FME SOLAR



Energy yield assessments for PV plants in complex terrain

2026

NORSK FORSKNINGSSENTER
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Date :30/06/26

Executive summary

This report presents a comparison study of four energy yield assessment tools, their functionality and their performance for PV plants in complex terrain. The plane-of-array (POA) irradiance of an operating bifacial PV plant in Norway is estimated using four tools, PVsyst, PVCase, RatedPower, and Climate Design Tool. The tools differ in complexity, scope, and physical models implemented, which all can affect the obtained results. The irradiance is modelled using raytracing for PVCase and Climate Design Tool, whereas PVsyst employs view factor modelling. RatedPower has options for running simulations using either view factor or raytracing modelling. We find that the model choice has a large impact on the simulated POA irradiance, where raytracing is more optimistic and provides higher estimates of yearly irradiance for both front and the rear side contributions than values obtained using view factor modelling.

To assess how the tools respond to terrain, simulations for the site with the actual terrain were compared with simulations of the same PV plant layout on an equivalent flat site for PVCase, PVsyst and Climate Design Tool. All three tools estimate lower annual total POA irradiation for the terrain case than for the flat reference case. However, the component-level response differs between the tools. The reduction in total POA is mainly associated with the front-side contribution, while the rear-side response differs more strongly between the raytracing tools and PVsyst. PVCase and Climate Design Tool estimate reduced rear-side irradiation when terrain is included compared to the flat site, whereas PVsyst estimates an increased rear-side contribution. This work shows that differences in model implementation and geometry handling can lead to different simulated POA irradiation estimates for PV plants in complex terrain.

Table of Contents

Executive summary 3
Introduction 5
1. PV plant modelling tools 6
1.1 PVSyst 6
1.2 PVCase 7
1.3 RatedPower 7
1.4 Climate Design Tool 8
1.5 Overview of EYA functionalities and physical models 10
2. Modelled PV plant 13
2.1 PVsyst model 14
2.2 RatedPower model 15
3. Results and discussion 15
4. Conclusions 20
5. Acknowledgements 20
References 21

Introduction

Ground mounted photovoltaic (PV) power plants in the Nordics are not limited to flat terrain and are subject to frequently changing cloud-cover in addition to low solar angles. Furthermore, bifacial installations are becoming the new standard and tracking systems have gained attention also in the Nordics. All these factors are increasing the complexity required for achieving accurate energy yield assessment (EYA) during PV plant development. PV development projects in the Nordics are also subject to limited margins. This means that de-risking is essential to achieve a larger share of PV in the Nordic energy systems, and accurate production forecasts are central to reduce uncertainties in PV development. Norway in particular has limited access to flat land, meaning that tools used to prepare EYAs should be able to account for the effects of the terrain on PV design and operating conditions. This includes variation in pitch, allowing for different orientations and tilt in PV rows and tables, and tracking algorithms accounting for variation in the terrain. Furthermore, complex terrain will also affect interrow shading and mismatch as well as rear-side irradiance.

EYA tools estimate the expected power production of a PV plant by running simulations that include irradiance modelling, PV module and inverter performance, and system losses. There is a wide range of available software for EYAs, which employ different physical models and different combinations of models. Commercial software is also often updated, which may lead to changes in the physical models applied. The accuracy of the simulations is not only dependent on the tool used, but also the quality of the input weather data and assumptions for performance losses. PVsyst is the de-facto industry standard tool for EYAs for PV plants, with many lenders and investors requiring that EYAs are performed in PVsyst. While PVsyst is widely used and allows detailed simulations of PV plant performance from the climate resource throughout the system to the electricity that is ultimately exported to the grid, the software has certain limitations including modelling and simulations of systems in complex terrain.

There are few in-depth studies that compare commercially available EYA tools. One study from 2026 compares 29 EYA simulations using a range of modelling tools, and found that the error in the modelled front side irradiance ranges from -11% to 1.99%, while the rear side irradiance errors can be as large as ± 100% [1]. The modelling tools used are anonymized, but the results clearly show that there in general are far larger errors in the simulated rear side contribution than for the front side. A similar study found that EYA tools employing the same irradiance model resulted in front side irradiance values differing by up to 123 W/m2 within a single timestamp [2]. Furthermore, there are large differences in the default derate losses suggested by the EYA tools. For example, PVsyst default losses add up to 3.56 %, while the number is 11.37% for RatedPower [2].

This report presents a comparison of the functionality and performance of three tools that are widely used in the industry, PVsyst, RatedPower, and PVCase, and Climate Design Tool which addresses some of the limitations of complex terrain in the other commercially available software. The report's focus is on the simulated front- and rear-side irradiance as plane-of-array (POA) irradiance is not only important for the energy yield, but will also be

affected by the flexibility of the software to represent non-homogenous PV layouts. The tools evaluated differ in scope, but have in common that their simulations rely on an accurate description of the irradiance conditions. The simulations are performed for an operating PV plant located close to Haugesund. The site is a decommissioned landfill, which limited the possibility to perform earthwork. Thus, the PV plant layout is terrain following, leading to variations in pitch, skew, and azimuth.

1. PV plant modelling tools

EYAs are essential during the development stage of PV projects. Their focus shifts as the project advances from early development towards construction. While understanding energy yield and yield uncertainties is crucial during the earlier stages of a project, engineering aspects become increasingly important during the more advanced phases. Different tools are needed at different stages of PV planning as accuracy requirements increase and the scope becomes more detailed. The process typically starts with software tools that focus on generation estimates and gradually moves towards more engineering-focused tools that provide outputs such as bill of quantities, layouts, and single line diagrams.

While PVsyst, RatedPower, and PVCase aim at full design and EYA simulations for PV plants, PVCase and RatedPower have a larger emphasis on power plant layout and engineering than PVsyst. Climate Design Tool on the other hand is aimed at preliminary design, with focus on spatially resolved irradiance modelling and PV power generation. The following sections introduce the four tools used in this work.

1.1 PVSyst

PVsyst is a widely used professional software for simulating and evaluating the electricity production from PV plants. PVsyst has been developed specifically for the solar industry to evaluate the expected energy yield of PV projects across their lifecycle, from early-stage concept development to detailed design and operational analysis.

