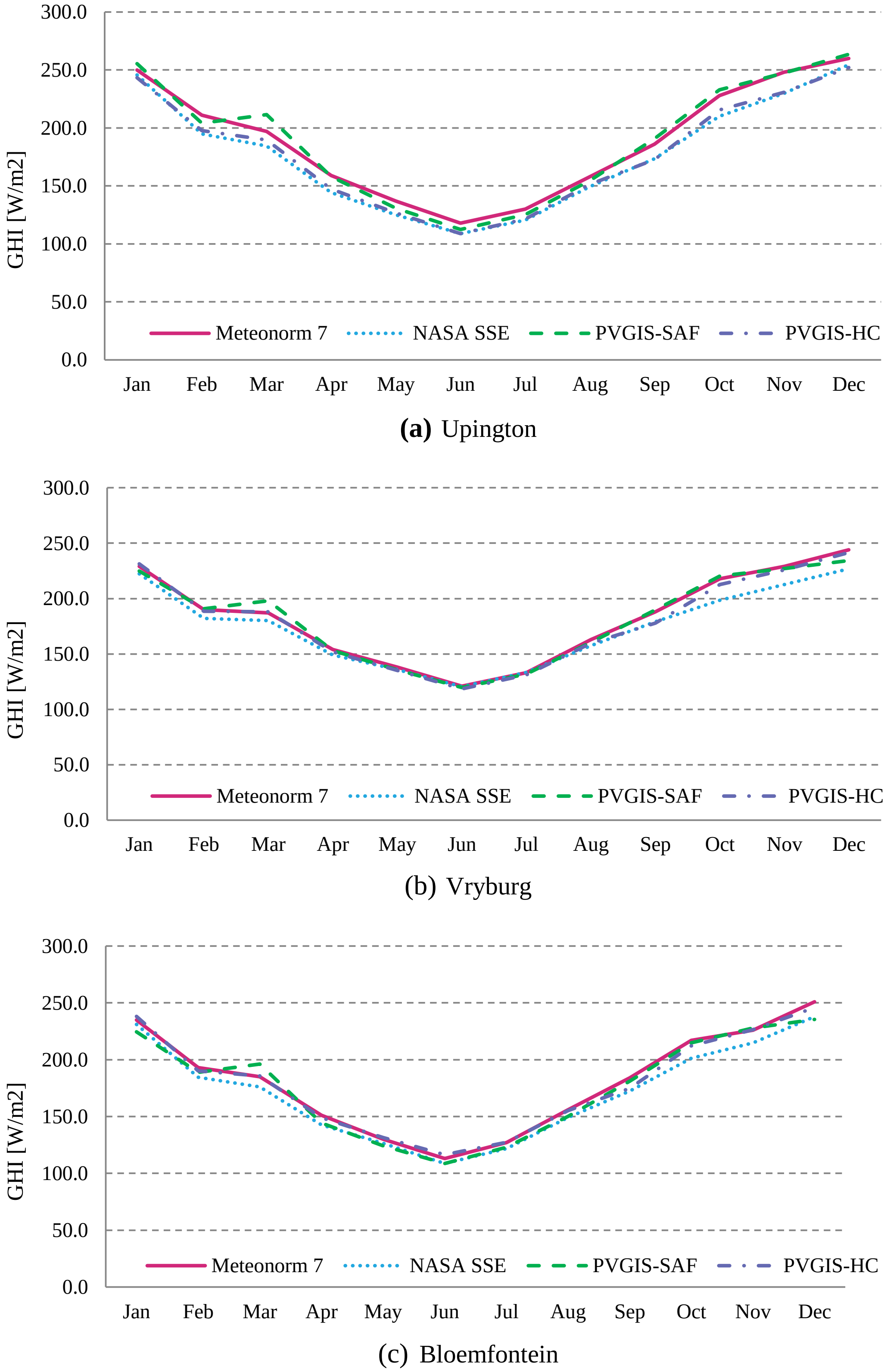


Figure 3: Comparison of monthly irradiance data for Upington, Vryburg and Bloemfontein

3.2.2 Temperature Data

The temperature data used in Arup's yield analysis (Table 4) has been obtained from Meteonorm over a period of 10 years (2000 – 2009) and verified with NASA-SSE data. From the data provided, it can be seen that Upington has the highest annual average temperature of the three sites, followed by Vryburg and then Bloemfontein.

	Meteonorm V7 (°C)		
Month	**Upington**	**Vryburg**	**Bloemfontein**
Jan	28.3	24.4	22.5
Feb	28.3	24.0	22.0
Mar	25.5	22.1	19.6
Apr	21.5	19.0	15.5
May	16.6	15.2	10.9
Jun	13.1	12.5	8.0
Jul	13.0	12.0	7.3
Aug	15.0	15.2	10.8
Sep	18.8	19.1	14.8
Oct	23.3	22.3	18.8
Nov	25.4	23.2	20.3
Dec	27.8	24.6	22.4
Year	**21.4**	**19.5**	**16.1**

Table 4: Temperature data for the three project locations

4 Design Assumptions

4.1 Facility Specifications

The technical specifications of the PV facility are described in the sections below under the subcategories of PV Modules, System Design Characteristics and Substructure Characteristics.

Full details for each individual simulation (excluding comparison module make and model information) as well as the PVSyst output report are included in Appendix B.

4.1.1 PV Module Characteristics

Table 5 provides the technical parameters for the four module technologies.

The First Solar module selected for the analysis was the 112.5Wp thin-film module, which was proposed by First Solar.

The module manufacturers for the other module technologies were preselected by First Solar and are typical suppliers in the market, which will be referred to as ‘Module 1’, ‘Module 2’ and ‘Module 3’.

Two poly-crystalline (‘Module 1’ and ‘Module 2’) and one mono-crystalline module (‘Module 3’) were selected from the current catalogues of the module suppliers. The nominal capacity of each of these technologies was selected as 310Wp based on module capacities currently being used in the local industry and what is available on the supplier databases.

PV Module Characteristics				
	First Solar – Thin Film	**Module 1 – Poly c-Si**	**Module 2 – Poly c-Si**	**Module 3 – Mono c-Si**
Model Range	First Solar Series 4™	Not disclosed	Not disclosed	Not disclosed
Model Number	FS-4112A-2			
Nominal Rated Power (STC) [Wp]	112.5	310	310	310
Sorting Tolerance	0-2.5W	0-3%	0-3%	-3/+5%
Module Efficiency at STC [%]	15.62	15.98	15.98	19.06
Temperature Power Coefficient [%/°C]	-0.34	-0.41	-0.42	-0.38

Table 5: PV Module Characteristics for the four module technologies

4.1.2 System Design Characteristics

The PV system was designed to maintain consistency of all system parameters across the four simulations as far as possible. Table 6 below shows the system design characteristics for each technology.

The inverter selection for all module simulations was predefined by First Solar as the 800kW SMA Sunny Central Inverter (SMA 800CP XT). SMA is a globally renowned inverter supplier and the selected model range is commonly used for local utility scale solar PV projects.

The total AC capacity was designed to be as close to 75MWac as possible. This resulted in an AC capacity of 75.2MWac based on the use of 94 inverters per project. The DC/AC Ratio was maintained at 1.12 for all simulations, resulting in a DC capacity of c. 84MWp.

The module-string configuration for each module choice was optimised so that the Open-Circuit Voltage (V_{OC}) was as close to the maximum inverter input voltage of 1000V as possible. Note that this resulted in the number of modules per string for First Solar and 'Module 3 – Monocrystalline' modules being lower than that for 'Module 1 – Polycrystalline' and 'Module 2 – Polycrystalline' due to the higher Open-Circuit Voltages applicable to these modules.

System Design Characteristics				
	First Solar – Thin Film	**Module 1 – Poly c-Si**	**Module 2 – Poly c-Si**	**Module 3 – Mono c-Si**
Nominal Capacity (DC) [kWp]	84,000	83,997	83,997	84,001
Inverter Capacity (AC) [kW]	75,200			
DC/AC Ratio	1.12			
Number of PV Modules	746,670	270,959	270,959	270,970
Number of Inverters	94			
Modules per String	10	19	19	14
Open-circuit Voltage (V)	952	973	959	986

Table 6: System Design Characteristics

4.1.3 Substructure Characteristics

Table 7 below shows the substructure characteristics for the fixed-axis and single-axis tracking substructures for all technologies at the various project locations.

