PVSYST SOFTWARE

Bifacial shed simulations with PVsyst

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Overview

- **Introduction**
  - Bifacial PV modules in PVsyst
  - Modelling the backside irradiance
- **PVsyst model for bifacial shed installations**
  - Model describing shed installations
  - Calculation of backside irradiation
  - Some qualitative results
- **Summary and Outlook**

PVsyst Photovoltaic Simulation Software

Modeling of PV installations

- From small residential to large utility installations
- Grid-Connected, Stand-Alone, Pumping
- Tracking Systems

High detail of simulation

- Near shadings from 3D drawings, Horizon definition
- Electrical mismatch model down to bypass diode granularity.
- Thermal model, optical losses, soiling, cabling losses, transformers, Ageing model, etc.

Detailed control of simulation parameters

- Many meteorological data sources can be imported and used
- Database with more than 10 000 PV modules and 3 000 Inverters
- Near shadings from 3D drawings, Horizon definition
- All loss and model parameters can be controlled by the user
- Many guiding messages and tools to help with the design
- Results with all intermediate calculations can be visualized and exported for further analysis

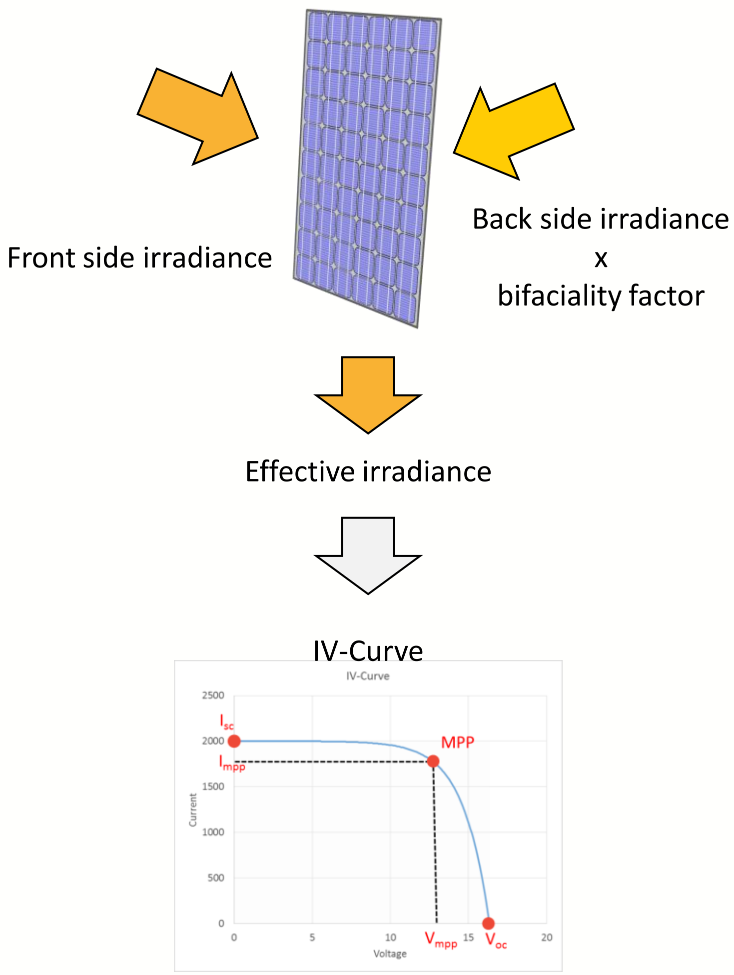
Follow evolution of PV technology

- Power optimizers
- Multi-MPPT inverters, string inverters
- **Bifacial PV modules**
- Etc.

Approach for Bifacial Modules in PVsyst

Treatment of bifacial modules

- Front side irradiance is added to backside irradiance x bifaciality factor (default is 0.8)
- From this Effective irradiance follows the IV-curve (single diode model).
- An additional mismatch factor is foreseen to account for inhomogeneous rear side illumination
- This approach is an approximation
- **Nameplate power P_{nom} has to be front side STC power!**

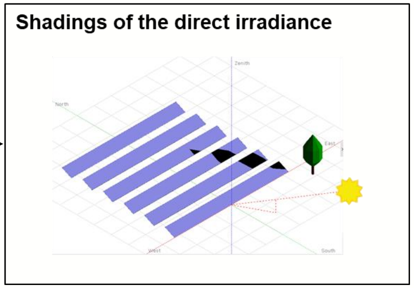


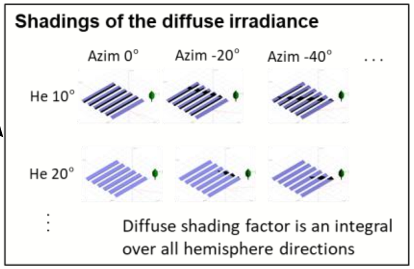
The main challenge is to calculate the additional backside irradiance including its inhomogeneity

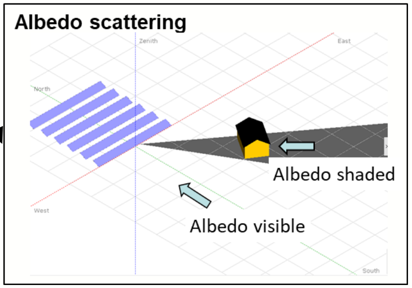
Irradiance Calculation and Ground Reflections

Standard PVsyst irradiance contributions

- **Direct**
  Subject to near shadings depending on sun position
- **Diffuse**
  Subject to shading factor that is constant for a given plane orientation
- **Albedo**
  Subject to shading factor that is constant for a given plane orientation
  Calculation of azimuth angles that are blocked