PVsyst incorporates meteorological data, component performance models, and system configuration parameters to prepare a model of a PV plant. Simulations are then run to estimate system losses and performance, thereby allowing users to quantify energy production and assess the impact of various design choices and loss mechanisms. The software has functionality for detailed analysis of key simulation inputs, including weather meteorological data, individual loss factors, and more.

PVsyst is widely recognized by lenders, independent engineers, and financial institutions as a bankable modelling platform. Its reporting outputs support technical due diligence, EYAs, and project risk analysis, making it a common tool for EYA for PV projects worldwide. However, the 2D view factor model implemented for irradiance estimations imposes limitations that can reduce the accuracy of the EYA for sites in complex terrain [3]. The 2D modelling requires simplifications of the layout where the ground is considered homogeneous below a PV row, module orientations are grouped into averages, and the

allowed variation in pitch within a plant sub-area is limited [3]. PVsyst version 8.1.1 was used in this work.

1.2 PVCase

PVCase is a software suite for design and EYAs for PV plants [4]. This includes four separate programs that cover the workflow from site selection, PVCase Prospect, to 3D power plant design, PVCase Ground Mount and Roof Mount, to energy yield assessment, PVCase Yield. Ground Mount is a plugin to AutoCAD where PV systems can be designed using automatic row placement while allowing for varying pitch. The generated layout can be optimized using simplified EYA simulations and the layout can be exported to PVCase Yield and PVSyst.

PVCase Yield employs raytracing to simulate the irradiance at site, and the sky dome is represented using the Perez model [6]. The ground albedo is an input variable and can have yearly or monthly resolution. Raytracing modelling accounts for shading from all included geometries in the layout, as well as reflection. The effective rear-side irradiance of bifacial modules is calculated by multiplying the POA irradiance with the module bifaciality factor. PVCase supports tracker systems with backtracking algorithms. However, the tracker algorithm implemented assumes a flat terrain.

The electrical response of the PV modules is calculated using a single-diode equation, and the module temperature is represented using an equivalent resistive-capacitive thermal circuit [5]. The electrical and thermal properties of the PV modules are coupled through the module temperature, and these two models are solved iteratively until convergence of both electrical and thermal response is achieved. The output of Yield simulations includes energy yield estimations, performance ratio, time series of average AC and DC power, rear- and front-side irradiance, and losses with an hourly resolution. PVCase Yield version 0.115.10 was used in this work.

1.3 RatedPower

RatedPower is a browser-based software platform for photovoltaic power plant design and EYA, integrating layout generation, electrical design, and performance simulation. For energy yield assessment, the tool offers two modelling approaches: a 2D standard energy model and a 3D raytraced energy model. The software was earlier called “pvDesign”, and both names still appear in technical documents and literature.

The 2D standard model relies on conventional POA irradiance transposition using a Perez-type sky model and view-factor-based shading calculations [7]. Shading between rows and from near-field objects is represented through simplified geometric projections, and bifacial rear-side irradiance is estimated from ground- and sky-view factors. As with other view-factor-based tools, this approach assumes relatively regular layouts with limited spatial variation in pitch, elevation, and orientation within defined sub-areas. Furthermore, the 2D model in RatedPower assumes a flat terrain. The 3D model performs irradiance calculations using raytracing on a detailed three-dimensional representation of the site. This enables treatment of complex terrain, irregular row geometry, and non-uniform shading conditions. Front- and rear-side irradiance are calculated at module level by resolving direct, diffuse, and

reflected components within the full 3D scene. Both models allow for fixed tilt systems and single-axis trackers with backtracking.

PV module performance is simulated using a one-diode electrical model including temperature correction and mismatch losses. The simulation outputs include hourly energy yield, performance ratio, specific yield, and loss breakdown. The 2D model allows time resolution down to 1 minute, while the 3D model is only implemented for hourly resolution. In addition to the EYA, RatedPower can also generate CAD drawings of the site and bills of materials. The generated layout can be exported to PVSyst. RatedPower version 33.35.0 was used in this work.

1.4 Climate Design Tool

Climate Design Tool (CDT) is a component-based toolset for climate-sensitive design analysis developed by the Climate and Buildings group at NMBU. The tool operates within the Grasshopper environment in Rhino 3D, allowing geometric modelling, parametric setup, simulation, and result visualization in a single workflow [8,9]. While CDT is being developed as a broader suite for climate-responsive design analysis, the current implementation has a particular focus on photovoltaic applications in early design phases. Climate Design Tool is slated for publication and open sharing late 2026.

A key strength of CDT is that it can work directly on detailed 3D geometry and therefore account for geometrical complexity that is difficult to represent in simplified PV design tools. This includes terrain variation, local obstructions, arbitrary panel orientations, custom spacing between rows, and detailed mounting geometry. Because the workflow is embedded in Rhino/Grasshopper, both imported and parametrically generated site and system geometries can be used directly in the simulation model [9-11]. An overview of the CDT workflow used in this study is shown in Figure 1. The workflow starts from terrain and system geometry in Rhino/Grasshopper, followed by model assembly, assignment of weather data and material properties, raytracing with Radiance, and post-processing of irradiance results into PV performance metrics.

The radiative calculations in CDT rely on preprocessing through Ladybug Tools and raytracing with the Radiance engine [10-14] . In this workflow, the geometry is prepared in Grasshopper, material properties are assigned, weather data are connected, and a Radiance model is generated for simulation. This makes it possible to calculate POA irradiance with high spatial resolution while accounting for complex shading and reflections from terrain, surrounding objects, and nearby surfaces [9]. Compared with more simplified view-factor-based approaches, this is particularly relevant in cases where reflected irradiance, self-shading, edge effects, or irregular terrain are important.