Substructure Characteristics		
Parameter	**Fixed Tilt**	**Tracking**
Orientation	0° (North Facing)	0° (North - South Axis)
Shading Limit Angle	23° (At module tilt angle)	23° (At a maximum module tilt angle of 45°)
Module Tilt Angle: - Bloemfontein - Upington - Vryburg	 26° 25° 24° (Optimized for site locations)	- 45° to + 45°
Module Layout	4 high in landscape	4 high in landscape
Backtracking Control	-	Applied to all module technologies except for First Solar modules

Table 7: Substructure Characteristics

Shading Limit Angle:

The row spacing (pitch) for each technology was chosen such that the shading limit angle for each system was uniform in order to normalise shading losses.

The shading limit angle, as shown in Figure 4, is the minimum angle of the sun from which mutual shading of PV sheds begins. This varies between different facilities due to land constraints, which may require that arrays are located closer together, and the requirements for electrical cable losses that would be too high with excessive row spacing. For the fixed-axis systems a shading limit angle of 23° has been selected. This is within the range of that used typically on utility scale projects in South Africa.

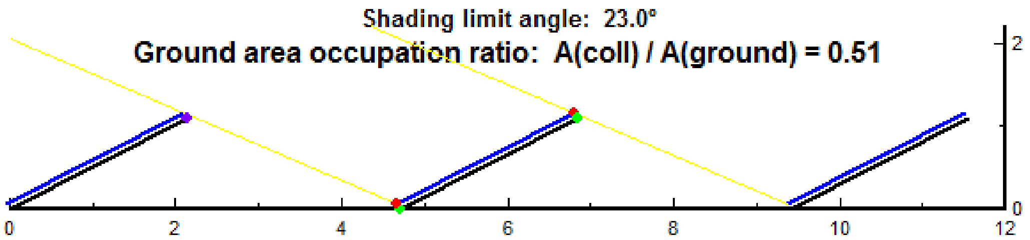


Figure 4: Calculation of shading limit angle[1]

For tracking systems, a shading limit of 23° was also used to determine the pitch by applying the angle to the tracking system at its maximum rotation of 45°. Similarly this angle has been selected by considering rotation angles typically used in the region.

Module Tilt:

The PV module tilt angle for the fixed-axis systems was optimised for each site and kept constant for all modules technologies at each site. The optimisation process took into account the

[1] Figure taken from PVSyst V6.34

point of maximum annual irradiation when considering the inter-row shading defined by the shading limit angle.

The tracking system rotation angle was specified by First Solar at -45° to 45° and maintained for all sites. This is a common range for tracking systems.

Module Layout:

The module layout of an array influences the string layout, which plays a role in the simulation of the electrical loss due to shading[2].

Typically in a fixed axis system, modules are positioned up to four modules in landscape or two modules in portrait. In this study all modules were modelled as four high in landscape, which is the common First Solar approach.

The tracking simulations have also been modelled as four high in landscape. This is used for First Solar, but is not common for other modules that generally use one in portrait or two in landscape. However, in terms of an energy yield analysis this approach is acceptable as backtracking controls are applied to the other PV technologies to prevent direct shading. This minimizes the electrical effect due to shading on the crystalline modules.

Backtracking:

Backtracking is used to prevent direct shading on modules typically during the early morning and later afternoon hours. The process involves reducing the tilt angle of the modules to prevent shading. It is primarily beneficial to alleviate electrical effect losses in crystalline modules.

Thin film modules, such as First Solar, are not affected by the electrical effect when orientated correctly. Thus in this case the greatest energy yield can be obtained by excluding backtracking controls. Further details on the electrical effect and backtracking functionality are provided in sections 4.2.2.3 and 4.3.1 respectively.

[2] See section 4.2.2.3 for a description of the electrical loss due to shading

4.2 Model Inputs

Table 8 below describes the modelling inputs used to perform the energy yield simulations for each of the module technologies. A detailed explanation of certain user-defined inputs is provided in the sections to follow.

Modelling Inputs					
		First Solar	**Module 1 – Poly c-Si**	**Module 2 – Poly c-Si**	**Module 3 – Mono c-Si**
Inclined Irradiation	Transposition Model	Hay: First Solar recommend using the Hay transposition model to convert from horizontal irradiation to in-plane irradiation. The same model has been used for all module types for consistency.			
Shading and Reflection	Shading Model	Shading model built in PVSyst as per system configuration.			
	Horizon shading loss	Calculated in PVSyst v6.34 Horizon obtained from Meteonorm v7			
	Structure shading loss	Calculated in PVSyst v6.34			
	Reflection loss (IAM factor)	Module specific IAM profile provided by the manufacturer.	Module specific IAM profile provided by the manufacturer.	IAM *bo* parameter 0.04 applied in PVSyst to generate the IAM profile based on recommendation from manufacturer.	Module specific IAM profile provided by the manufacturer.
	Soiling loss	Consistent monthly soiling loss applied for each module type.			
PV Modules	Monthly spectral adjustment	Monthly Spectral Adjustment applied as per First Solar documentation PD-5-423 REV 2.1 - Module Characterization Energy Prediction Adjustment for Local Spectrum.	No adjustment applied as not part of manufacturer energy modelling recommendations.		

Modelling Inputs

		First Solar	Module 1 – Poly c-Si	Module 2 – Poly c-Si	Module 3 – Mono c-Si
PV Modules (Cont.)	PV loss / gain due to irradiance level	Calculated in PVSyst v6.34			
	Thermal losses	Thermal loss factor applied: 30.7 W/m² Based on recommendation of manufacturer	Thermal loss factor applied: 29.0 W/m² Standard Assumption	Thermal loss factor applied: 29.0 W/m² Standard Assumption	Thermal loss factor applied: 29.0 W/m² Based on recommendation of manufacturer
	Shadings : electrical loss	No Electrical Effect Applied. Linear shading used due to thin film module characteristics in orientation.	80% Electrical Effect applied to account for shading of string cells.		
	DC health factor loss	-1% Generic loss applied to account operational losses due to aspects such as faulty module connections, blown fuses and defective modules.			
	Power sorting tolerance adjustment	+0.6% Gain has been applied due to modules being positively sorted with a tolerance of 0-2.5W (0 - 2.2%).	+0.8% Gain has been applied due to modules being positively sorted with a tolerance of 0-3%.	+0.8% Gain has been applied due to modules being positively sorted with a tolerance of 0-3%.	0.5% Gain has been applied due to modules having a tolerance of +5/-3%
	Module array mismatch loss	-1% Generic loss applied to account for modules with differing I-V curves.			
	DC Ohmic wiring loss	-1.5% Generic loss applied. String lengths would be different with different module types due to the different open circuit voltage characteristics. However, for this analysis this has been kept constant and is assumed to be a design specification.			
AC electrical components	Inverter efficiency loss	Calculated in PVSyst using inverter file created according to latest datasheet for SMA 800CP XT			
	AC Ohmic wiring loss	-0.5% Generic loss applied. Considered for this analysis to be a design specification.			
	Transformer resistive loss	-1% Generic loss applied as not affected by module choice.			
	Transformer iron loss	-0.1% Generic loss applied as not affected by module choice.			
Operational Losses	Grid curtailment	Not considered			
	Self-consumption	580MWh Approximated from specified inverter auxiliary consumption of 1900W at rated capacity applied for 8 hours per day and night-time consumption of 100W applied for 16 hours.			

Modelling Inputs					
		First Solar	**Module 1 – Poly c-Si**	**Module 2 – Poly c-Si**	**Module 3 – Mono c-Si**
	Plant availability	Not considered			
	Grid availability	Not considered			
Degradation	Ave Year 1 Degradation (i.e. average of degradation at start and end of year)	0% No degradation has been applied during year 1 as manufacturer has confirmed that this has been taken into account already in the specified power rating during. This is consistent with the manufacturer recommended modelling guidelines.	-1.3% Generic average first year degradation for polycrystalline modules has been applied.	-1.3% Generic average first year degradation for polycrystalline modules has been applied.	-0.16% Based on reported findings by independent consultant commissioned by manufacturer.