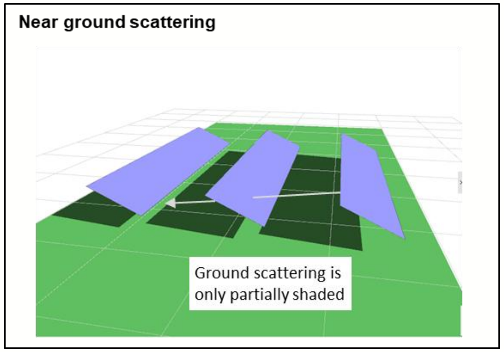






Introduced Near Ground Scattering

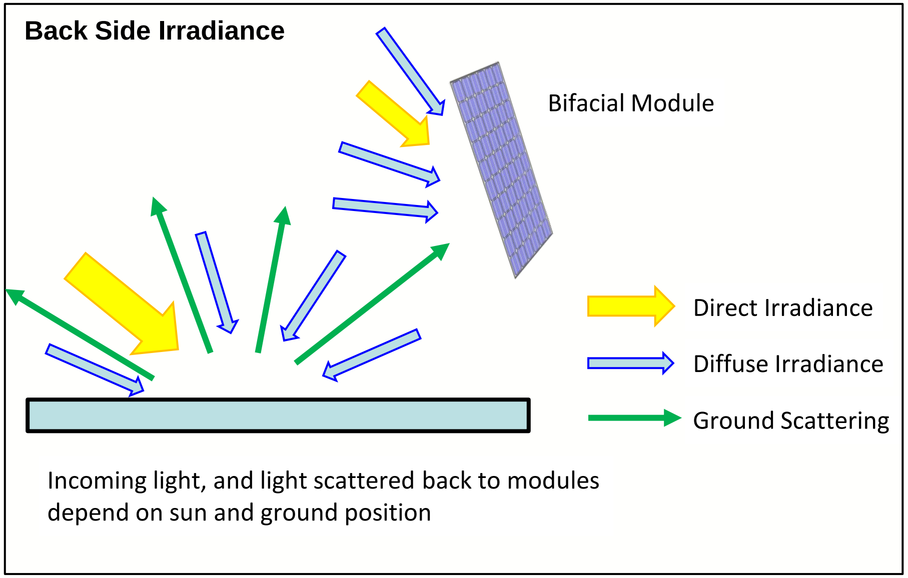
- **Near Ground Scattering (for bifacial simulations)**
  Light scattered back from ground that is close to the PV modules.
  Subject to near shadings with solid angle calculation.
  Depends on sun position!



Systems with Bifacial Modules in PVsyst

Basic approach for bifacial modelling

- Amount of diffuse and direct irradiance on back side
- Fraction of direct irradiance that reaches the scattering ground (depends on sun position)
- Fraction of diffuse irradiance that reaches the scattering ground (single factor)
- Ground Albedo for the scattering off the ground
- Factor for back and front side acceptance (View Factor)
- (Constant loss factor describing shadings of mounting structures, cabling and junction boxes)



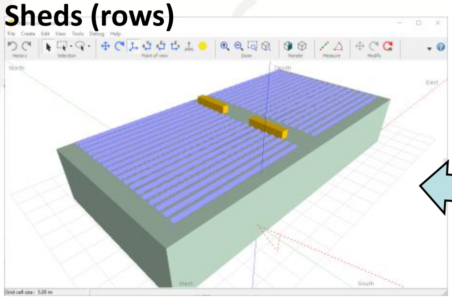
Assumptions for ground scattering

- Direct and sky diffuse irradiance contribute to ground illumination
- **Sky diffuse is isotropic**
- **The diffuse reflection is isotropic (Lambertian Surface)**
  Only scattering is considered (no specular reflections)
- Non-homogeneous illumination of backside is neglected at this stage

Bifacial Modules in Sheds

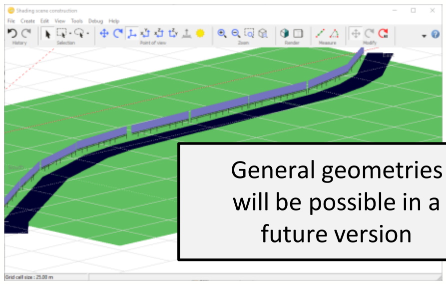
Bifacial modules are used in different situations

Sheds (rows)



In the current version, PVsyst models bifacial systems for shed geometries.

Vertical mounting



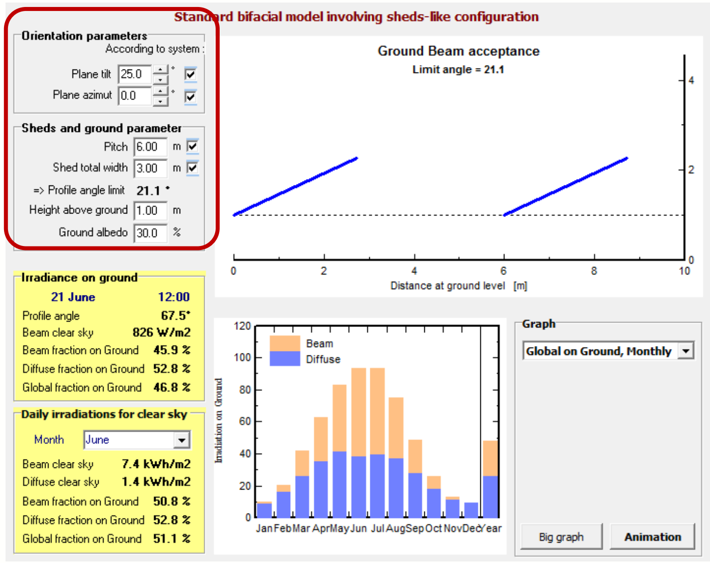
General geometries will be possible in a future version