PV performance is calculated using a simplified but physically informed PV model for both monofacial and bifacial modules [9]. The model combines front- and rear-side irradiance with ambient temperature, wind speed, module efficiency, temperature coefficient, bifaciality,

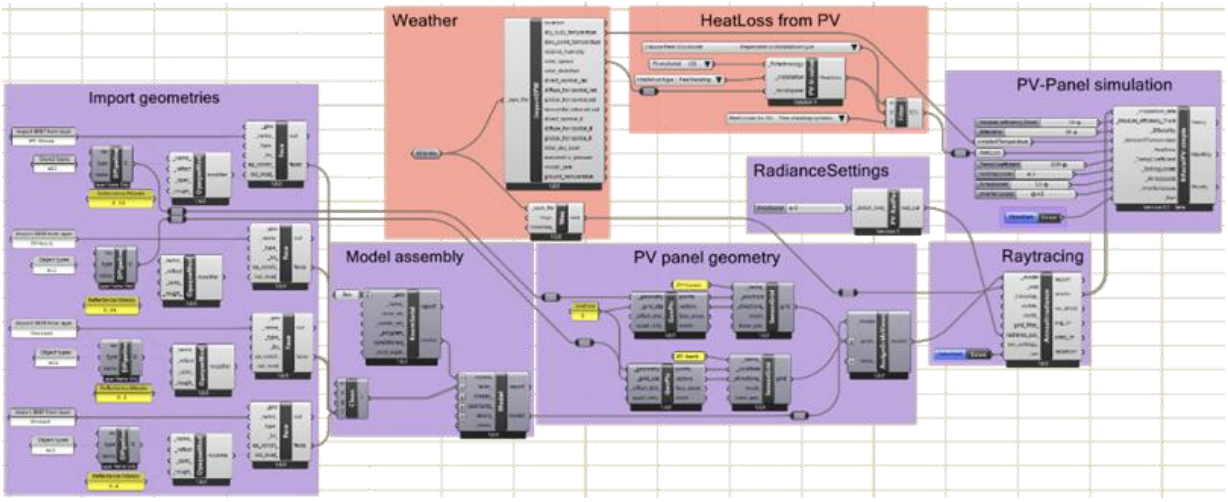


Figure 1: *Overview of the Climate Design Tool workflow in Grasshopper, from import and preparation of terrain and PV geometry, through weather data selection and Radiance-based raytracing, to post-processing of irradiance results into PV performance metrics. (Previously published in [9]).*

and system loss factors. Module temperature is represented through a heat-loss formulation based on irradiance, ambient temperature, and wind speed, while yield is calculated from irradiance and temperature-adjusted efficiency [9,15,16]. Simulating strings, with separate inverters etc., is possible but in practice it heavily complicates the modelling process. PV production is therefore processed without considering stringing. In its present form, the aim is to capture the main physical effects with high 3D model fidelity, moderate PV model complexity, and relatively short computational time. In view-factor based models, most losses are calculated step-wise and are therefore often available as individual values. CDT uses raytracing for irradiance calculation, and the PV conversion is calculated for each module, covering many different physical aspects in high spatial detail. Thus, the losses available, without custom configurations, are more limited in this approach. This apparent lack of detail is not an indication of less precise or detailed models, but the inverse, that the models are more precise, and the calculation is more spatially detailed than is typical of view-factor based models. An overview of losses is shown in figure 2 as a PV conversion flow diagram.

The approach described by Petersen and Frimannslund was validated both against measurements and PVsyst, showing good agreement with both measurements and reference tools, despite the moderate complexity of the PV model itself [9]. For CDT, the main advantage is therefore not only the PV performance model itself, but the combination of detailed 3D geometry handling, high-fidelity raytracing, and direct integration in a modelling environment already used by architects and engineers. This makes CDT particularly relevant as a flexible analysis tool for early-stage design and comparison of PV layouts in complex terrain.

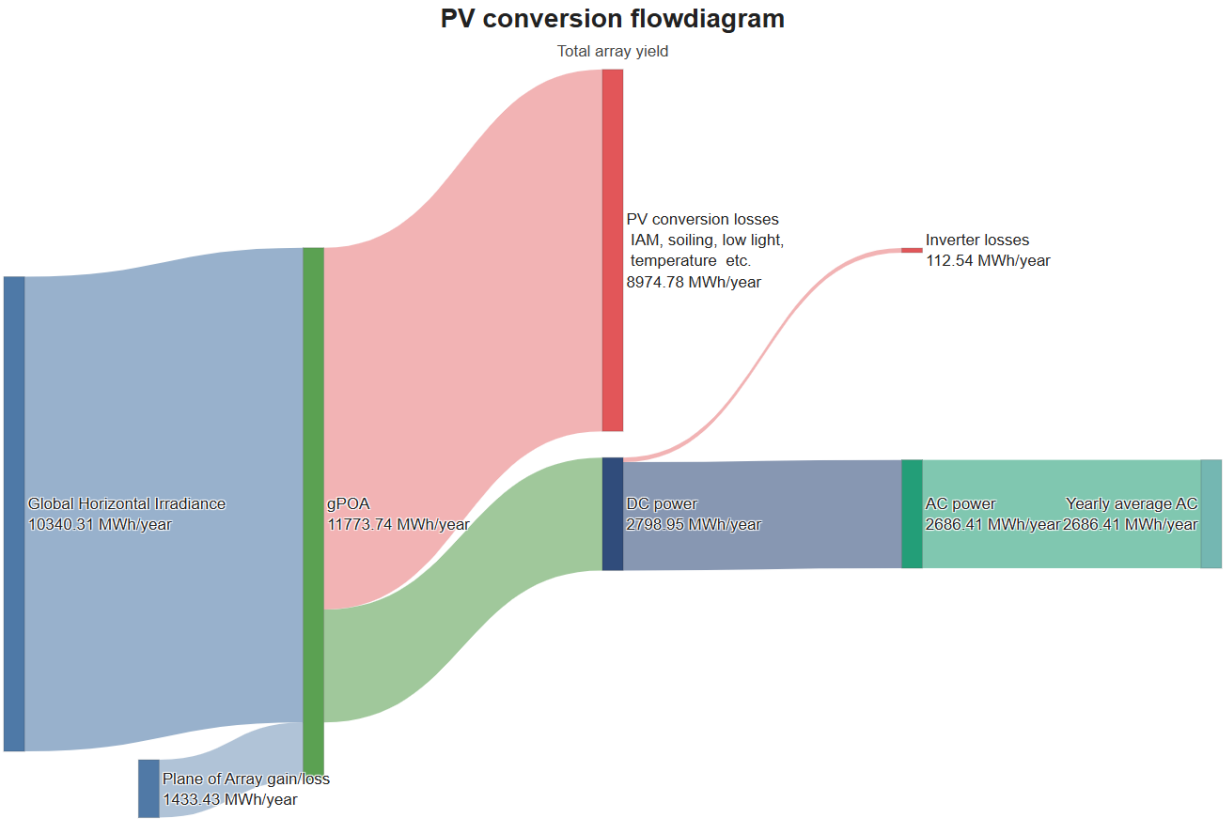


Figure 2: *PV conversion flow diagram showing the losses, and gains, given as outputs in a Climate Design Tool.*

