Energy Prediction and Construction Cost Estimation Report

Project:
SunMine Pilot Project
Sullivan Mine, Kimberley, British Columbia Canada (2.0 MWp)

Prepared For:
EcoSmart

Prepared By:

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1. Introduction and Summary Results

DNV KEMA was tasked by EcoSmart to estimate capital costs and perform an energy estimate for a 2MW dc ground mount vertical axis tracker system located at the lat/long coordinates 49.67° / -115.95° at the site of the decommissioned Sullivan Mine near Kimberley, British Columbia, Canada. The system consists of 6,864 modules arranged in groups of 48 on 143 vertical axis trackers, which corresponds to an effective 290 W module size for 2.0 MWp. DNV KEMA has simulated the system with Trina Solar TSM-290PC14 modules and four Solectria SGI-500 480V inverters resulting in 1,990.56 MWp. The modules are mounted on the vertical axis trackers at 57° tilt and an azimuthal range of motion from -120° to +120°.

DNV KEMA estimated capital costs for construction of the site, and expects these to be approximately $1.83 per watt peak (based on costs as of August 2013). Interconnection to the grid will be accomplished at a 69 kV substation located approximately 1.1 km from the PV plant. DNV KEMA developed an energy forecast for this site using the commercially available modeling software PVsyst. DNV KEMA expects the first-year energy delivery to be 3,891 megawatt-hours.

The approach used to generate an estimate of the first year's energy output is described in following section. For subsequent years, DNV KEMA recommends assuming an annual degradation rate of 0.75% per year to account for degradation in PV module performance as well as system-level increasing module mismatch and degradation of electrical terminals and inverter components.

DNV KEMA entered module and system specifications into the commercial PV simulation software PVsyst. The program was configured to use meteorological data from Environment Canada's Cranbrook CWEC dataset. The PVsyst report is included in Section 5, which details simulation inputs and outputs, including a loss tree analysis.

2. Construction Costs

PV system construction costs are dependent on many variables, the most significant being: module type and efficiency; structure (fixed versus tracking); local labor rates; interconnection type; and details of location. PV system capital costs generally include three major components and numerous minor components that are often collectively abbreviated as balance of system, or BOS. Table 1 and Figure 1 present a typical cost breakdown for a project of the scale and configuration of the SunMine Pilot. Information is drawn from DNV KEMA's recent experience with similar sized projects. These costs include equipment through the step up transformer, but not the wire runs from that point to the interconnection.

Table 1. Typical Capital Cost Breakdown at Scale, Context and Configuration of SunMine

Allocation	Cost/Wp ($)	Percent of Overall
Module	0.65	35.5%
Tracker including controls and foundation	0.42	23.0%
Inverter and switchgear	0.27	14.8%
Balance of System Materials	0.25	13.7%
Installation Labor	0.08	4.4%
Site preparation, trenching, fencing	0.08	4.4%
Engineering	0.08	4.4%
Total	1.83	100.0%

DNV KEMA understands that EcoSmart has an existing relationship with the mine, where certain heavy equipment and construction experience may be available at somewhat lower than typical costs. Balancing this, the sloped terrain and presence of glacial boulders may raise site preparation and foundation costs. The costs above are estimates intended to be useful in evaluating EPC contractor bids. Included in balance of system and miscellaneous costs are items such as combiner boxes, wiring, SCADA components, security system and fencing. Any buildings, if required, are not included. Also not included are applicable local taxes and land acquisition or leasing costs.