Table 8: Modelling inputs for PVSyst yield simulations

4.2.1 Shading and Reflection

4.2.1.1 Shading: PVSyst Model. Horizon and Structure

The shading model, created in PVSyst as a 3D model, is based on the substructure design of the PV system for each module technology at each location.

Potential horizon shading affects have been analysed using Meteonorm v7. It was found that there are no significant horizon shading losses at any of the sites.

4.2.1.2 Reflection Loss

Reflection losses are due to the incidence angle at which the sun is entering the atmosphere and striking the surface of the panel. At incidence angles which are not normal to the atmospheric layer or to the panel there will be a certain degree of reflectance. This loss is based on an Incidence Angle Modifier (IAM) for various angles, which is often estimated as follows:

$$IAM = 1 - bo\left(\frac{1}{cosi} - 1\right)$$

First Solar, ‘Module 1 – Polycrystalline’ and ‘Module 3 – Monocrystalline’ have been contacted and provided predefined IAM factors, while ‘Module 2 – Polycrystalline’ has recommended a *bo* value of 0.04.

4.2.1.3 Soiling Loss

Soiling losses are dependent on the site conditions and the frequency that the modules will be cleaned. For this analysis, soiling losses have been estimated based on monthly precipitation levels. The precipitation values were obtained from Meteonorm v7 database and the resultant monthly soiling loss values were computed according to the loss scale shown in Table 9.

Monthly Precipitation [mm]	Soiling Loss
0-20	3%
20-50	2%
>50	1%

Table 9: Soiling Loss Scale

Note that for the First Solar modules, a monthly spectral loss adjustment has been applied as a system input combined with the soiling loss since there is no specific input in PVSyst for this adjustment. The revised monthly soiling loss values are a sum of the monthly spectral loss and the monthly soiling loss. Further details of this process is described in section 4.2.2.1.

4.2.2 PV Modules

4.2.2.1 Monthly spectral adjustment

PV modules respond differently to different spectral distributions of irradiation. This spectral distribution is site specific and varies based primarily on the amount of water vapour in the atmosphere together with dust, ozone and other particles.

Modules are rated at Standard Test Conditions (STC), which assumes a standard spectral distribution defined by ASTM G173[3]. Thus the performance of modules under different spectral distributions (which occur in practice) will differ from these conditions.

First Solar have studied this effect and recommend a methodology for estimating adjustments due to the spectral distribution to model their modules more accurately (See modelling note below).

It is understood that this effect has less of an influence for crystalline modules and it is thus not deemed necessary to apply in the model. The crystalline manufacturers have not defined specific adjustments required for their modules.

Thus Arup have followed current module manufacturer applied spectral adjustments to the First Solar simulations as a base case and excluded these from the remaining crystalline modules. However, the First Solar results with the spectral adjustment removed are also presented as a sensitivity test.

[3] ASTM G173 *"Standard Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface"*

PVSyst modelling note:

The monthly spectral adjustment is applied to First Solar modules in accordance with the modules deviation from site-specific spectral irradiance from STC. The adjustment is known as a spectral shift factor (M) and it is approximated on a monthly basis from the hourly relative humidity (RH) and ambient temperature values as prescribed in First Solar's documentation (PD-5-423 REV 2.1) entitled: Module Characterization Energy Prediction Adjustment for Local Spectrum.

For use in PVSyst, the hourly shift factors are irradiance weighted and averaged for each calendar month to yield aggregate monthly spectral shift factors. As per PVSyst loss notation, positive M values denote a loss in energy due to spectrum while negative values denote an energy gain. The monthly spectral shift factors are incorporated into PVSyst with the monthly soiling loss values, calculated in the process described in section 4.2.1.3**. Once the monthly soiling loss and spectral shift values are added together, an adjustment is made to the DC health (module quality) loss so that the most negative monthly combined spectral and soiling loss value (if applicable) is zero. In this way, the criteria of a non-negative soiling loss is maintained in PVSyst and the offsetting of the additional spectral loss parameter is transferred to the DC health loss.**

4.2.2.2 Thermal Loss

PV module performance decreases with increases in temperature. The loss is based on the module's power temperature coefficient presented in Table 5 and the field thermal loss factor.

The thermal loss factor is the rate of module heat loss and is due to the effects of convection around the panels, which reduces the temperature of the modules and improves performance.

First Solar has recommended using a constant loss factor of 30.7 W/m^2 for their modules. This is marginally greater than the PVSyst default of 29.0 W/m^2 for "Free" mounted modules with air circulation. However, noting that this recommendation was based on comparisons with operational data[4] and that thin-film modules are constructed differently to typical crystalline modules, the manufacturer's recommendation was considered reasonable.

The manufacturer of 'Module 3' has recommended the use of the standard 29.0 W/m^2 value with their modules and this has been maintained for 'Module 1' and 'Module 2'.

4.2.2.3 Shading: Electrical Loss

Typical crystalline modules consist of a number of cells connected in series. The electrical effect is the loss that occurs when one or more of these cells experiences shading, which limits the current flow through all other cells in the series.

The effect of string shading is approximated in PVSyst by considering when a string of modules experiences shading. A shading loss modelled 100% "according to module strings" will provide the most conservative upper limit for shading losses whereas a shading loss model which measures the linear effect[5] will represent a lower limit. Arup have applied a typical estimate of an 80% electric effect loss for the simulations of the alternative crystalline modules.

The electrical effect is not applicable to thin film modules, such as the First Solar modules, if they have been orientated correctly. These effectively consist of thin long cells running the entire width of the modules. Thus in landscape orientation each cell in the module has an equal amount

[4] See First Solar's documentation PD-5-301-04 SS v1.1 entitled *"Series 4 System Parameter Specification for PVSYST"*

[5] Linear effect refers to a linear relationship between the proportion a module is shaded and energy yield.

of shading i.e. there are no cells completely shaded, which are connected in series to cells that are not shaded. This means that the shading is linear and no additional electrical effect applies.

4.2.2.4 DC Health Loss

The DC Health Factor Loss is considered to be a steady-state performance loss, which accounts for faults such as:

- Under-performing strings due to module connection issues;
- Blown fuses;
- Defective modules;
- In-homogeneities due to temperature gradients; and
- MPPT tracking efficiency on system performance.

The 1% DC Health factor loss was applied all module technologies, given that it is applicable to all types of PV modules.

4.2.2.5 Power Sorting tolerance adjustment

The power sorting tolerance adjustment was based on specifications from each module manufacturer on how modules are sorted according to a certain power margin.

This adjustment was applied to account for variances between the flashed DC capacity of the facility and the nominal capacity, as typically facilities with positively toleranced modules have a flashed DC capacity greater than the nominal capacity.

First Solar (0-2.5W), ‘Module 1’ (0-3%) and ‘Module 2’ (0-3%) use a positive power tolerance, while ‘Module 3’ (-3% to +5%) has a negative to positive tolerance scale that results in a ‘net positive’ tolerance.

The calculation of the power sorting tolerance adjustment has been estimated based on net power tolerance of the module reduced by a factor of 4/15, commonly used for modules as a default value in PVSyst.

4.2.2.6 DC Ohmic wiring loss

The total cable loss between the modules and inverters is related to cable length and thickness / type.

As discussed in section 4.1.2 the number of modules per string varies between each module type due to varying open-circuit voltage characteristics. In addition, due to the varying module efficiency, the array sizes differ as well as the overall size of the facility.

Thus if identical string and other DC cables were used for each configuration it is likely that the associated losses would differ.

In this analysis Arup has taken a simplified approach and assumed that each configuration is to be designed to a specified DC loss of 1.5%.

We note that this excludes economic considerations from the analysis, as cable thickness would likely vary between these configurations in order to meet the specification, and the cost of the cables is influenced by the cable size.

4.2.3 AC Electrical Components

4.2.3.1 AC Ohmic wiring loss

AC cable losses occur between the inverters and the point of utility connection. If uniform cables are used for each facility, the losses will likely differ due to the different size of each facility. However, this difference is likely to be relatively small.

Arup has taken the same approach as for the DC cable losses and applied a constant 0.5% AC loss, which was considered as a design specification.

4.2.3.2 Transformer losses

Standard estimates for the transformer iron eddy-current loss (0.1%) and resistive/inductive losses (1%) have been applied for all technologies.