1.5 Overview of EYA functionalities and physical models

Table 1 and 2 present an overview of functionalities and physical models of the four EYA tools assessed in this work. Table 1 lists the scope and relevant utility functionality included in each tool. Possibilities for export and import of layout were included as this is highly relevant when two or more tools are combined to leverage the different capabilities of EYA tools. Neither PVCase nor RatedPower allows for layout import, but both have implemented export in PVsyst format. This reflects the emphasis of both providers as design tools, as well as the industry standard requirement of PVsyst EYAs for bankability considerations.

PVCase Ground Mount requires AutoCAD for PV plant design, which is associated with a cost in addition to the PVCase license. RatedPower on the other hand only provides full design

freedom for users with an upgraded license, where only automatic layout generation is included for the standard user. The 3D raytracing simulations are also only available with an upgraded license. PVsyst runs as a stand-alone software where all functionality is included. Climate Design Tool will be published openly later in 2026, requiring Rhino3D and Ladybug tools.

Table 1: *Overview of the functionalities of the four tools considered in this work, including implemented data accessibility.*

	PVsyst	PVCase	RatedPower	Climate Design Tool
Scope	Primarily EYA	Full design and EYA	Full design and EYA	Primarily EYA and detailed optical modelling
Design capabilities and software	Yes	Yes – as an AutoCAD plugin	Yes – cloud based. Full design freedom if upgraded license	Yes – through Rhino3D
Batch Simulations	Yes	Yes	Yes	Yes
Automated design tools	Yes	Yes	Yes	No
Layout import	Yes	No	No	Yes (PVsyst, any 3D format)
PVsyst export	N/A	Yes, 3D layout export	Yes, 3D layout export	No
Implemented meteorological data	Meteonorm 8.1 PVGIS included, other sources including Solcast, SolarAnywhere and Solargis may be imported at a premium	PVGIS 5.3, SolarAnywhere at a premium	PVGIS SolarAnywhere NASA albedo	EPW import from e.g. klimadataforbygninger.no, climatedataforbuildings.eu or EPW Map
Implemented terrain data	Various import formats	Google terrain	Copernicus 30m Terrain, Google terrain	Options for terrain import through other tools implemented in Rhino and Grasshopper
Component library	Yes	No	Yes	N/A
PV module data	Datasheet PAN-file	Datasheet PAN-file	Datasheet PAN-file	Datasheet – efficiency, temperature coefficient, and bifaciality factor
Inverter data	Datasheet OND-file	Datasheet OND-file	Datasheet OND-file	Datasheet – nominal efficiency and clipping limit

Table 2 lists relevant physical models implemented in the four tools. Central to this work is the irradiance models, where all tools have raytracing capabilities, except for PVsyst which uses a view factor model. View factor models have a low computational load, but rely on a simplified PV layout where rows are represented by a 2D cross-section. Raytracing has a higher computational load, but allows for a full 3D treatment of the irradiance and shading conditions. Both PVsyst and CDT are well documented in open sources, making it possible for users to evaluate the results in the context of the physical models applied, as well as underlying assumptions and simplifications. PVCase Yield provides documentation for the users only after a license is purchased, where the detail in the method description can be limited. RatedPower has openly published the documentation for the 2D view factor model, but not for the raytracing option.

Table 2: *The physical models implemented in the four tools considered in this work.*

	PVsyst	PVCase	RatedPower	Climate Design Tool
Optical modelling	View Factor	Raytracing	Options for both view factor and raytracing	Raytracing
Layout limitations	Modules must be grouped into averages for complex terrain	Each defined sub-area have the same azimuth and pile-height range	Each defined sub-area have the same azimuth and pile-height range	CDT can treat any geometry imported or built in Rhino as a PV module
System mounting	Fixed tilt Single-and Dual-axis tracking	Fixed tilt Single-axis tracking Rooftop	Fixed tilt Single-axis tracking	Fixed tilt – any object can represent a PV module Single-axis tracking via post processing.
Electrical modelling	Single-diode model	Single-diode model	Single-diode model	Temperature and irradiance corrected efficiency
Stringing	Yes	Yes	Yes	Not Implemented
Mismatch	Yes	Yes	Yes	Visual evaluation, calculation to be implemented.
Time resolution	Any (Hourly default)	Hourly and 15 min	View factor: down to 1 min Raytracing: hourly	Hourly as of now, sub hourly to be implemented.

2. Modelled PV plant

The comparison of PVsyst, PVCase, RatedPower, and Climate Design Tool is performed as a case study simulating a Norwegian ground mounted system located at Haugaland interkommunale miljøverk, close to Haugesund, see Figure 3. The PV plant is located at a decommissioned landfill, which significantly limited the possibility for earthwork at the site. The PV plant is a fixed-tilt bifacial system with a tilt angle of 30˚ and an installed capacity of 3 MW_p located in a south facing hill. While the overall orientation of the system is south facing, the terrain following layout has resulted in sub-areas where the PV tables are not oriented directly south. Similarly, the rows are not completely horizontal in the east-west direction, as tables are slightly skewed due to variations in the terrain. The east-west cant of a single table can reach values up to 10%.