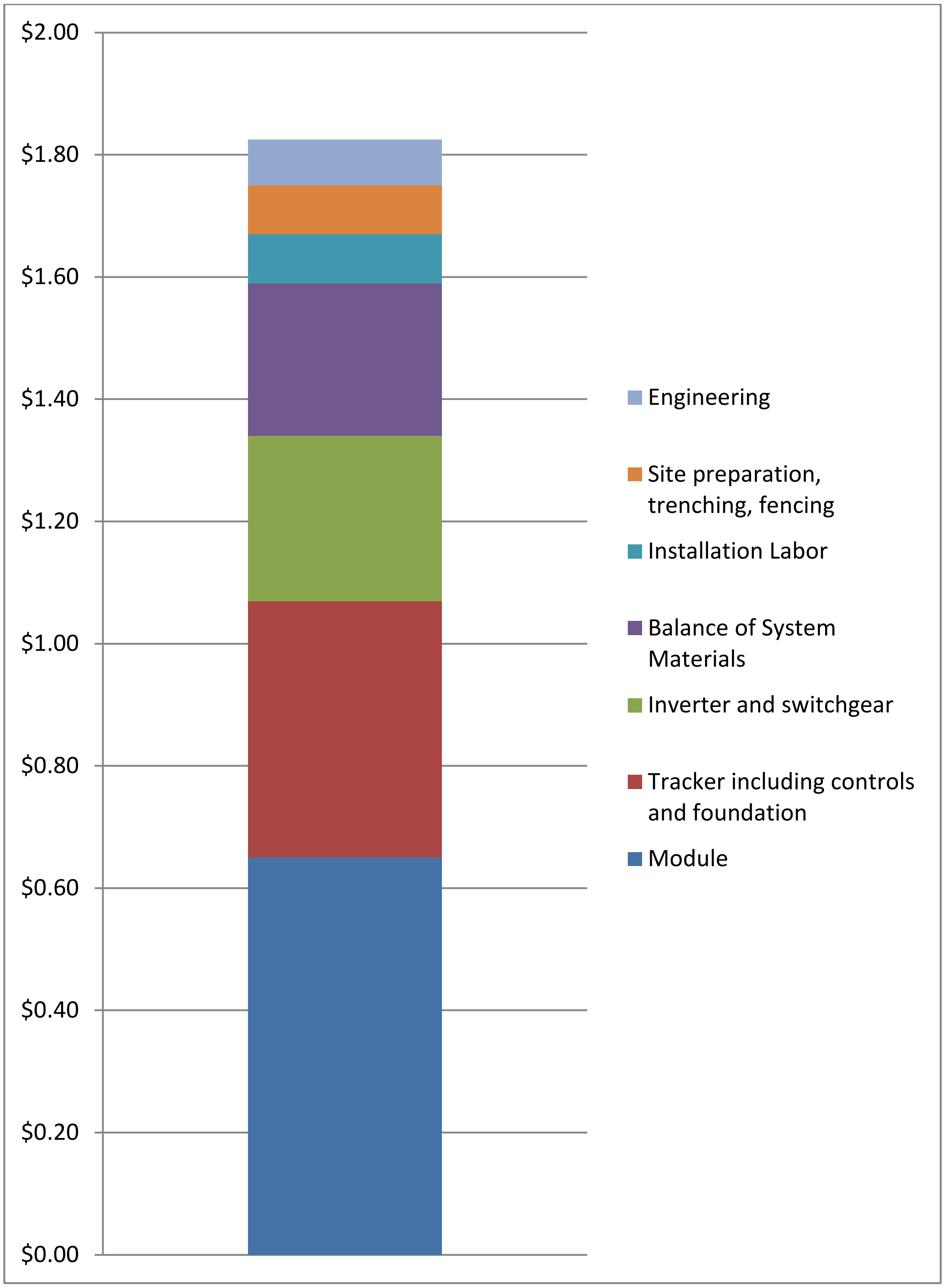


Figure 1. Typical Capital Cost Breakdown at Scale, Context and Configuration of SunMine

3. Energy Modeling Inputs

Weather File Selection

Most of the inherent modeling uncertainty is tied to the choice of the weather file. DNV KEMA analyzed irradiance data from three different sources to determine the most appropriate data file for the SunMine site. Data sources considered include Environment Canada's Canadian Weather for Energy Calculations (CWEC) data files for Cranbrook (ID 718800), Meteonorm data at the latitude and longitude of the site, and NASA-SSE data at the same coordinates.

The typical meteorological years for the weather sources are shown in Figure 2 below.