4.2.4 Operational Losses

4.2.4.1 Self-consumption

Central inverters consume additional energy to power the auxiliary systems such as cooling fans. This is typically not included in the specified efficiency on the data sheet.

Arup have approximated the inverter self-consumption based on the operating information provided in the SMA 800CP XT datasheet. The total annual self-consumption was calculated based on 8 hours of operation at maximum self-consumption at 1900W during the day and 16 hours of night time self-consumption at 100W, which equates to 580MWh/year. This has been applied to all technologies.

Self-consumption from plant lighting, security, office power, and the tracking system, where applicable, are expected to be low comparatively and have not been considered in this analysis.

4.2.4.2 Degradation

First Solar have provided confirmation that the recorded capacity of each module includes the first year degradation. Thus degradation was excluded from the yield simulations of these modules.

The manufacturer of ‘Module 3 – Monocrystalline’ commissioned a report by an independent consultant, which indicates that these modules show minimal degradation at 6 months and relatively low degradation after one year of operation of 0.33%. Arup have used this result to apply a degradation of 0.16% as the average rate over the first year.

For typical polycrystalline modules such as those considered for ‘Module 1’ and ‘Module 2’, there are varying reports on the initial and annual degradation. Arup have previously obtained data from similar manufacturers that indicate degradation after the first year of operations to range between 1.5% and 4.5%, although the latter is conservative and significantly worse than that in the warranty (typically 2.5% after one year). Further references indicate degradation during the first year of between 1% and 3.5%[7]. Consequently, an average degradation of 1.3% was applied for the first year.

7 See for example:

- Pingel et al, *“Initial Degradation Of Industrial Silicon Solar Cells In Solar Panels”;*

4.3 Model Outputs

The following sections discuss specific system performance outputs calculated in PVSyst for all the simulations.

A summary of the outputs for each site is included in Appendix A and full results for each simulation are included in Appendix B.

4.3.1 Shading

The system performance affected by shading is based on the structure shading loss as well as the electrical loss due to shading. The structure shading loss is calculated by PVSyst by simulating the motion of the sun in hourly time-steps. This is a simple geometric calculation which will determine which portions of the arrays are in shade during each time step.

Fixed axis:
When considering the calculated loss results of fixed-axis systems, there is a constant structure shading loss across all the technologies for each site. This is expected as a constant shading angle was applied to all systems[8].

The electrical loss due to shading for the fixed tilt systems is a relatively minor loss (0.1% - 0.2%) and is only applicable for 'Module 1', 'Module 2' and 'Module 3' modules. As discussed above[9], First Solar modules orientated correctly are not subject to electrical shading.

Single axis tracking:
Backtracking controls were applied to the crystalline module simulations, which actively minimises losses due to direct shading. The single axis tracker follows the angle of the sun, but when the sun is at lower angles and mutual shading of each row would typically occur, the tracking system reduces the angle of all modules.

This removes losses due to direct shading and results in zero electrical loss for all module technologies. However, the modules are still partially shaded from the diffuse portion of irradiance; thus a structure shading loss occurs.

First Solar modules do not use backtracking controls, which results in greater losses due to structure shading than with the crystalline modules.

4.3.2 PV loss/gain due to irradiance level

The conversion efficiency of a PV module reduces at low light intensities and increases at higher light intensities. There is therefore a loss/gain in output of a module in practice compared with the standard irradiance conditions the modules are tested at (1,000 W/m^2). This loss/gain depends on the characteristics of the module and the intensity of the incident irradiance in the field. PVSyst calculates the irradiance level loss/gain based on the information contained in the PV module data sheet.

For fixed-axis systems, the PV loss/gain due to irradiance level ranged from 0.1% gain to a loss of 0.4%. For single-axis tracking system the loss/gain was expectedly higher due to the higher incident irradiance and ranged from 0.2% gain to 0.3% loss. The First Solar modules

- Coello, 2011, *"Degradation Of Crystalline Silicon Modules: A Case Study On 785 Samples After Two Years Under Operation";*
- Makrides et al, 2010, *"Degradation Of Different Photovoltaic Technologies Under Field Conditions"*.

[8] See section 4.1.3

[9] See section 4.2.2.3

experienced the highest gain due to the irradiance level; whereas ‘Module 3’ modules had the greatest loss for all simulations.

4.3.3 Thermal Losses

The range of temperatures that modules experience during a year is heavily dependent on the range of ambient temperatures at a site.

Upington has the highest average temperature of all three test sites with a yearly average ambient temperature of 21.4 °C, followed by Vryburg (19.5 °C) and then Bloemfontein (16.1 °C). As expected, the thermal losses of all module technologies were greatest in test sites with higher temperatures.

Furthermore the thermal losses experienced by the modules in the single axis tracking facilities was marginally greater than the fixed tilt equivalents. This was also an expected trend as modules in tracking systems receive more irradiation and therefore heat, compared to fixed-axis systems; leading to an increased thermal loss.

In the simulations, the First Solar modules experienced the lowest thermal losses across all three locations in both fixed and tracking systems, which is expected due to the lower temperature power loss coefficient. ‘Module 3’ performed next best in all configurations, followed by ‘Module 1’ and then ‘Module 2’ modules.

4.3.4 Inverter Performance

The SMA 800CP XT inverter was used in all simulations. This resulted in a uniform loss of 1.5% annually for each technology, configuration and site.

When the string power increases above the inverter threshold on the I-V curve, there is an additional loss referred to as *inverter loss over nominal power* present. For each site this varied between the different module technologies. The modules with the greatest power output experienced the highest losses. This was expected as the same proportion of nominal DC module power to AC inverter power was applied across technologies.

The greatest inverter loss over nominal power losses were experienced by the tracking systems. This was expected as in these simulations the power output of each module string was greater than the fixed tilt scenarios.

4.3.5 DC Ohmic Wiring Loss

All modules were simulated with a 1.5% DC Ohmic wiring loss input, which is applicable at STC conditions (1000W/m^2 and 25°C). The simulated output loss of all modules was the same for all fixed-axis systems with each showing a 1.2% loss across all locations.

There was a slight variance for the single-axis tracking systems results. The losses varied marginally from 1.3% to 1.4% amongst the modules technologies and locations. This is likely due to minor rounding errors in the simulation.

4.3.6 AC Ohmic Wiring Loss

All modules were simulated with a 0.5% AC Ohmic wiring loss input, which is applicable at STC conditions (1000W/m^2 and 25°C). The simulated output loss of all the modules was the same for all Fixed Tilt systems with each showing a 0.3 % loss across all locations.

There was a slight variance for the single-axis tracking system results. First Solar showed a 0.4% loss for all tracking systems across all locations. This was matched by ‘Module 3’ which also showed a 0.4% loss for all tracking systems in all locations. ‘Module 1’ and ‘Module 2’ modules maintained a constant 0.3% loss for all tracking systems in all locations. Similarly to the DC loss, these are minor rounding errors in the calculation and should not have a material effect on the results.

5 Results and Conclusions

Table 10 and Figures 5 to 7 below summarize the simulation results for the first year of production, across all sites, substructure configurations (fixed-axis or single-axis tracking) and module technologies. Further detailed comparisons are shown on a site by site basis in Appendix A and on a per simulation basis in Appendix B.

The table presents the specific yield, as well as the Performance Ratio (PR). Note that for the tracking systems the PR was calculated for all technologies using the in-plane irradiation excluding backtracking (ideal angles) for consistency.