***Figure 3**: The PV plant is located in a complex terrain, with varying slopes, orientations, and pitch.*

To evaluate the performance of the EYA tools included in this study, simulations are both performed for the as-built layout and for an identical layout in a flat terrain. This allows for identifying differences in simulation results directly caused by the complex terrain at the site. Both models were built using PVCase Ground Mount, where the terrain was imported from the google terrain database [17-18]. The meteorological data used for all simulations was a 30-year TMY file with hourly resolution retrieved from the climate data from buildings database [19-20]. The TMY file was chosen by finding the closest grid point in the database, located approximately 20 km from the PV plant.

The albedo values and soiling losses used are listed in Table 4. Earlier comparison studies of energy yield assessment tools have found that different choices of derate losses are a large driver for errors and biases in PV plant simulations [1-2]. Thus, all optional losses except soiling were disabled for the simulations in this work. The non-optional losses estimated by the EYAs arise as a result of the physical models applied, and include for example shading losses, losses due to PV modules operating at temperatures above the standard test conditions, and inverter efficiency losses. PVsyst, RatedPower and CDT apply a PV cell temperature model dependent on tunable heat loss factors. For all simulations, the constant heat transfer component, U_0, was set to 29 W/m^2K and the convective heat transfer component U_1 was set to 0 W/m^2K.

Table 4: *Monthly albedo and soiling loss values applied in the EYA simulations*

	Albedo	Soiling loss (%)
January	0,30	1.00
February	0.30	1.27
March	0.24	1.00
April	0.20	1.00
May	0.20	1.00
June	0.20	1.00
July	0.20	1.00
August	0.20	1.00
September	0.20	1.00
October	0.20	1.00
November	0.20	1.00
December	0.20	2.12

2.1 PVsyst model

The 3D model from PVCase was imported into PVsyst without any major issues. To make PVsyst work with tables that have different orientation, tables that share *approximately* the same orientation must be grouped into separate sub-arrays, as indicated in Figure 4 by the two different colors. The word *approximately* was chosen purposefully, as the reader may appreciate that the grey tables do not have the exact same tilt and azimuth. PVsyst automatically groups tables with a relatively similar orientation into heterogeneous fields, using tilt difference 10 ° as the highest allowed within a group of tables. The user may override the default value, and 16° was used in this work to make it possible to run the simulations. Treating differently oriented tables as one is disadvantageous in that PVsyst will calculate a weighted average tilt and azimuth of all the relevant tables based on their surface area, which leads to growing inaccuracies in the energy yield simulations as larger deviations are permitted.

The procedure of adding separate arrays as indicated in Figure 4 avoids, or at least limits, this inaccuracy but requires some additional time to set up the model correctly. It may also cause some challenges including distributing inverters correctly.

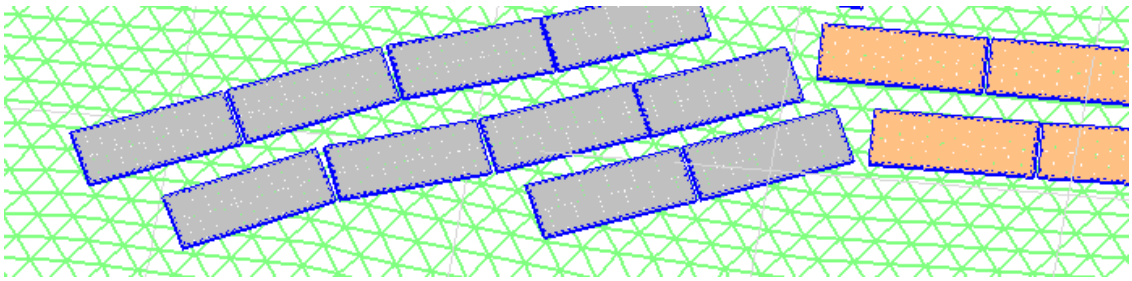


Figure 4: *Tables simulated in PVsyst are grouped based on having approximately the same orientation. The table grouping is here indicated in grey and orange. The mean orientation of each group is used for irradiance modelling.*

2.2 RatedPower model

RatedPower does not have an option for importing terrain or PV power plant layout from other modelling tools. This means that the model applied in RatedPower had to be built within the software. This has led to some differences between the model employed in RatedPower and the other three tools. The design freedom for users of RatedPower is dependent on their type of license. The basic subscription only includes automatic table placement in user-defined PV areas, where manual editing is available only in advanced subscriptions. Building models that are an exact match of layout generated in PVCase was not possible, even with an upgraded license.

Design limitations in RatedPower include only one allowed azimuth within a sub-area, and that the electrical configuration can reject otherwise valid placement of PV tables due to long cable runs between inverter and string. To overcome table rejection, the layout had to be constructed using a low DC/AC ratio, leading to a higher number of inverters at site. The number of modules as well as pitch distance matches exactly the other models. The table placement is matched at the best of our ability using the layout generation in RatedPower. Furthermore, RatedPower does not allow for disabling ohmic losses as the software requires specification of cabling in the layout to perform EYA simulations, and ohmic losses are determined directly from the cable run length.

This project was granted one simulation using the 3D raytracing model of RatedPower, allowing for modelling the PV system in terrain. However, this limits the comparison of the performance of RatedPower in terrain relative to the flat reference.

3. Results and discussion

Energy yield simulations were performed for all four tools, PVCase, RatedPower, PVsyst and CDT. Both models implemented in RatedPower were included, the 2D standard view-factor based model and the 3D raytracing option. Figure 5 displays the total yearly irradiation estimated for all models, where front- and rear side POA contributions are indicated. It can be noted that the 2D version of RatedPower only reports the total irradiance in the POA, and not the front- and rear side components. There is a spread in the estimated POA irradiance, where PVCase, RatedPower 3D, and CDT predict larger total irradiance than RatedPower and PVsyst. PVsyst yields lower estimates of both the front and rear side contributions, where the rear side contribution is 30% lower than the mean of rear-side irradiance estimates for the other tools. PVCase, RatedPower 3D, and CDT rear-side estimates differ by 15 kWh/kW_p/year. The tools using view factor modelling, RatedPower and PVsyst are not aligned in their total irradiance estimates, which differ by 197 kWh/kW_p/year. This might be related to the separate model used for the RatedPower simulations, but it can also be noted that PVsyst simplifies terrain effects while RatedPower assumes a flat terrain.