PVsyst Model for regular shed configurations

Simplified 2D calculation
Rows without boundary effects (infinitely long)
Parameters:

- Tilt, Azimuth
- Width, Pitch
- Height above ground
- Ground Albedo

The factors for the bifacial calculation can be determined by integrating over the distance between rows
Direct irradiance is only computed for front side.
Near ground scattering is only computed for backside.



Calculation for Bifacial Sheds (2D Model)

Irradiance reaching the ground
Direct (B) — Sky Diffuse (A)

↓

Ground Albedo

↓

View Factors: Sky — Front — Rear(C)

- Sky → Loss
- Front → Add to front irradiance*
- Rear(C) + Sky Diffuse on rear (D) + Direct on rear → Rear shadings → Module bifaciality

Add to front irradiance* + Module bifaciality → Global irradiance on module

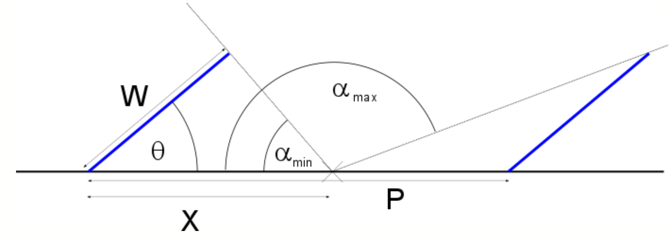
↓

Array losses

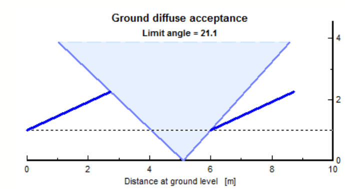
Front side mismatch* — Rear side mismatch

*Standard PVsyst simulation

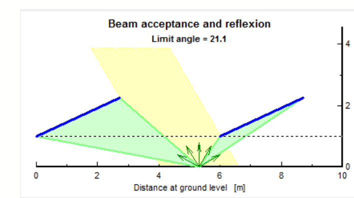
Shed Definitions



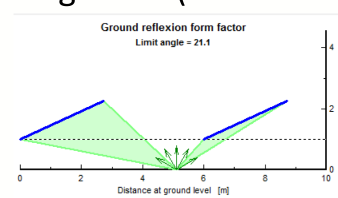
A. Ground acceptance of diffuse light



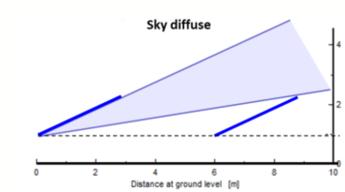
B. Ground Acceptance of direct light



C. Backside acceptance of ground (view factor)



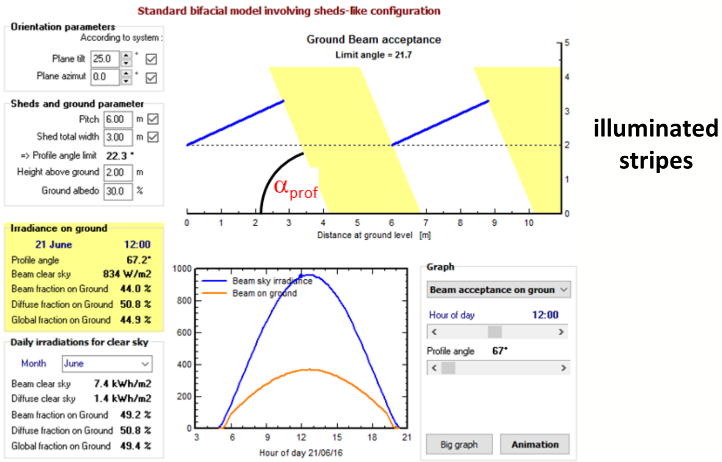
D. Sky diffuse on back side



Calculation of Irradiance on Ground

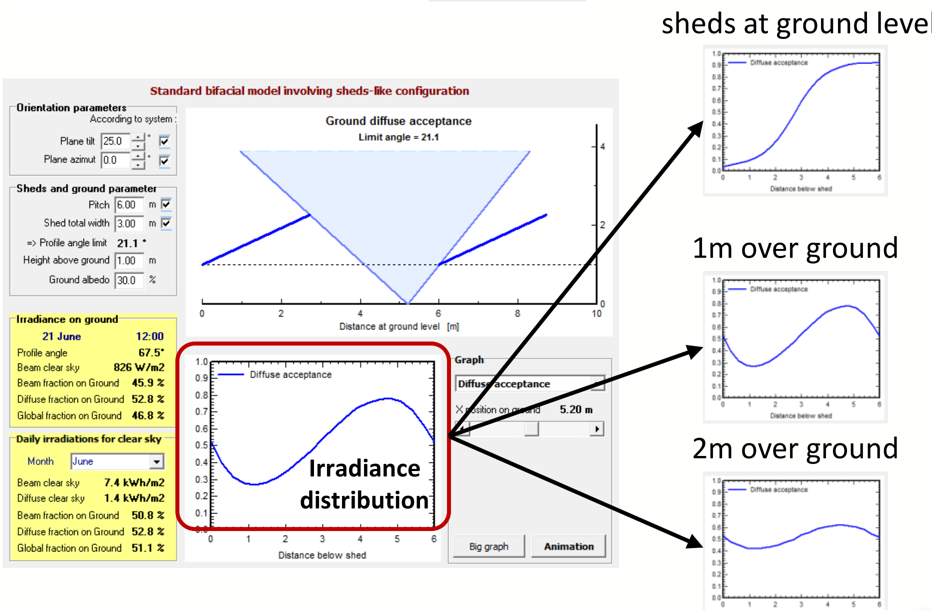
Direct irradiance

- Profile Angle and shed geometry determine the amount of directly illuminated ground surface.
- Height over ground and profile angle determine the position of the illuminated stripes