Average annual performance during year 1								
				First Solar – Thin Film Base Case	**First Solar – Thin Film** Excl. Spectral Adjustment	**Module 1 – Poly c-Si**	**Module 2 – Poly c-Si**	**Module 3 – Mono c-Si**
Bloemfontein	Fixed Tilt	Energy Yield	kWh/kWp	2 033	2 035	1 972	1 967	2 021
		PR	%	84.2%	84.3%	81.7%	81.4%	83.7%
		Variance	%	-	0.1%	-3.0%	-3.2%	-0.6%
	Tracking	Energy Yield	kWh/kWp	2 373	2 376	2 298	2 292	2 349
		PR	%	81.0%	81.1%	78.4%	78.2%	80.2%
		Variance	%	-	0.1%	-3.1%	-3.4%	-1.0%
Upington	Fixed Tilt	Energy Yield	kWh/kWp	2 078	2 091	2 015	2 008	2 069
		PR	%	82.3%	82.8%	79.8%	79.5%	81.9%
		Variance	%	-	0.6%	-3.0%	-3.4%	-0.4%
	Tracking	Energy Yield	kWh/kWp	2 472	2 486	2 388	2 378	2 448
		PR	%	79.5%	80.0%	76.8%	76.5%	78.7%
		Variance	%	-	0.6%	-3.4%	-3.8%	-1.0%
Vryburg	Fixed Tilt	Energy Yield	kWh/kWp	2 021	2 011	1 945	1 939	1 995
		PR	%	84.2%	83.7%	81.0%	80.8%	83.1%
		Variance	%	-	-0.5%	-3.8%	-4.1%	-1.3%
	Tracking	Energy Yield	kWh/kWp	2 384	2 374	2 293	2 286	2 345
		PR	%	80.9%	80.5%	77.8%	77.5%	79.5%
		Variance	%	-	-0.4%	-3.8%	-4.1%	-1.6%

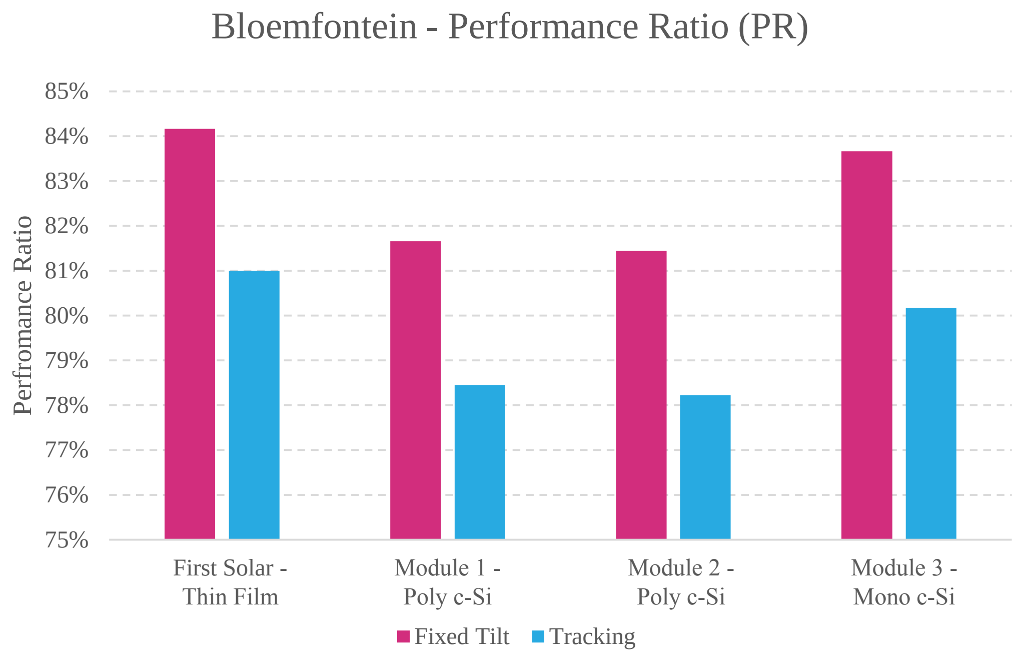
Table 10: Summary of results of Yield Analysis Simulations during year 1.The difference in energy yield for each simulation compared to the First Solar base case is highlighted.

The year one results show that the First Solar modules had the highest estimated energy yield across all sites. The relative performance of these modules compared to the alternatives was greatest in the single axis tracking scenarios.

The simulation results of the First Solar modules without the spectral adjustment applied[10] have also been shown as a sensitivity analysis. These indicate that applying the spectral adjustment decreases the estimate energy yield in certain locations (Bloemfontein and Upington), while increasing it in others (Vryburg) due to the differences in meteorological conditions at each site.

Note that for the scenarios tested, First Solar was estimated to have the highest estimated energy yield whether or not spectral adjustment was considered.

[10] See section 4.2.2.1



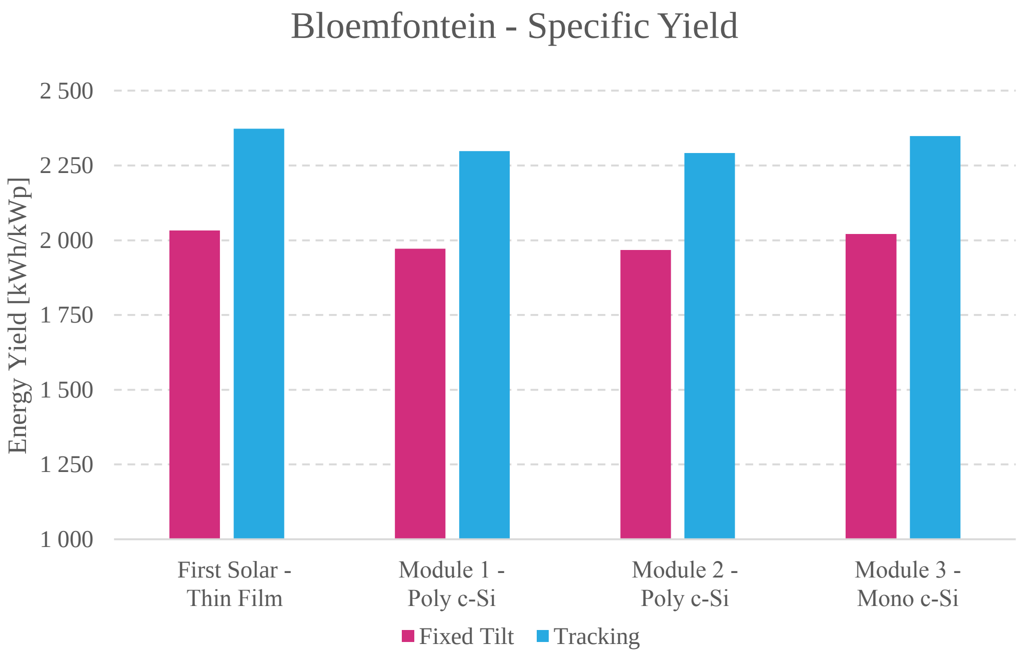
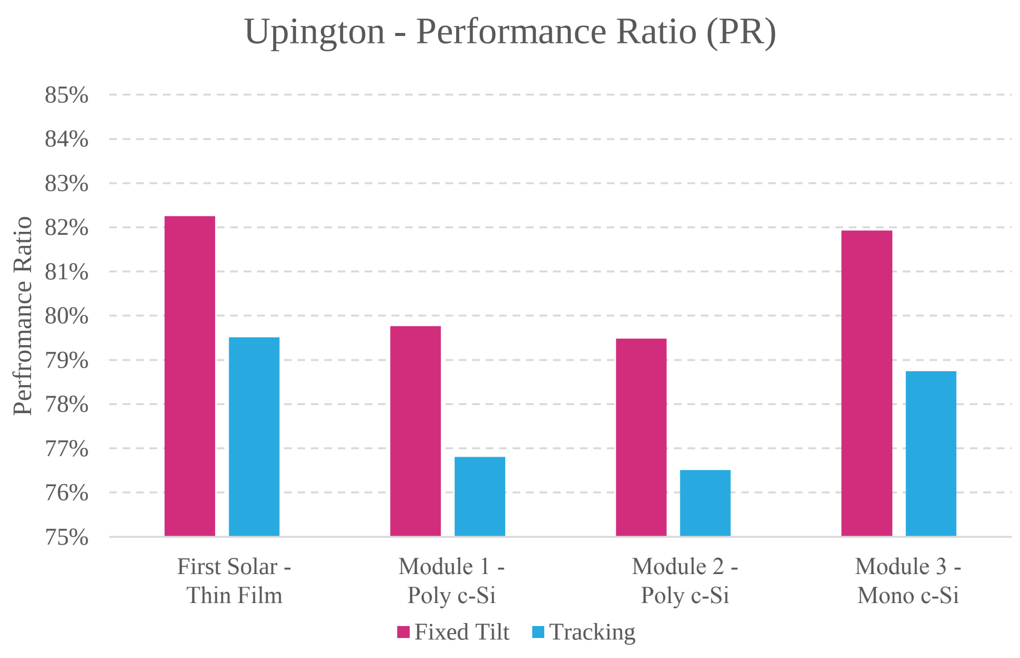


Figure 5: Simulated performance in Bloemfontein during the first year of production.