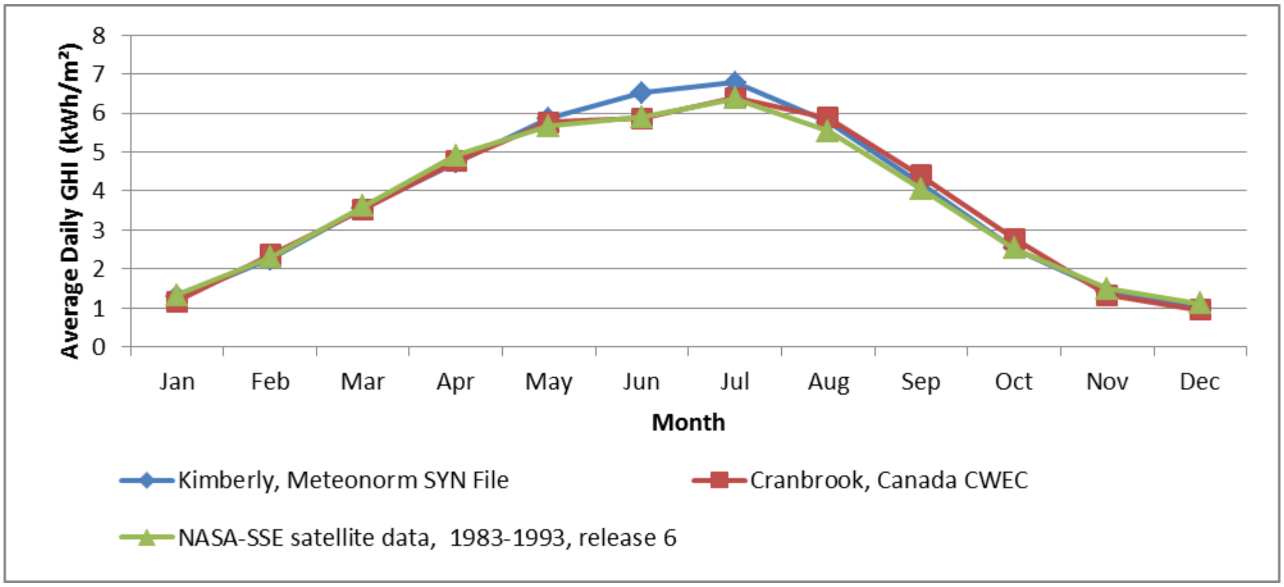


Figure 2: Average daily global horizontal irradiation, various weather sources

DNV KEMA reviewed the three weather sources under consideration. The average daily GHI values for the entire typical year from each source were within 2.25% of each other, and when passed through the same PVsyst model, capturing effects of tilt and tracking, the variance was similar. Taking the annual variance in GHI from Cranbrook CWEEDS data, and assuming a normal distribution, a rough estimation of annual GHI probabilities of exceedance is given below:

- P90 is approximately 96.5% of the typical year
- P95 is approximately 95.5% of the typical year
- P99 is approximately 93.6% of the typical year

Therefore, the variance between the three sources can be considered less significant than the interannual variance. The Meteonorm data were considered less trustworthy than the other two satellite-derived sets in this case due to the long (>200 km) distance to any of the sites used to feed its interpolation algorithm. The Cranbrook CWEC data were selected to generate the energy prediction via PVsyst due to their reference by EcoSmart and their intermediate average amongst the three weather files considered. DNV KEMA has not reviewed in detail the installation, instrumentation quality, or rigor of maintenance of EcoSmart's year-long on-site resource measurement, but notes that since none of the other weather sources are ground measurements this data may be valuable as a point of reference to estimate bias error in the published sources.

Selection and Modeling of Components

DNV KEMA selected a 290 W module rating to closely match EcoSmart's designations of 2 MWp output with 6,864 modules, selecting the Trina TSM-290PC14 to be broadly representative of a 72-cell utility-scale-oriented polycrystalline silicon module sourced from China. EcoSmart approved this choice. While strings of 11 modules were optimal given the 72-cell, 290 W modules and voltage ratings of most nominal 600V central inverters checked, configuration of strings of 12 modules was the nearest number by which 48-module tracking units would be evenly divisible. 12-module string length results in an open circuit voltage several percent above 600V at the minimum expected temperature on site. DNV KEMA selected a 500 kW inverter as a common size evenly meeting the DC rating of the site with four units at nominal output. The Solectria SGI-500 480V model was used due to the closer-than-most compatibility with the 12-module strings' open circuit voltage in cold temperatures (allowing to 625 V), though even in this case the compatibility is marginal. DNV KEMA verified nearly identical energy output using strings of 11 modules, though some aspects of wiring and tracker topologies would grow more complex and wiring losses could be elevated if this topology was selected. Thus, while DNV KEMA does not represent the present configuration modeled in PVsyst as being the absolute optimal detailed design, we feel it is a realistic "typical" set of components for the site, and one closely resembling the configuration parameters drafted by EcoSmart.

DNV KEMA verifies all models of modules and inverters used in energy simulations using manufacturer's data sheets, and will augment published specifications with detailed test data if available. When current-voltage curves are not available at multiple irradiances and temperatures, DNV KEMA relies exclusively on values presented in the datasheet. Availability of internally-checked PVsyst models has been one additional factor informing selection of the modules and inverters modeled.

Trackers remained non-specific in the simulation, but were constrained to track within an azimuth range of due south +/-120°, slightly under the range of azimuths where the sun is above the horizon in Kimberley at any time of year.

Assumptions

DNV KEMA entered module and system specifications into the commercially available PV energy modeling software PVsyst. Shading analysis concluded that shading from mountains on the horizon would be the most significant source, with losses of 2.0%. Shading from on row of trackers to rows behind was the only other source, and was found to be approximately 1.8% by two different approaches. The first of these was through use of 3D modeling in Google Sketchup, which included non-rectangular tracker layout as indicated by EcoSmart. An example of early morning inter-array shading using this approach is depicted in Figure 3. The second was a PVsyst near shading simulation for vertical axis trackers, as visible in the PVsyst report. Each approach captured the geometry including a 20% grade downhill to the south. The Sketchup approach included a mild grade uphill to the West as observed on the topographical map provided by EcoSmart. The PVsyst approach assumed linear response to shading (optimistic with respect to energy) but could only capture a rectangular tracker form (conservative with respect to shading). The PVsyst internal calculation was used directly due to the commercial availability, easier potential for exact replication by other parties, and similar results between approaches. Shading analyses did not include any modeling of nearby trees; EcoSmart indicated that trees would be removed as needed for insignificant shading losses given the brownfield nature of the site.