Diffuse irradiance

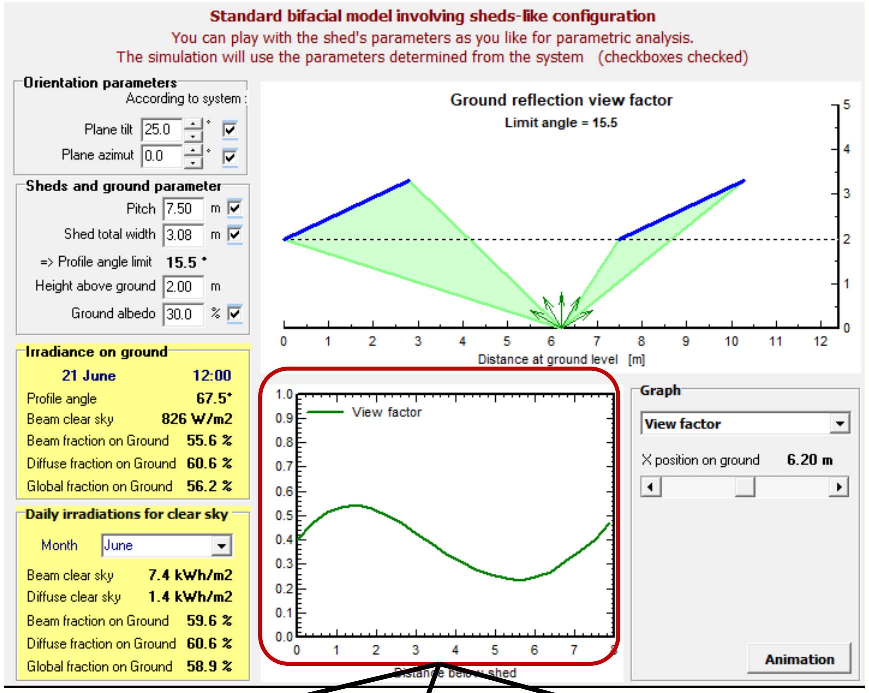
- Diffuse irradiance from sky is isotropic.
- Ground acceptance of diffuse light is a function of the position on the ground.
- It is constant over the year and needs to be computed only once.
- Underneath the sheds the irradiance is smaller.
- Inhomogeneity tends to level out with increasing mounting height.

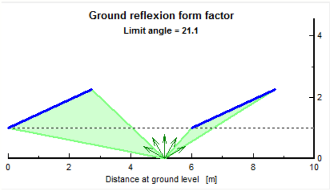


Calculation of View Factors

Backside acceptance of ground (View Factor)

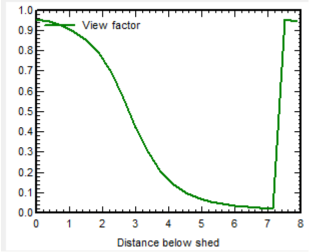
- Ground scattering is isotropic (Lambertian Scattering)
- View Factor is a function of the position on the ground.
- Underneath the sheds the view factor is large.
- Inhomogeneity tends to level out with increasing mounting height.



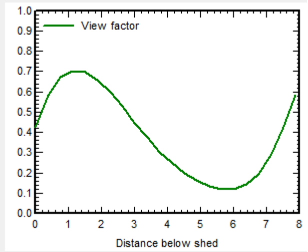


Ground scattering is isotropic (Lambertian Scattering)

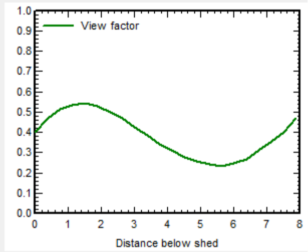
sheds at ground level



1m over ground



2m over ground

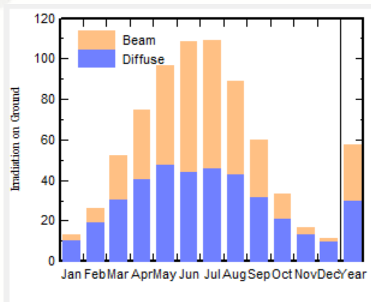


Calculation of Total Ground scattering on Backside

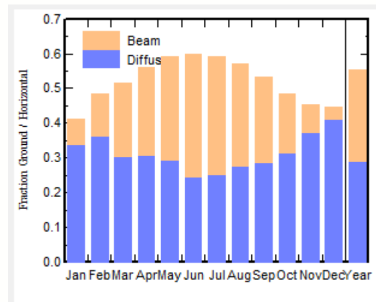
Putting it all together

Irradiance on ground

Absolute irradiance



Normalized to horizontal

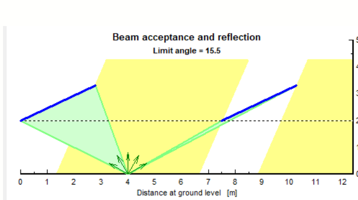


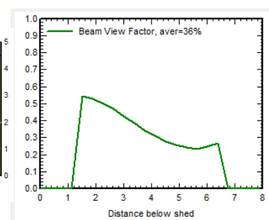
Irradiance on Ground is specific for location and geometry.
In this case (Geneva):