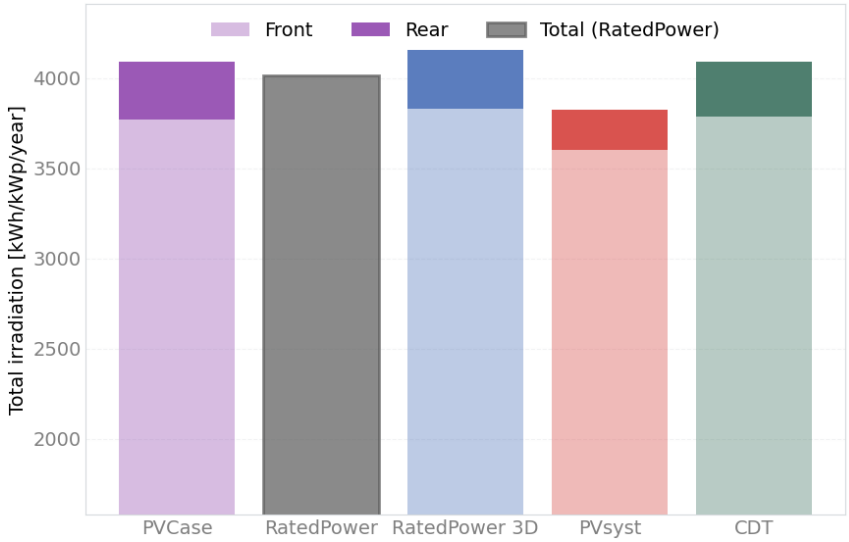


Figure 5: *Total yearly irradiation for the four tools compared in this work. The darker colors indicate the rear-side contribution, and lighter the front side. RatedPower only reports total POA irradiation, and not the front- and rear side components separately.*

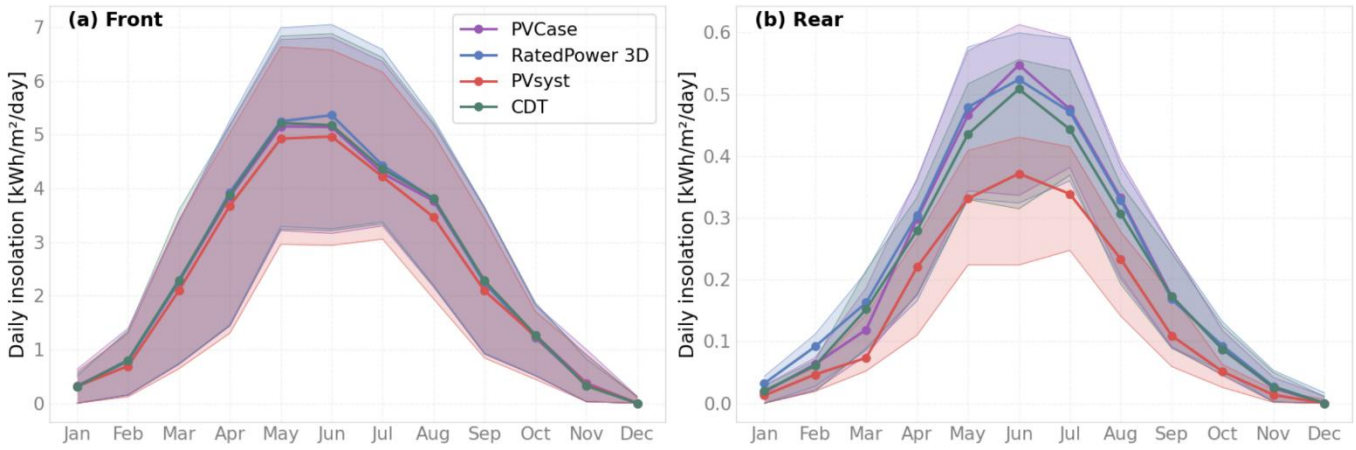


Figure 6: *Monthly Median daily insolation for the front (a) and (b) the rear plane-of-array, respectively. The colored bands indicate the interquartile range, reflecting the monthly range of simulated values.*

Figure 6 shows the monthly median of the daily insolation in the front (top panel) and rear (bottom panel) POA. The shaded bands indicate the interquartile range, and represents the monthly spread in the daily insolation. All the tools agree fairly well for the front side POA, where PVsyst provides estimates slightly lower than the other tools throughout the year. The simulated rear-side irradiance shows larger relative differences, where PVsyst estimates are clearly lower, both median values and the interquartile range. The three tools that show good agreement, PVCase, RatedPower 3D, and CDT rely on raytracing for irradiance simulations, while PVsyst and RatedPower employ view factor modelling. The results show that the irradiance model used will have an effect on the simulated irradiance, where the raytracing tools are more optimistic than for the view factor tools.

Figure 7 shows spatially resolved irradiance maps obtained using CDT plotting the total yearly insolation of each module at the site. The figure clearly illustrates the difference in shading conditions that can arise in PV plants in complex terrain, with large variations both for the front and the rear side POA. The terrain leads to variation in both row spacing and cant, but also varying distance between the table backside and the ground. This highlights both the challenges of designing and operating PV plants in complex terrain, as well as the complexity that has to be accounted for in energy yields and irradiance simulations.