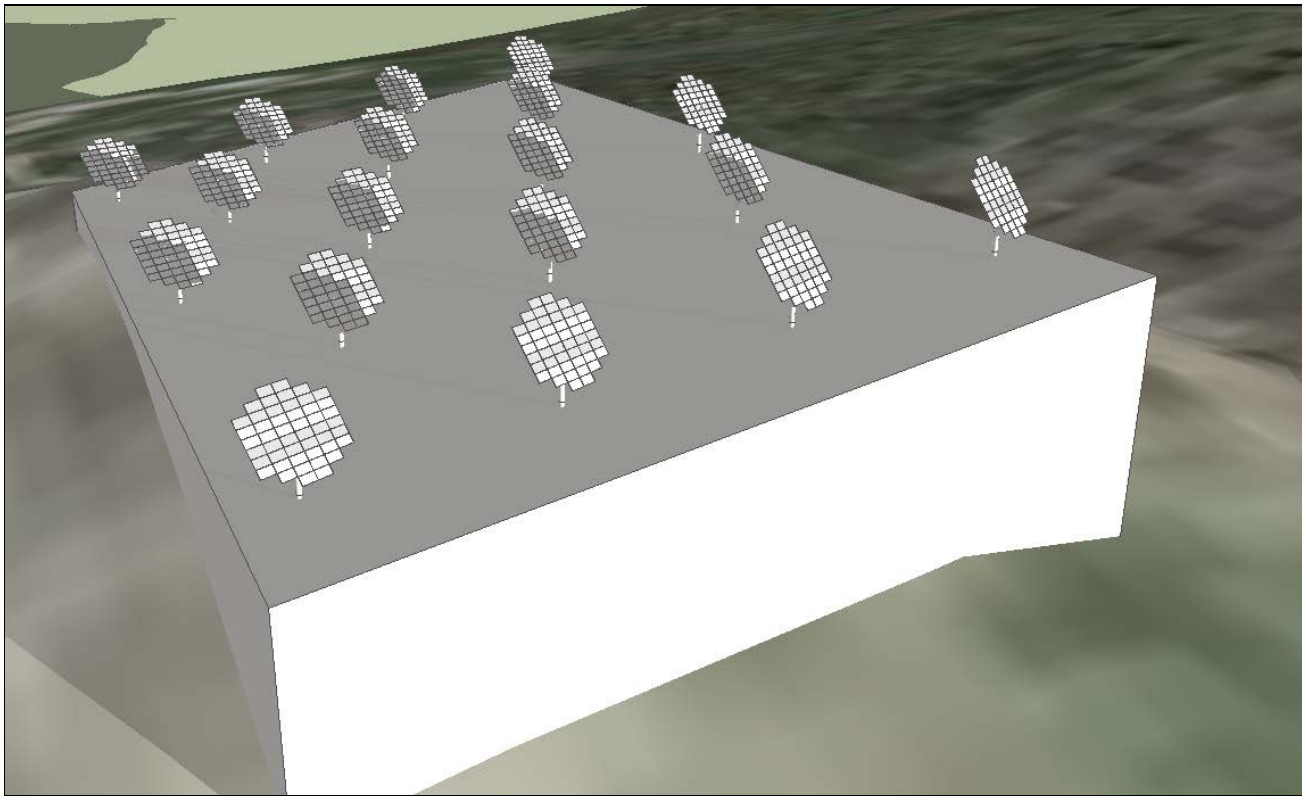


Figure 3. 3-Dimensional Representation of an Array Segment on May 21, 4:30 AM

It is common for as-delivered modules to vary slightly from their nameplate power. The Trina TSM-290PC14 modules used quote an output tolerance at STC of 0 ~ +3%. DNV KEMA assumed that the module distribution would be centered at the lower quartile of the tolerance window, which results in a boost of 0.8%. This is one input to the module quality factor (MQF).

To complete the calculation of MQF, DNV KEMA also applied a 2% loss to account for light induced degradation (LID). LID occurs in the first days to weeks of exposure to sunlight, while long-term degradation is expected to occur at a slow rate over the life of the system and is correlated to the module technology (polycrystalline). An additional 0.5% loss is incorporated into the MQF for all simulations to account for non-ideal inverter maximum power point tracking. Finally, DNV KEMA included a 0.1% modeling adjustment to account for the difference in the module's modeled output and the nominal power rating. All of these contribute to an overall MQF loss of 1.8%.

Regarding mismatch, the combination of series and parallel mismatch can be estimated analytically via PVsyst as long as the production tolerance, nature of the distribution, and number of series and parallel strings is known. The series mismatch is the most significant source of mismatch, but large numbers of parallel circuits also contribute to the composite mismatch. This is especially true because unavoidable and differing levels of DC voltage drop will occur among parallel circuits within a distributed array, all feeding a common inverter. For this system, the combined impact of all mismatch effects is moderate (0.4% loss).

DNV KEMA calculated wire losses based on standard assumptions informed by the expanse of the project and distance to the interconnection. The DC ohmic loss was 1.4% for each array segment under standard test conditions (STC). The total AC ohmic loss from the inverters to the point of interconnection is 1.3% in wiring under STC.