- Almost no direct in winter
- Fraction of diffuse on ground is constant over the year

Combine Ground acceptance with View Factor

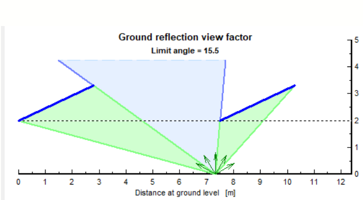
Direct

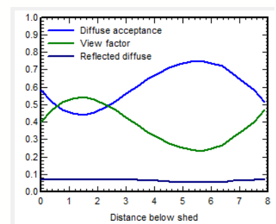




+

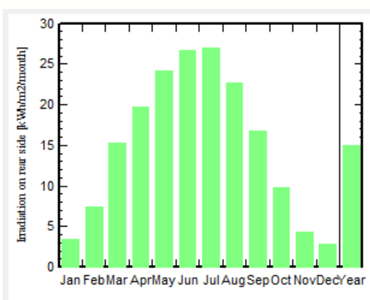
Diffuse



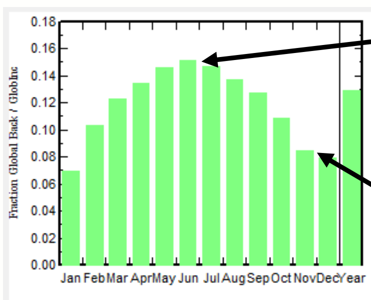


Ground Scattering on Backside:

Absolute irradiance



Normalized to Front



15% in summer

13% per year

8% in winter

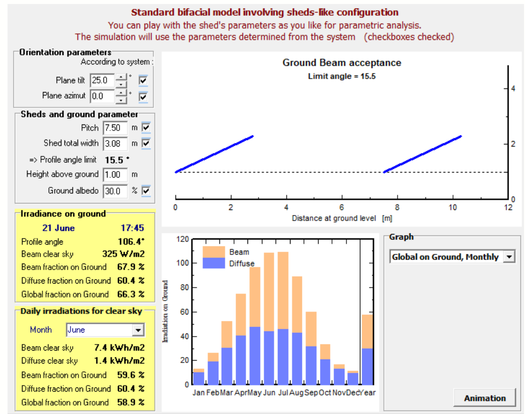
For this location and geometry, the additional bifacial gain is obtained mainly in summer

Example shed installation

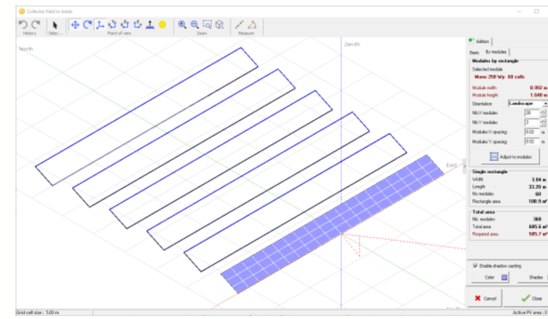
Basic PV system with sheds:

90 kWp in
6 rows of 3 x 20 modules landscape
Location Geneva, Switzerland: 46.3° N, 6.1° E
25° Tilt, 7.5m Pitch, 3m Width (GCR=0.4)
Mounted 1m over ground
Ground Albedo: 0.3
PV surface: 600 m²
Ground surface: 33m x 45m = 1500 m²