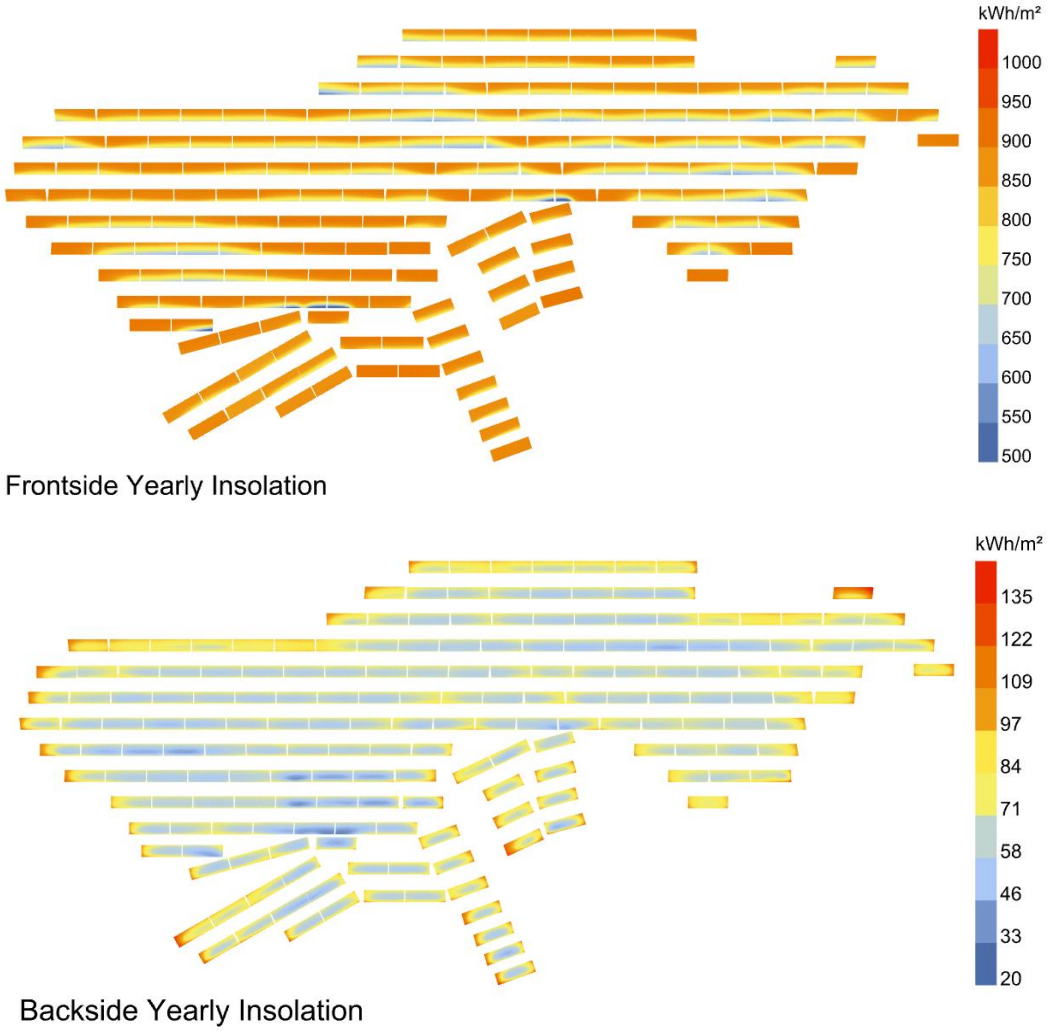


Figure 7: *Front (top) and rear (bottom) side yearly insolation map simulated using Climate Design Tool.*

The terrain-case comparison shows that the tools differ both in total annual irradiance, where the largest tool-to-tool differences are found for the rear side POA. However, these results alone do not distinguish between tool differences and differences in terrain handling. To isolate the terrain response, simulations for the actual terrain at site are compared with an identical layout on a flat site. Figure 8 displays the total annual irradiation for both the site

with and without terrain, as well as the differences in the total, front, and rear components of the POA irradiation for PVCase, CDT and PVsyst. RatedPower is not included as the 2D model does not include terrain effects. Only one simulation using the premium 3D model was available to the project, meaning that comparison between terrain and the flat reference was not feasible. The PVCase, CDT, and PVsyst simulations show that all three tools agree that the annual irradiation is reduced when terrain is included in the simulations compared to the flat reference. The largest reduction is seen for PVsyst, which also provides a lower estimate of irradiation for both cases. However, while both PVCase and CDT estimate a reduced rear side irradiation for the site with terrain compared with the flat, PVsyst indicates an increased rear side contribution for the terrain. PVsyst also estimates a larger reduction in the front side POA than the two other tools.

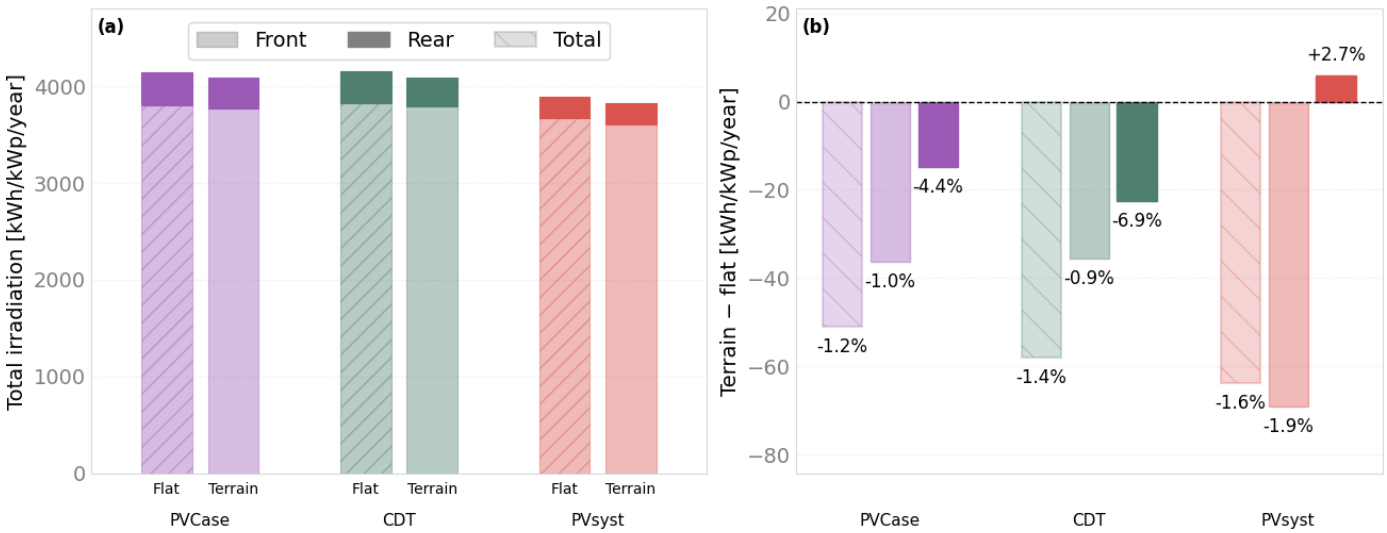


Figure 8: *(a) shows the total yearly front and rear components of the plane-of-array irradiance for the terrain and a flat site simulations. (b) displays the difference in total irradiation for the total, front, and rear irradiation between the terrain and flat-site simulations.*