This system has one assumed step-up transformer (2,000 kVA), which contributes approximately 0.7% annual energy loss due to a combination of fixed and variable losses.

Soiling losses result from a combination of many factors: system configuration, the intensity and amount of rainfall and snowfall, the accumulation of dust, type of soil, and other site specific conditions such as bird droppings, proximity to highways, etc. Local precipitation levels combined with steep tilt suggest that the modules will receive sufficient rainfall to keep them free of dust and debris in the summer. DNV KEMA used an internal snow loss model, which was developed from field-based snow tests[1], to calculate expected snow losses based on historical snowfall patterns in Cranbrook and array design parameters. The annual energy lost due to soiling and snowfall is approximately 1.9% in a typical year.

Energy losses associated with equipment failures, unplanned outages, or planned downtime are applied to the overall PVsyst production estimate. DNV KEMA assumes an energy loss value of 1.0% for commercial and small utility-scale systems using proven components, which corresponds roughly to three full days of lost production per year.

Table 2 below lists the PVsyst input assumptions.

Table 2. PV System Assumptions

Item	Value	Comment
Configuration	Vertical axis tracking	
Tilt	57°	
Azimuth Range	-120° to 120°	
Lat/Long	49.6°N/ -115.8°W	Default Cranbrook site with CWEC data

[1] T. Townsend and L. Powers, "Photovoltaics and snow: An update from two winters of measurement in the Sierra," in 2011 37th IEEE Photovoltaic Specialists Conference, 2011 © IEEE. doi: 10.1109/PVSC.2011.6186627

Item	Value	Comment
Altitude, m	940	Cranbrook
Ground albedo	0.2-0.5	Varies seasonally
Module	Trina TSM-290PC14	290W
Total # of modules	6,864	
# of modules per string	12	
# of parallel strings	572	
Inverters	4 ea. Solectria SGI-500 and	2 MW total
NOCT, °C	47	
Wire loss, %	2.7%	At STC, 1.4% DC, 1.3% AC
Shade loss, %	3.8%	Horizon, adjacent trackers
Soiling loss, %	1.9%	
Module quality loss, %	1.8	Includes nameplate (***gain*** of 0.8%), MPPT (0.5%), LID (2.0%), modeling adjustment (0.1%)
Mismatch, %	0.4	
Incidence Angle Modifier Loss, %	1.4	ASHRAE Eqn, b_o=0.05
Transformer rating, MVA	2.0	
# of transformers	1	
Transformer efficiency,%	0.4 variable, 0.1 fixed	General assumption from manufacturer data sheets for similar size transformers
Loss due to reactive loads, %	0	Assumed to be negligible
Availability loss, %	1.0	Equivalent to three days of system down time

4. Results

Annual Energy Production

Table 3 summarizes the final results of the simulation at the location of the interconnection.

DNV KEMA post-processed the PVsyst output to calculate the final result. The PVsyst simulations account for most system losses; however, they do not include losses such as overnight inverter losses, fixed and variable transformer losses including overnight losses associated with keeping the transformers energized, AC ohmic cable losses, and annual system downtime (availability).

To account for these additional losses, net plant production is reduced by hourly nighttime consumption. Plant auxiliary loads have also been evaluated and are included in the energy generation estimates. These losses were calculated outside of PVsyst (post processed) using the PVsyst simulated 8760 hourly data for one year and subtracted from the PVsyst value for overall plant generation. The resulting annual generation, based on the long term average weather, is listed below in Table 3.

The model, based on the long term average weather, is generally understood to carry an uncertainty of ±10% at a 95% confidence level for annual generation estimates.

Table 3. Key Performance Simulation Results

Project Name	PVsyst Results, MWh	Post-Processed Losses	Projected 1st year MWh	1st Year Yield, kWh/kW_P
SunMine Pilot	3,996	2.7%	3,891	1955

The details and results from PVsyst are attached in Section 5 titled "Performance Simulation Summary". This includes key simulation inputs and outputs, detailed in the loss tree. The results from the PVsyst output report reflect the energy output at the inverter and should not be referenced as the final system generation; as mentioned above, night time consumption losses and plant availability are not included in the PVsyst summary and were deducted in separate calculations. The final system generation can be referenced in Table 3 above.

Annual Degradation

Industry literature suggests annual degradation rates of mono- and poly-crystalline PV systems range between 0.5-1.0% annually. DNV KEMA typically recommends using a 0.75% system-level degradation for the proposed system. This loss is not included in the results in Section 0.