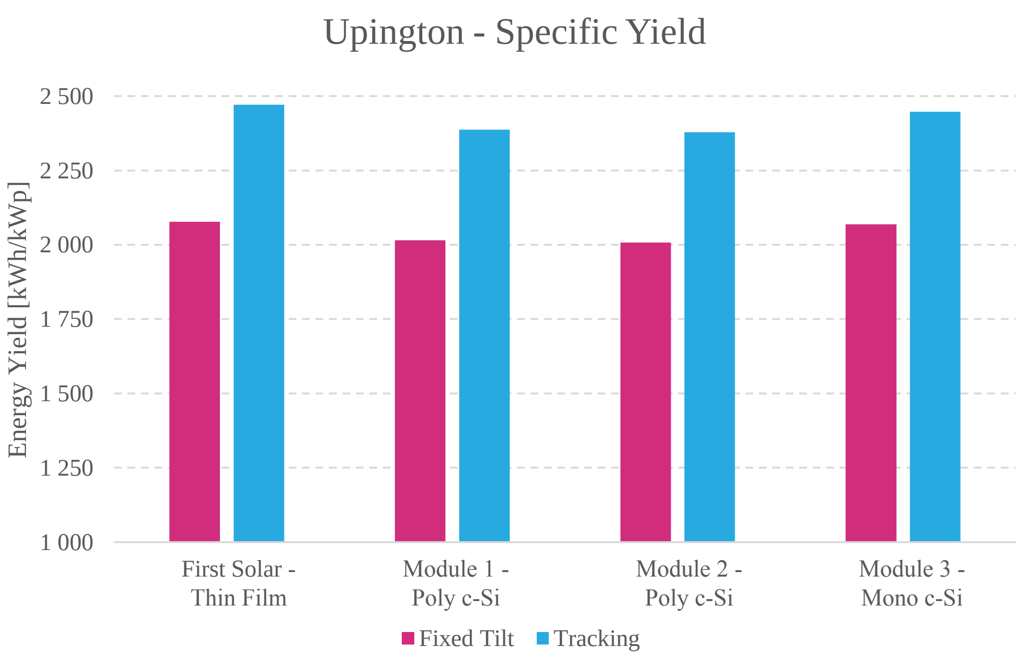
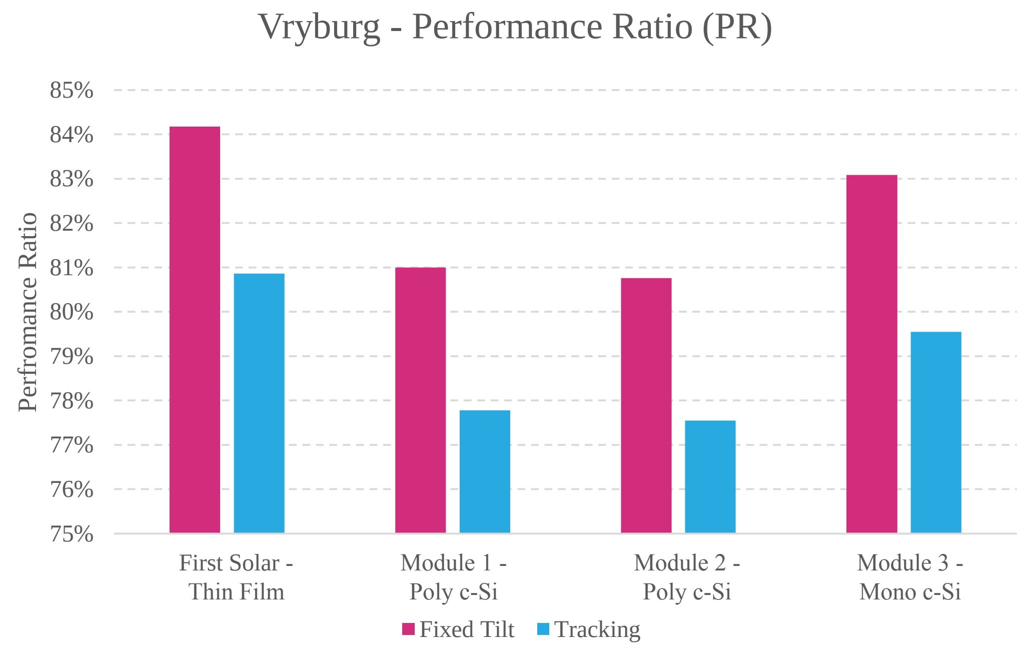


Figure 6: Simulated performance in Upington during the first year of production.



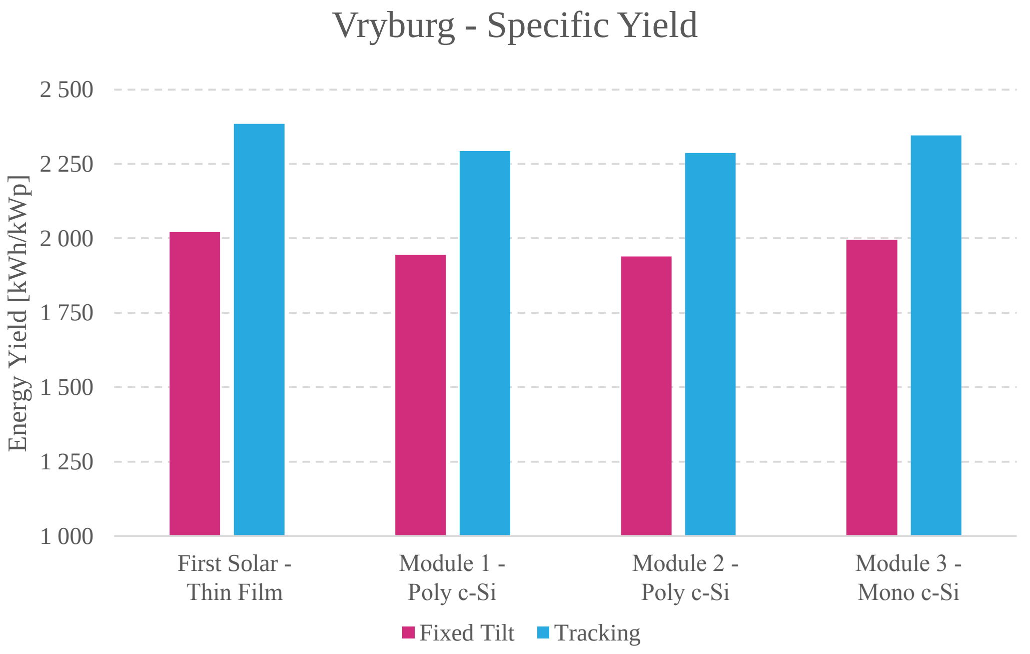


Figure 7: Simulated performance in Vryburg during the first year of production.