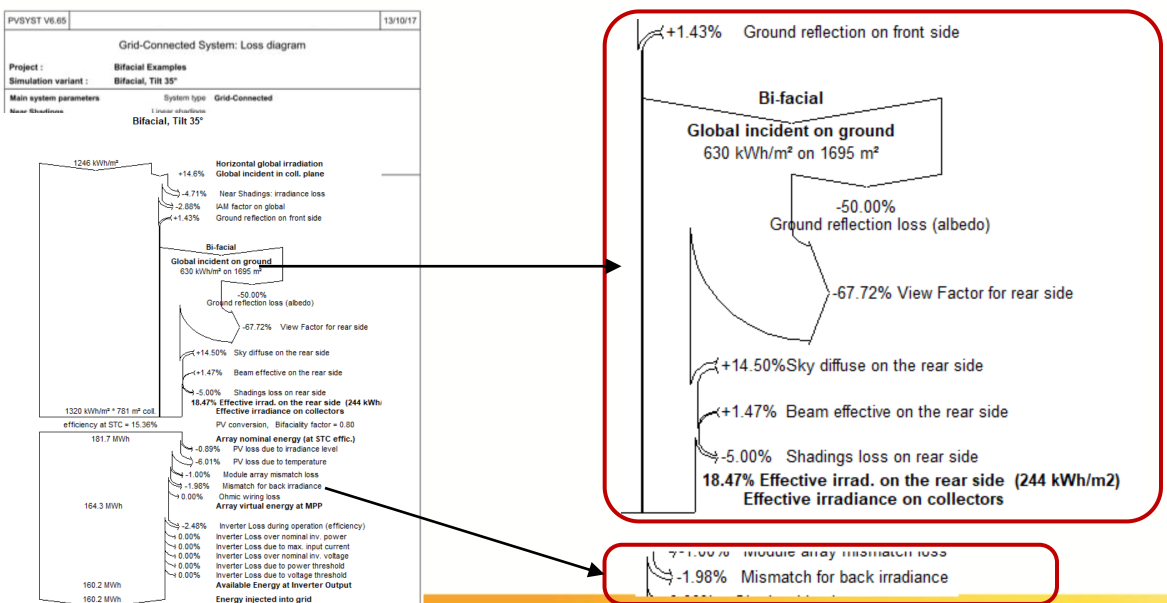
Definition of bifacial shed model



3D shading scene



PVsyst Report with simulation results

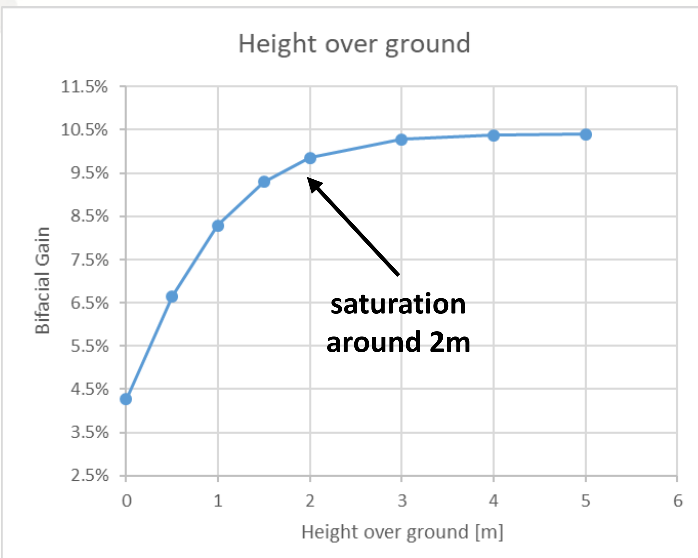


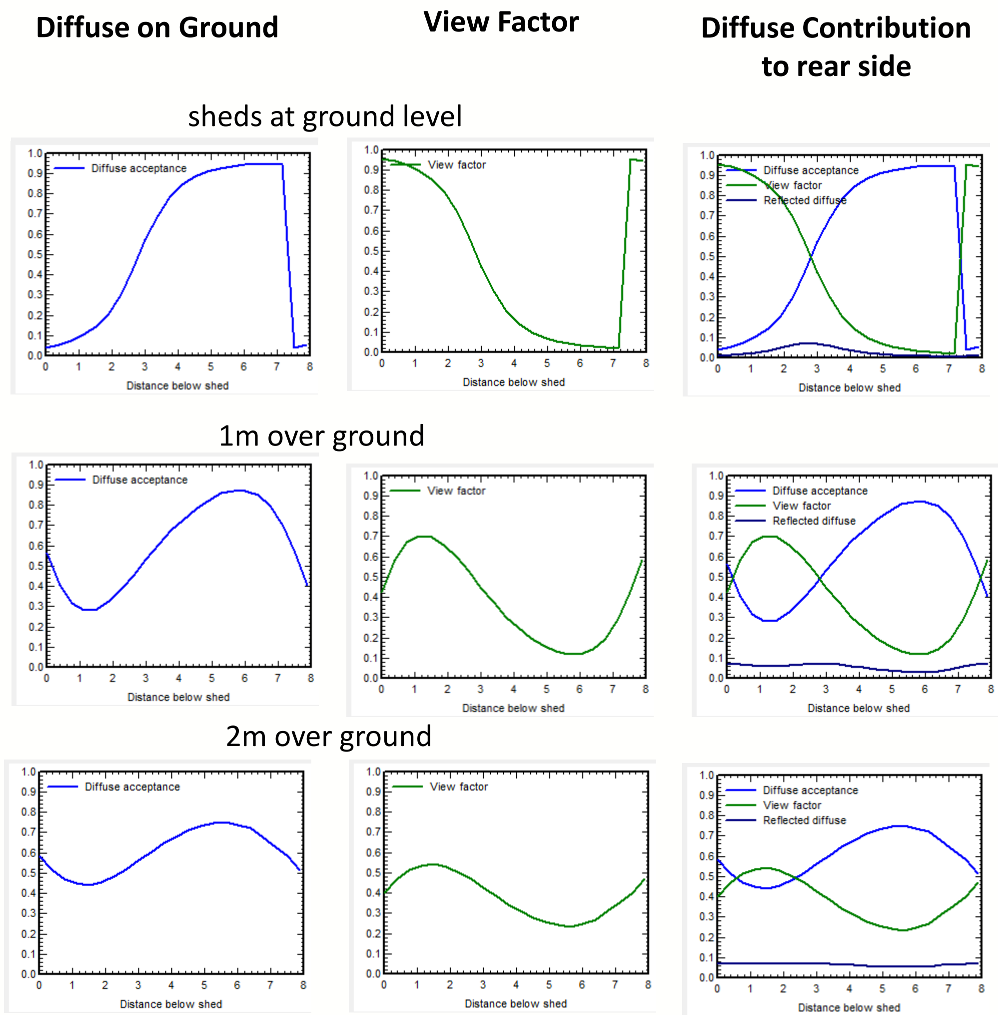
Global incident on ground
Ground scattering
Backside view factor
Front side view factor
Diffuse sky irradiance on back side
Beam irradiance on back side
Shadings on backside
Bifaciality factor
Mismatch for back irradiance