5. Performance Simulation Summary

Grid-Connected System: Simulation parameters

Project : **EcoSmart SunMine**

Geographical Site **Cranbrook** **Country** **Canada**

Situation Latitude 49.6°N Longitude 115.8°W
Time defined as Legal Time Time zone UT-8 Altitude 940 m
Monthly albedo values

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Albedo	0.50	0.50	0.35	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.35	0.50

Meteo data : Cranbrook, Canada EPW

Simulation variant : **SunMine Pilot 2MWp**

Simulation date 20/11/12 19h40

Simulation parameters

Tracking plane, Vertical Axis Plane Tilt 57°
Rotation Limitations Minimum Azimuth -120° Maximum Azi muth 120°

Models used Transposition Perez Diffuse Measured

Horizon Average Height 2.4°

Near Shadings Linear shadings

PV Array Characteristics

PV module Si-poly Model **TSM-290PC14 APP01**
Manufacturer Trina Solar
Number of PV modules In series 12 modules In parallel 572 strings
Total number of PV modules Nb. modules 6864 Unit Nom. Power 290 Wp
Array global power Nominal (STC) **1991 kWp** At operating cond. 1767 kWp (50°C)
Array operating characteristics (50°C) U mpp 388 V I m pp 4552 A
Total area Module area **13319 m²** Cell area 12029 m²

Inverter Model **SGI500-480V APP01**
Manufacturer Solectria
Characteristics Operating Voltage 300-500 V Unit Nom. Power 500 kW AC
Inverter pack Number of Inverter 4 units Total Power 2000 kW AC

PV Array loss factors
Thermal Loss factor Uc (const) 25.0 W/m²K Uv (wind) 1.2 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.) NOCT 47 °C
Wiring Ohmic Loss Global array res. 1.4 mOhm Loss Fraction 1.4 % at STC
Array Soiling Losses

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
9.0%	4.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	3.0%	8.0%

Module Quality Loss Loss Fraction 1.8 %
Module Mismatch Losses Loss Fraction 0.4 % at MPP
Incidence effect, ASHRAE parametrization IAM = 1 - bo (1/cos i - 1) bo Parameter 0.05

Grid-Connected System: Simulation parameters (continued)

User's needs : Unlimited load (grid)

Grid-Connected System: Horizon definition

Project : **EcoSmart SunMine**

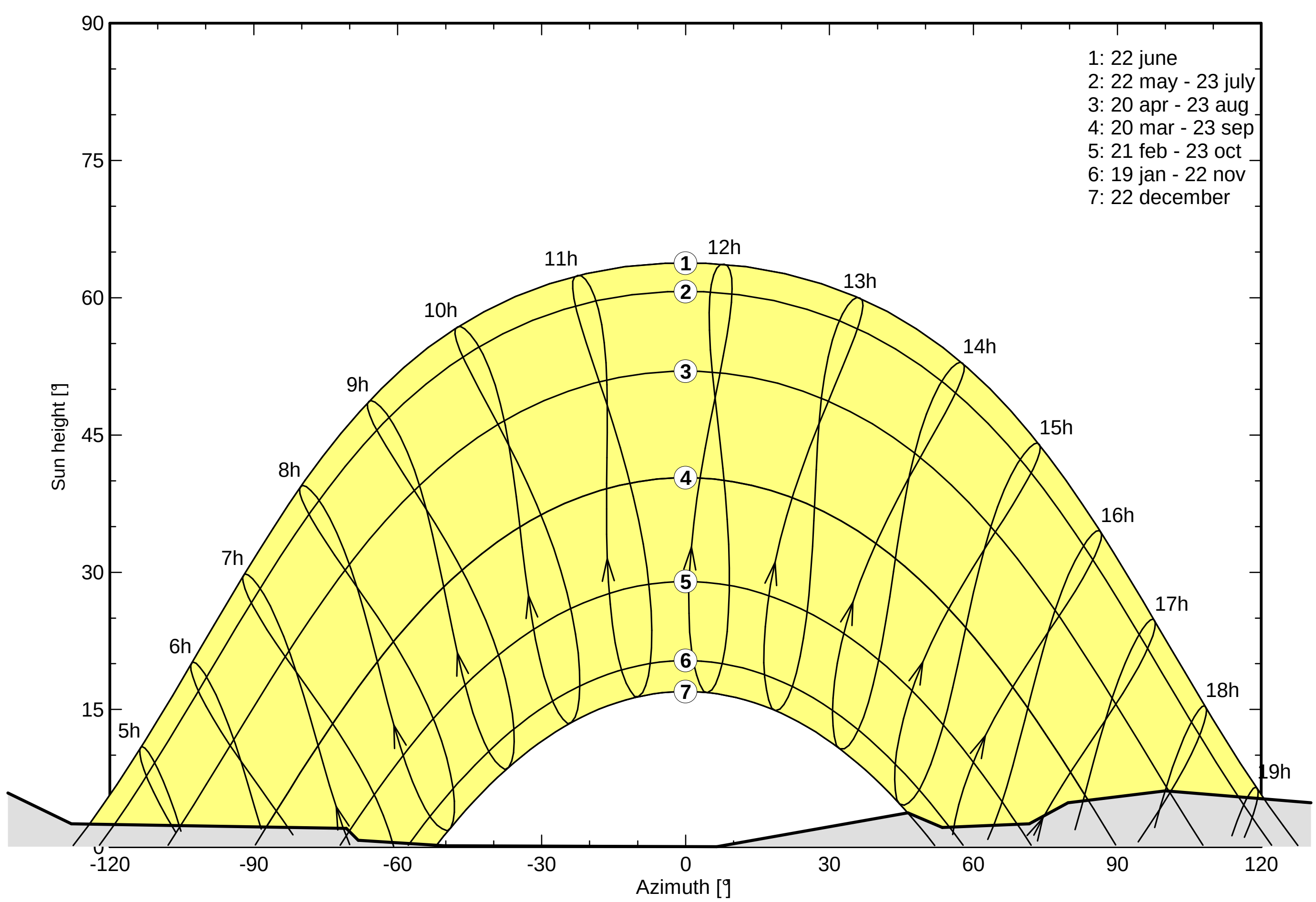
Simulation variant : **SunMine Pilot 2MWp**