Appendix A

Site Result Summary

ARUP				
	TITLE:	Energy Yield Comparison	Completed By:	EB
	SITE LOCATION:	Bloemfontein	Checked By:	AB
			Date:	15/05/08
			REV:	1

Table 1: Comparison of system losses

System performance calculations												
			Fixed Tilt					Tracking				
			First Solar – Thin Film	First Solar – Thin Film - Excl Spectral	Module 1 - Poly c-Si	Module 2 - Poly c-Si	Module 3 – Mono c-Si	First Solar – Thin Film	First Solar – Thin Film - Excl Spectral	Module 1 - Poly c-Si	Module 2 - Poly c-Si	Module 3 – Mono c-Si
Annual irradiation in module plane		[kWh/m2]	2 415	2 415	2 415	2 415	2 415	2 930	2 930	2 818	2 818	2 818
Shading and Reflection	Horizon shading loss	[%]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Structure shading loss	[%]	-2.1%	-2.1%	-2.1%	-2.1%	-2.1%	-5.4%	-5.4%	-1.9%	-1.9%	-1.9%
	Reflection loss (IAM factor)	[%]	-1.3%	-1.3%	-1.9%	-2.0%	-0.8%	-0.6%	-0.6%	-1.3%	-1.4%	-0.4%
	Soiling loss	[%]	-1.9%	-1.9%	-1.9%	-1.9%	-1.9%	-1.7%	-1.8%	-1.8%	-1.8%	-1.8%
Irradiance on collectors		[kWh/m2]	2 289	2 289	2 274	2 273	2 301	2 709	2 705	2 682	2 678	2 704
Total module area		[m2]	537 602	525 756	525 756	525 769	441 875	537 602	525 756	525 756	525 769	441 875
Module Efficiency at STC		%	15.62%	15.98%	15.98%	15.98%	19.06%	15.62%	15.98%	15.98%	15.98%	19.06%
Array Nominal Energy		[MWh]	192 257	192 208	191 061	190 962	193 865	227 443	227 129	225 280	225 059	227 751
PV Modules	Monthly Spectral Adjustment	[%]	-0.1%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%
	PV loss / gain due to irradiance level	[%]	0.0%	0.0%	0.0%	-0.1%	-0.4%	0.1%	0.1%	0.0%	0.0%	-0.3%
	Thermal losses	[%]	-5.2%	-5.3%	-6.7%	-6.9%	-6.1%	-5.8%	-5.9%	-7.6%	-7.7%	-6.8%
	Shadings : Electrical Loss	[%]	0.0%	0.0%	-0.1%	-0.1%	-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
	DC Health Factor Loss	[%]	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
	Power sorting tolerance adjustment	[%]	0.6%	0.6%	0.8%	0.8%	0.5%	0.6%	0.6%	0.8%	0.8%	0.5%
	Module array mismatch loss	[%]	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
	DC Ohmic wiring loss	[%]	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%
Array Virtual energy at MPP		[MWh]	177 370	177 398	173 797	173 312	176 242	208 523	208 314	203 124	202 443	205 847
AC electrical components	Inverter efficiency loss	[%]	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%
	Inverter loss over nominal power	[%]	-0.5%	-0.4%	-0.2%	-0.1%	-0.3%	-1.3%	-1.0%	-0.5%	-0.4%	-0.8%
	AC Ohmic wiring loss	[%]	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.4%	-0.4%	-0.3%	-0.3%	-0.4%
	Transformer resistive loss	[%]	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
	Transformer iron loss	[%]	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
Total energy excluding self consumption		[MWh]	171 333	171 514	168 451	168 015	170 592	199 928	200 182	196 224	195 656	198 211
Grid Curtailment Loss		[%]	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Self Consumption Loss		[%]	0.34%	0.34%	0.34%	0.34%	0.34%	0.29%	0.29%	0.29%	0.29%	0.29%
Plant Availability Loss		[%]	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Grid Availability Loss		[%]	0.0%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total energy injected into the grid (excl. degradation)		[MWh]	170 757	170 938	167 874	167 438	170 016	199 351	199 606	195 648	195 080	197 635
Specific energy injected into the grid (excl. degradation)		[kWh/kWp]	2 033	2 035	1 999	1 993	2 024	2 373	2 376	2 329	2 322	2 353
Performance Ratio (excl. degradation)		[%]	84.2%	84.3%	82.7%	82.5%	83.8%	81.0%	81.1%	79.5%	79.3%	80.3%

Table 2: Comparison of annual perfromance

Average annual performance during year 1											
		Fixed Tilt					Tracking				
		First Solar – Thin Film	First Solar – Thin Film - Excl Spectral	Module 1 - Poly c-Si	Module 2 - Poly c-Si	Module 3 – Mono c-Si	First Solar – Thin Film	First Solar – Thin Film - Excl Spectral	Module 1 - Poly c-Si	Module 2 - Poly c-Si	Module 3 – Mono c-Si
Average Degradation applied	[%]	0.00%	0.00%	1.32%	1.32%	0.16%	0.00%	0.00%	1.32%	1.32%	0.16%
Total energy injected into the grid	[MWh]	170 757	170 938	165 658	165 228	169 744	199 351	199 606	193 065	192 505	197 319
Specific energy injected into the grid	[kWh/kWp]	2 033	2 035	1 972	1 967	2 021	2 373	2 376	2 298	2 292	2 349
Performance Ratio	[%]	84.16%	84.25%	81.65%	81.44%	83.66%	81.00%	81.10%	78.45%	78.22%	80.17%
Rel Difference (Specific Energy basis) - Including Spectral Adjustment	[%]	-		-3.0%	-3.2%	-0.6%	-		-3.1%	-3.4%	-1.0%
Rel Difference (Specific Energy basis) - Excluding Spectral Adjustment	[%]		-	-3.1%	-3.3%	-0.7%		-	-3.3%	-3.6%	-1.1%

ARUP				
TITLE:	Energy Yield Comparison	Completed By:	EB
SITE LOCATION:	Upington	Checked By:	AB
		Date:	15/05/08
		REV:	1

Table 1: Comparison of system losses

System performance calculations												
			Fixed Tilt					Tracking				
			First Solar – Thin Film	First Solar – Thin Film - Excl Spectral	Module 1 - Poly c-Si	Module 2 - Poly c-Si	Module 3 – Mono c-Si	First Solar – Thin Film	First Solar – Thin Film - Excl Spectral	Module 1 - Poly c-Si	Module 2 - Poly c-Si	Module 3 – Mono c-Si
Annual irradiation in module plane		[kWh/m2]	2 526	2 526	2 526	2 526	2 526	3 109	3 109	2 994	2 994	2 994
Shading and Reflection	Horizon shading loss	[%]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Structure shading loss	[%]	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%	-5.2%	-5.2%	-1.7%	-1.7%	-1.7%
	Reflection loss (IAM factor)	[%]	-1.2%	-1.2%	-1.9%	-2.0%	-0.8%	-0.5%	-0.5%	-1.1%	-1.2%	-0.4%
	Soiling loss	[%]	-2.6%	-2.5%	-2.5%	-2.5%	-2.5%	-2.5%	-2.5%	-2.5%	-2.5%	-2.5%
Irradiance on collectors		[kWh/m2]	2 388	2 388	2 374	2 371	2 401	2 859	2 859	2 837	2 834	2 858
Total module area		[m2]	537 602	537 602	525 756	525 769	441 875	537 602	525 756	525 756	525 769	441 875
Module Efficiency at STC		%	15.62%	15.62%	15.98%	15.98%	19.06%	15.62%	15.98%	15.98%	15.98%	19.06%
Array Nominal Energy		[MWh]	200 515	200 555	199 405	199 243	202 235	240 122	240 050	238 362	238 104	240 800
PV Modules	Monthly Spectral Adjustment	[%]	-0.6%	0.0%	0.0%	0.0%	0.0%	-0.6%	0.0%	0.0%	0.0%	0.0%
	PV loss / gain due to irradiance level	[%]	0.1%	0.1%	0.0%	0.0%	-0.3%	0.2%	0.2%	0.2%	0.1%	-0.2%
	Thermal losses	[%]	-7.1%	-7.1%	-8.9%	-9.1%	-8.1%	-7.6%	-7.6%	-9.7%	-10.0%	-8.8%
	Shadings : Electrical Loss	[%]	0.0%	0.0%	-0.1%	-0.1%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
	DC Health Factor Loss	[%]	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
	Power sorting tolerance adjustment	[%]	0.6%	0.6%	0.8%	0.8%	0.5%	0.6%	0.6%	0.8%	0.8%	0.5%
	Module array mismatch loss	[%]	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
	DC Ohmic wiring loss	[%]	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%	-1.3%	-1.3%	-1.4%	-1.4%	-1.3%
Array Virtual energy at MPP		[MWh]	180 482	181 672	177 251	176 612	179 984	215 009	216 156	209 991	209 150	212 998
AC electrical components	Inverter efficiency loss	[%]	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%
	Inverter loss over nominal power	[%]	-0.1%	-0.1%	0.0%	0.0%	0.0%	-0.2%	-0.2%	-0.1%	0.0%	-0.1%
	AC Ohmic wiring loss	[%]	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.4%	-0.4%	-0.3%	-0.3%	-0.4%
	Transformer resistive loss	[%]	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
	Transformer iron loss	[%]	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
Total energy excluding self consumption		[MWh]	175 094	176 227	172 071	171 456	174 680	208 195	209 389	203 813	203 019	206 536
Grid Curtailment Loss		[%]	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Self Consumption Loss		[%]	0.33%	0.33%	0.33%	0.34%	0.33%	0.28%	0.28%	0.28%	0.28%	0.28%
Plant Availability Loss		[%]	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Grid Availability Loss		[%]	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total energy injected into the grid (excl. degradation)		[MWh]	174 518	175 651	171 494	170 880	174 103	207 618	208 812	203 237	202 443	205 960
Specific energy injected into the grid (excl. degradation)		[kWh/kWp]	2 078	2 091	2 042	2 034	2 073	2 472	2 486	2 420	2 410	2 452
Performance Ratio (excl. degradation)		[%]	82.3%	82.8%	80.8%	80.5%	82.1%	79.5%	80.0%	77.8%	77.5%	78.9%