Height over ground

Height over ground

With higher mounting, the opposite behavior of ground illumination and acceptance gets attenuated.
Increase saturates around 2m (ground will appear homogeneously illuminated)



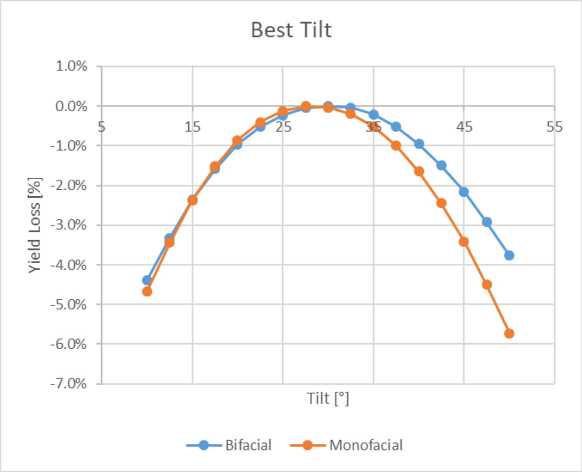


Impact of Tilt and Pitch

Bifacial impact on best tilt

Best tilt is slightly higher for bifacial.
Maximum in bifacial curve is slightly flatter.
Bifacial definitions:

- 2 m above ground
- 80% bifaciality factor
- GCR: 40%
- Ground albedo factor: 0.3

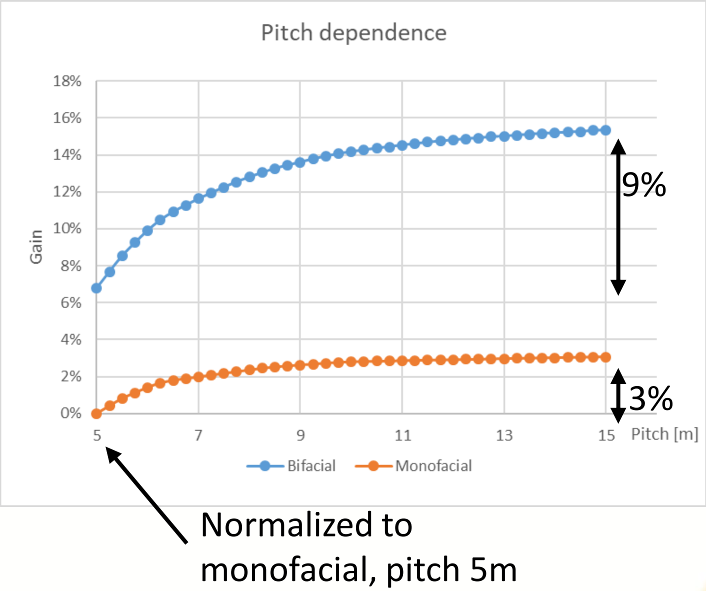


Gain increase as function of pitch

Bifacial definitions:

- 2 m above ground
- 80% bifaciality factor
- Tilt: 25°
- Ground albedo factor: 0.3

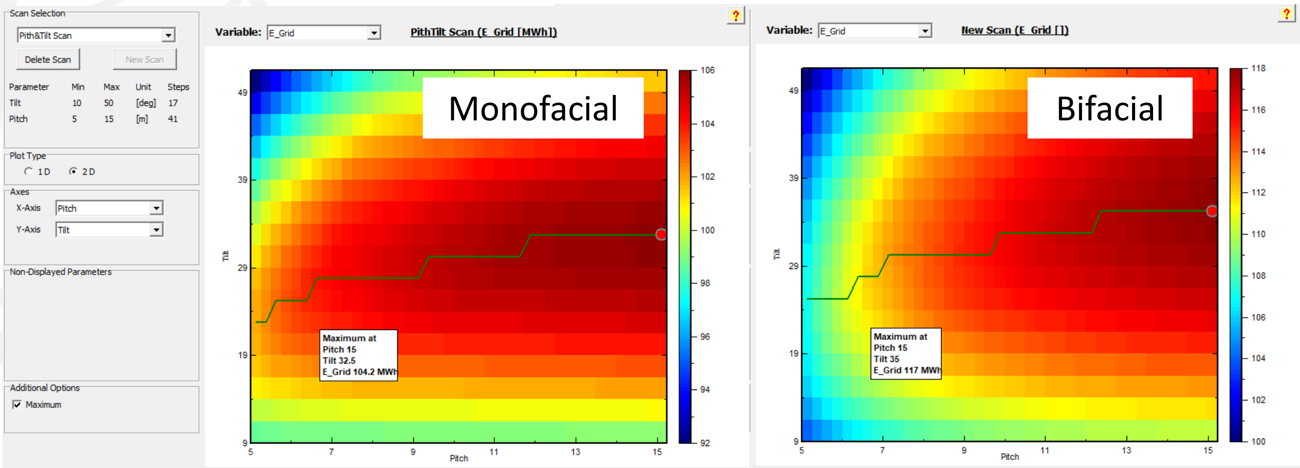
Increase of pitch (row spacing) reduces mutual shadings and thus increasing the yield.
Ground in between rows also gets more irradiance, leading to an increased yield gain for bifacial systems.
Best pitch becomes much more of an optimization issue.