Main system parameters	System type	**Grid-Connected**		
Horizon	Average Height	2.4°		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis, Plane Tilt	57°		
PV modules	Model	TSM-290PC14 APP01	Pnom	290 Wp
PV Array	Nb. of modules	6864	Pnom total	**1991 kWp**
Inverter	Model	SGI500-480V APP01	Pnom	500 kW ac
Inverter pack	Nb. of units	4.0	Pnom total	**2000 kW ac**
User's needs	Unlimited load (grid)			

Horizon	Average Height	2.4°	Diffuse Factor	0.99
	Albedo Factor	100 %	Albedo Fraction	0.95

Height [°]	6.6	2.5	2.0	0.7	0.1	0.0	3.7	2.1	2.5	4.8	6.1	4.6
Azimuth [°]	-144	-128	-71	-68	-50	6	46	53	72	80	100	135

SunMine Horizon Line



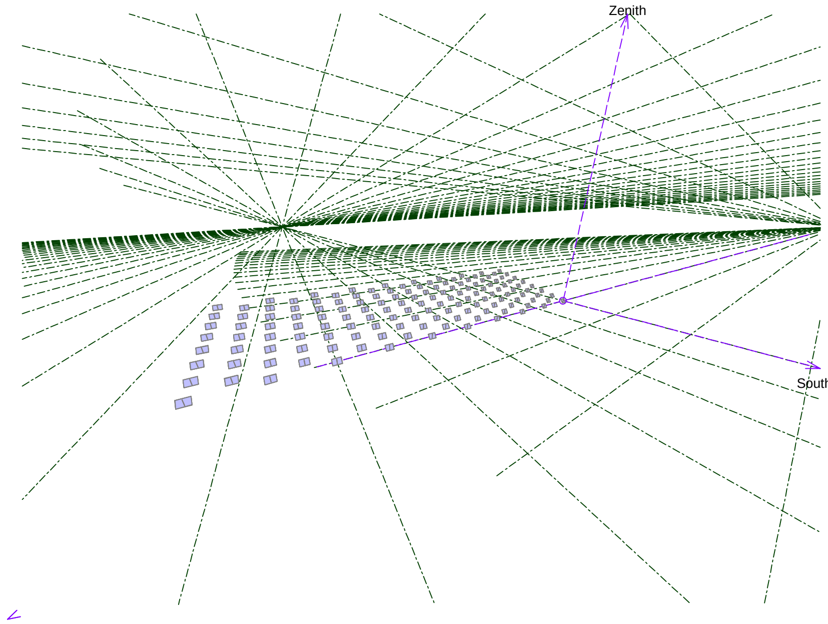
Grid-Connected System: Near shading definition

Project : **EcoSmart SunMine**

Simulation variant : **SunMine Pilot 2MWp**

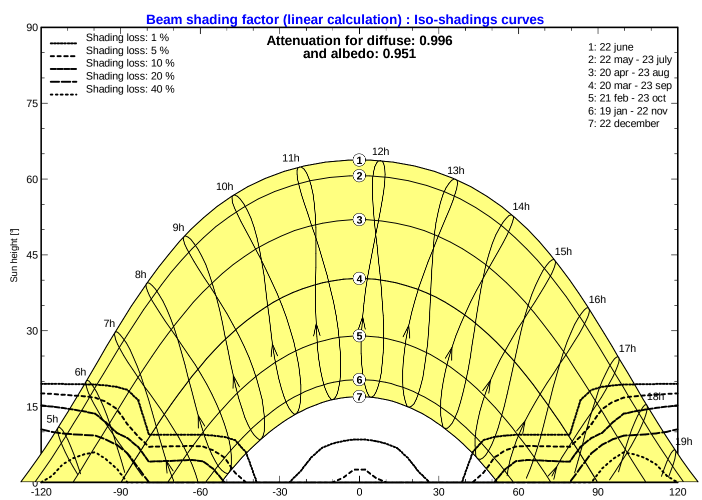
Main system parameters	System type	**Grid-Connected**		
Horizon	Average Height	2.4°		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis, Plane Tilt	57°		
PV modules	Model	TSM-290PC14 APP01	Pnom	290 Wp
PV Array	Nb. of modules	6864	Pnom total	**1991 kWp**
Inverter	Model	SGI500-480V APP01	Pnom	500 kW ac
Inverter pack	Nb. of units	4.0	Pnom total	**2000 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