Table 2: Comparison of annual perfromance

Average annual performance during year 1											
		Fixed Tilt					Tracking				
		First Solar – Thin Film	First Solar – Thin Film - Excl Spectral	Module 1 - Poly c-Si	Module 2 - Poly c-Si	Module 3 – Mono c-Si	First Solar – Thin Film	First Solar – Thin Film - Excl Spectral	Module 1 - Poly c-Si	Module 2 - Poly c-Si	Module 3 – Mono c-Si
Average Degradation applied	[%]	0.00%	0.00%	1.32%	1.32%	0.16%	0.00%	0.00%	1.32%	1.32%	0.16%
Total energy injected into the grid	[MWh]	174 518	175 651	169 230	168 624	173 825	207 618	208 812	200 554	199 770	205 630
Specific energy injected into the grid	[kWh/kWp]	2 078	2 091	2 015	2 008	2 069	2 472	2 486	2 388	2 378	2 448
Performance Ratio	[%]	82.25%	82.79%	79.77%	79.48%	81.93%	79.51%	79.97%	76.81%	76.51%	78.75%
Rel Difference (Specific Energy basis) - Including Spectral Adjustment	[%]	-		-3.0%	-3.4%	-0.4%	-		-3.4%	-3.8%	-1.0%
Rel Difference (Specific Energy basis) - Excluding Spectral Adjustment	[%]		-	-3.7%	-4.0%	-1.0%		-	-4.0%	-4.3%	-1.5%

ARUP			
TITLE:	Energy Yield Comparison	Completed By:	EB
SITE LOCATION:	Vryburg	Checked By:	AB
		Date:	15/05/08
		REV:	1

Table 1: Comparison of system losses

System performance calculations												
			Fixed Tilt					**Tracking**				
			First Solar – Thin Film	**First Solar – Thin Film - Excl Spectral**	**Module 1 - Poly c-Si**	**Module 2 - Poly c-Si**	**Module 3 – Mono c-Si**	**First Solar – Thin Film**	**First Solar – Thin Film - Excl Spectral**	**Module 1 - Poly c-Si**	**Module 2 - Poly c-Si**	**Module 3 – Mono c-Si**
Annual irradiation in module plane		[kWh/m2]	2 401	2 401	2 401	2 401	2 401	2 948	2 948	2 840	2 840	2 840
Shading and Reflection	Horizon shading loss	[%]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Structure shading loss	[%]	-1.9%	-1.9%	-1.9%	-1.9%	-1.9%	-5.3%	-5.3%	-1.9%	-1.9%	-1.9%
	Reflection loss (IAM factor)	[%]	-1.3%	-1.3%	-2.0%	-2.0%	-0.8%	-0.6%	-0.6%	-1.2%	-1.3%	-0.4%
	Soiling loss	[%]	-2.0%	-2.0%	-2.0%	-2.0%	-2.0%	-1.8%	-1.9%	-1.9%	-1.9%	-1.9%
Irradiance on collectors		[kWh/m2]	2 278	2 278	2 263	2 261	2 290	2 726	2 723	2 701	2 898	2 722
Total module area		[m2]	537 602	525 756	525 756	525 769	441 875	537 602	525 756	525 756	525 769	441 875
Module Efficiency at STC		%	15.62%	15.98%	15.98%	15.98%	19.06%	15.62%	15.98%	15.98%	15.98%	19.06%
Array Nominal Energy		[MWh]	191 306	191 257	190 124	190 013	192 919	228 882	228 613	226 911	226 725	229 340
PV Modules	Monthly Spectral Adjustment	[%]	0.6%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%
	PV loss / gain due to irradiance level	[%]	0.0%	0.0%	0.0%	-0.1%	-0.4%	0.1%	0.1%	0.1%	0.0%	-0.3%
	Thermal losses	[%]	-6.0%	-6.1%	-7.7%	-7.9%	-7.0%	-6.7%	-6.7%	-8.6%	-8.8%	-7.7%
	Shadings : Electrical Loss	[%]	0.0%	0.0%	-0.1%	-0.1%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
	DC Health Factor Loss	[%]	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
	Power sorting tolerance adjustment	[%]	0.6%	0.6%	0.8%	0.8%	0.5%	0.6%	0.6%	0.8%	0.8%	0.5%
	Module array mismatch loss	[%]	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
	DC Ohmic wiring loss	[%]	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%	-1.3%	-1.3%	-1.3%	-1.3%	-1.3%
Array Virtual energy at MPP		[MWh]	176 230	175 051	171 228	170 714	173 778	209 080	207 816	202 385	201 694	205 204
AC electrical components	Inverter efficiency loss	[%]	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%	-1.5%
	Inverter loss over nominal power	[%]	-0.4%	-0.3%	-0.1%	-0.1%	-0.2%	-1.2%	-0.9%	-0.4%	-0.3%	-0.7%
	AC Ohmic wiring loss	[%]	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.4%	-0.4%	-0.3%	-0.3%	-0.4%
	Transformer resistive loss	[%]	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
	Transformer iron loss	[%]	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
Total energy excluding self consumption		[MWh]	170 336	169 470	166 103	165 627	168 403	200 824	199 995	195 756	195 169	197 887
Grid Curtailment Loss		[%]	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Self Consumption Loss		[%]	0.34%	0.34%	0.35%	0.35%	0.34%	0.29%	0.29%	0.29%	0.30%	0.29%
Plant Availability Loss		[%]	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Grid Availability Loss		[%]	0.0%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total energy injected into the grid (excl. degradation)		[MWh]	169 759	168 893	165 527	165 051	167 827	200 248	199 418	195 179	194 593	197 311
Specific energy injected into the grid (excl. degradation)		[kWh/kWp]	2 021	2 011	1 971	1 965	1 998	2 384	2 374	2 324	2 317	2 349
Performance Ratio (excl. degradation)		[%]	84.2%	83.7%	82.1%	81.8%	83.2%	80.9%	80.5%	78.8%	78.6%	79.7%

Table 2: Comparison of annual perfromance

Average annual performance during year 1											
		Fixed Tilt					**Tracking**				
		First Solar – Thin Film	**First Solar – Thin Film - Excl Spectral**	**Module 1 - Poly c-Si**	**Module 2 - Poly c-Si**	**Module 3 – Mono c-Si**	**First Solar – Thin Film**	**First Solar – Thin Film - Excl Spectral**	**Module 1 - Poly c-Si**	**Module 2 - Poly c-Si**	**Module 3 – Mono c-Si**
Average Degradation applied	[%]	0.00%	0.00%	1.32%	1.32%	0.16%	0.00%	0.00%	1.32%	1.32%	0.16%
Total energy injected into the grid	[MWh]	169 759	168 893	163 342	162 872	167 558	200 248	199 418	192 603	192 024	196 995
Specific energy injected into the grid	[kWh/kWp]	2 021	2 011	1 945	1 939	1 995	2 384	2 374	2 293	2 286	2 345
Performance Ratio	[%]	84.17%	83.75%	81.00%	80.76%	83.08%	80.86%	80.53%	77.78%	77.54%	79.55%
Rel Difference (Specific Energy basis) - Including Spectral Adjustment	[%]	-		-3.8%	-4.1%	-1.3%	-		-3.8%	-4.1%	-1.6%
Rel Difference (Specific Energy basis) - Excluding Spectral Adjustment	[%]		-	-3.3%	-3.6%	-0.8%		-	-3.4%	-3.7%	-1.2%