Optimization studies and Analysis

Full optimization has to consider Tilt together with Pitch

Optimization tool to study yield as function of tilt and pitch



Bifacial installations prefer slightly higher tilt than monofacial

Detailed analysis possibilities

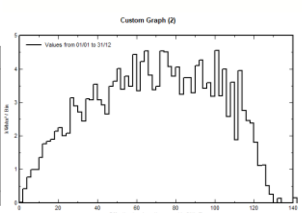
PVsyst provides a vast number of tools to perform default and custom analysis

Built-In Tables and Graphs

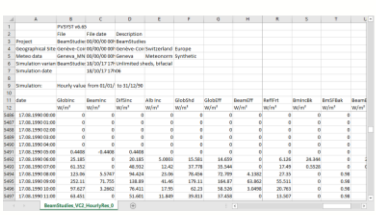
Bifacial, Tilt 25°

Effective incident energy (Transpos., IAM, Shadings)

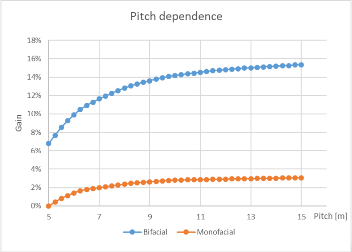
	GlobHor kWh/m²	GlobInc kWh/m²	GlobShd kWh/m²	GlobIAM kWh/m²	GlobEff kWh/m²	DiffEff kWh/m²
January	32.1	50.0	48.4	46.8	46.8	19.30
February	53.9	73.5	72.1	69.8	69.8	33.88
March	101.1	126.7	124.8	121.1	121.1	51.55
April	133.3	148.8	146.4	141.8	141.8	65.53
May	163.8	167.7	164.9	159.7	159.7	74.57
June	180.7	179.0	176.3	170.8	170.8	68.39
July	183.6	186.8	184.0	178.4	178.4	72.15
August	155.8	168.3	165.7	160.6	160.6	68.33
September	112.0	133.4	131.4	127.6	127.6	52.90
October	68.2	91.1	89.6	86.8	86.8	36.61
November	36.5	52.7	51.4	49.7	49.7	23.73
December	25.2	37.2	35.7	34.5	34.5	17.77
Year	1246.1	1415.1	1390.8	1347.4	1347.4	584.71



ASCII output for custom analysis

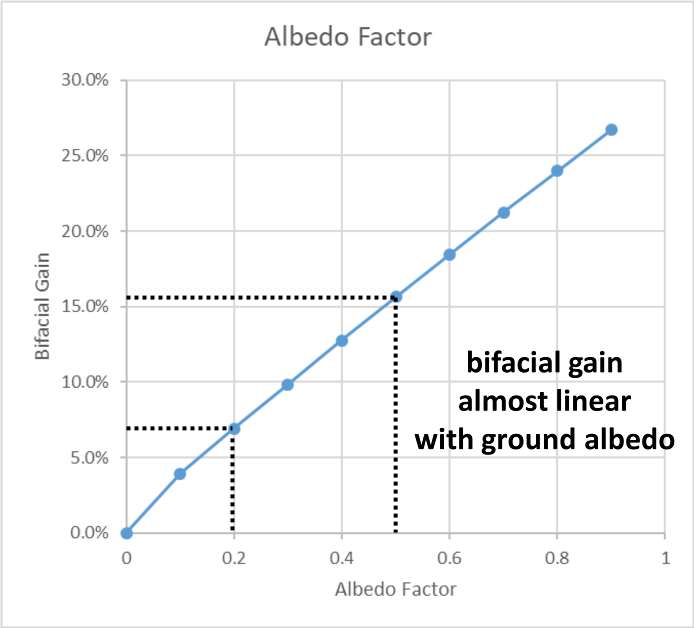


Batch mode (parametric scans)



Ground reflection (Albedo factor)

Bifacial Gain as function of Albedo Factor



Ground Type	Albedo factor
Worn Asphalt	0.12
Bare Soil	0.17
Green Grass	0.25
Desert sand	0.40
New concrete	0.55
Fresh snow	0.8-0.9

For common Albedo factor ranges (0.2 – 0.5) and the considered 90 kWp shed installation, the simulation predicts 7-16% bifacial gain.

Next Steps for PVsyst Bifacial Framework

Improvement of current bifacial model

Corrections still missing (important for vertical mounting):
- Circumsolar anisotropy for back side diffuse calculations
- IAM for direct light on back side and ground reflections
- The current simulation is recommended to be used only up to 60° Tilt

Model irradiance non-uniformity on back side

Model for bifacial PV modules on Trackers

Tracking devices are particularly challenging because the orientation and shading conditions are permanently changing.
First step will be to model a 'dynamic' shed scenario (horizontal axis trackers)

Bifacial treatment of any PVsyst 3D scene

Statistical approach with a random distribution of ground points:
Compute irradiance on ground points (Direct and Diffuse).
Calculate view factors for all PV back sides.
Limitations:
- No specular reflections
- Only the ground surface scatters back

Summary and Outlook

- Simulation of Bifacial PV systems with shed (row) layout is possible in PVsyst
  - V6.60 – 6.63 had an incorrect GCR factor (significantly underestimated yield)
  - V6.64: added sky diffuse irradiance on back side
  - V 6.65: added direct irradiance on back side
- Several approximations are made to handle the calculation
  - 2D shed model for shed layout (no border effects)
  - Ground reflection is diffuse and isotropic
  - Shadings of the mounting structure on the backside are accounted with a constant de-rate factor
  - An additional factor accounts for inhomogeneous illumination
- Main contributions of back side illumination are captured
- The approach will be generalized to allow the bifacial calculation for any 3D shading scene
- Validation with measured data (vertical installation) is in preparation
- **Every feedback is very welcome!**