EcoSmart SunMine: SunMine_RealCase_01



Grid-Connected System: Main results

Project : **EcoSmart SunMine**

Simulation variant : **SunMine Pilot 2MWp**

Main system parameters	System type	**Grid-Connected**		
Horizon	Average Height	2.4°		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis, Plane Tilt	57°		
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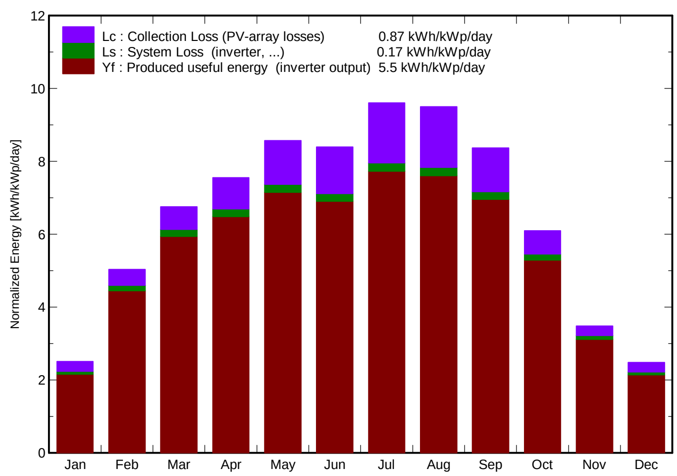
Inverter pack	Nb. of units	4.0	Pnom total	**2000 kW ac**
User's needs	Unlimited load (grid)			

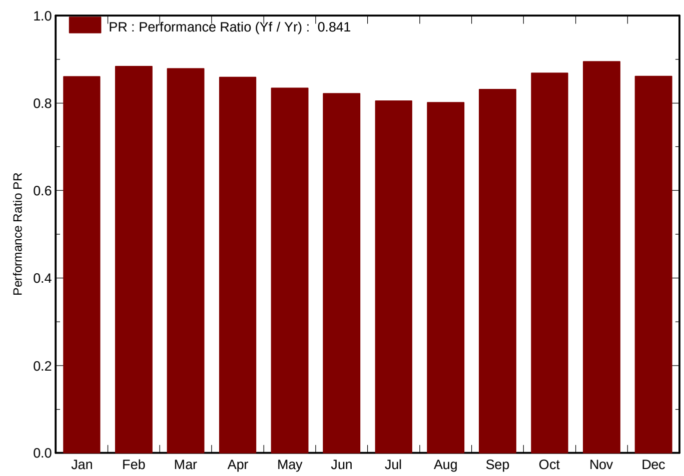
Main simulation results

System Production	**Produced Energy**	**3996 MWh/year**	Specific prod.	2008 kWh/kWp/year
	Performance Ratio PR	84.1 %		

Normalized productions (per installed kWp): Nominal power 1991 kWp



Performance Ratio PR



SunMine Pilot 2MWp

Balances and main results

	GlobHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	EffArrR	EffSysR
	kWh/m²	°C	kWh/m²	kWh/m²	MWh	MWh	%	%
January	36.1	-7.90	78.0	74.8	138.3	133.6	13.32	12.86
February	66.2	-3.23	141.1	135.2	256.2	248.2	13.64	13.21
March	109.5	2.41	209.5	201.2	378.4	366.5	13.56	13.13
April	143.0	5.99	226.7	214.3	399.7	387.4	13.24	12.83
May	178.4	10.54	265.8	248.2	454.8	441.4	12.85	12.47
June	175.6	14.36	251.9	236.8	424.9	412.2	12.66	12.29
July	197.8	18.66	297.7	280.1	491.1	476.8	12.39	12.03
August	182.3	17.29	294.4	277.7	483.6	469.6	12.33	11.98
September	132.1	11.66	251.1	240.3	428.3	415.6	12.80	12.42
October	86.0	5.40	188.9	181.5	336.9	326.7	13.39	12.98
November	39.9	-2.03	104.6	100.8	192.6	186.4	13.82	13.38
December	29.3	-6.56	77.1	73.7	136.9	132.1	13.34	12.87
Year	1376.0	5.60	2386.7	2264.7	4121.7	3996.4	12.97	12.57

Legends:

GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

Grid-Connected System: Loss diagram

Project : **EcoSmart SunMine**

Simulation variant : **SunMine Pilot 2MWp**

Main system parameters	System type	**Grid-Connected**		
Horizon	Average Height	2.4°		
Near Shadings	Linear shadings			
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User's needs	Unlimited load (grid)			

Loss diagram over the whole year