Figure 9 shows the monthly median of the daily difference between the terrain and flat-site simulations for the total and the rear side POA irradiation. Introducing terrain reduces the total POA irradiation for all three tools, where PVsyst estimates a larger reduction in the winter months and a smaller reduction during summer compared with PVCase and CDT. For CDT, the largest terrain-driven reductions in the irradiation are indicated in the summer months. The rear-side irradiation clearly separates the tools using raytracing, PVCase and CDT, from the view factor modelling in PVsyst. Both PVCase and CDT indicate a clear terrain-driven reduction in the rear side contribution, with a clear seasonal trend where the largest reduction is seen in the summer months. CDT indicates a larger reduction in the rear POA than PVCase. PVsyst simulations also show a seasonal trend, but indicate that the rear side irradiation is increased from the flat site to the terrain, peaking in the summer months.

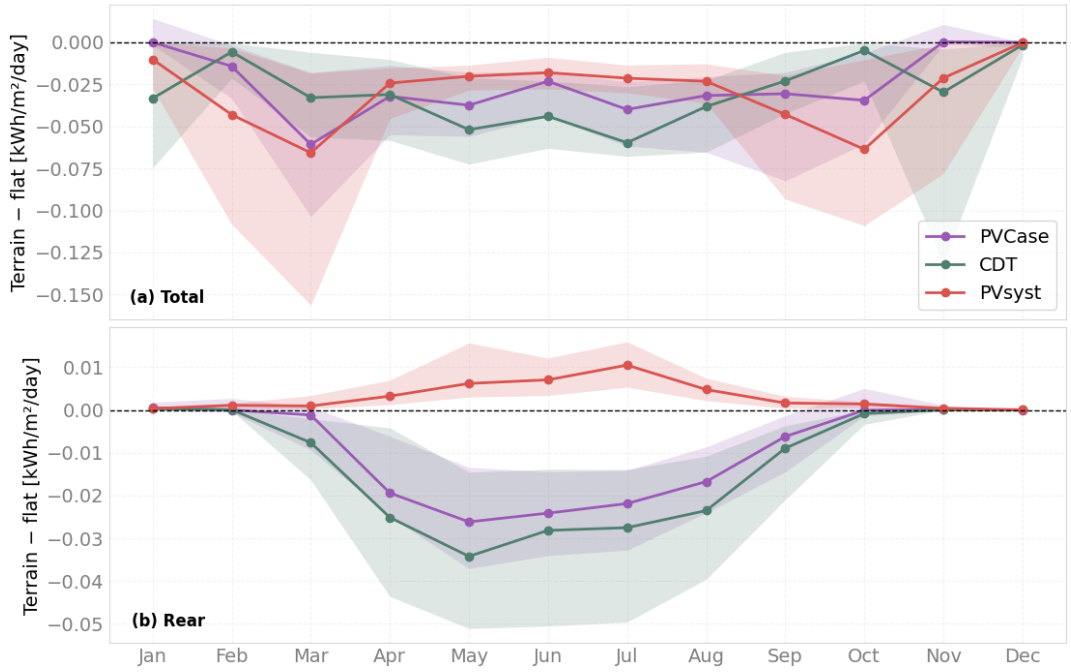


Figure 9: *The monthly median of daily differences in irradiation between simulations of flat site and terrain for the total (a) and the rear side (b) plane-of-array. The bands indicate the interquartile range, reflecting the range of difference values for each month.*

The simulations for the site with terrain included, and the comparison with a flat reference site, display a difference in the results obtained with view factor modeling and raytracing. The view factor models, RatedPower 2D and PVsyst, estimate lower total annual irradiation and rear side irradiation than the raytracing models implemented in PVCase, CDT, and RatedPower 3D. This is also seen for PVsyst for the flat reference case. Introducing terrain further increases this gap: where PVsyst showed a larger reduction in front side irradiation due to terrain (−1.9%) than both PVCase (−1.0%) and CDT (−0.9%), and was the only of the three tools that indicated an increased rear side irradiance when terrain was introduced.

These discrepancies can be due to the differences in how view factor and raytracing modeling treat the input terrain and PV layout. Raytracing is a 3D model, where all details in the terrain and layout can be accounted for directly. View factor modeling relies on a 2D simplification where PV tables are represented by a cross section defined by one tilt, row height, and pitch that is assumed to repeat identically along the full length of the row. For a south facing system as simulated here, this means that a slope in the north-south direction can be captured, but not a slope in the east-west direction. PVsyst simplifies this further by computing the irradiance for a group of tables with similar orientations, representing the group using a single mean orientation. These simplifications particularly impact the rear side irradiance, which is sensitive to the ground conditions beneath each table. The near shading in PVsyst is also computed using these averaged group orientations, which can impact the estimated interrow shading, and thus the front side irradiance.

4. Conclusions

This report has compared the functionality of and simulated POA irradiation for four EYA tools applied to a bifacial fixed tilt PV plant in complex terrain. The tools differ both in scope and in the physical models implemented. PVsyst is widely used for bankable EYAs, but relies on view factor modelling that requires simplifications of the PV plant layout that can be limiting for complex layouts in varied terrain. PVCase and RatedPower combine design and EYA functionality, but the workflow and the layout flexibility differ between the tools. CDT is aimed at early-stage EYA, and provides a framework for detailed spatial assessment of both irradiance and PV performance.

The comparison shows that tool choice has a clear influence on the simulated POA irradiance. For the terrain case, PVCase, RatedPower 3D, and CDT estimate a higher total POA irradiance than PVsyst and the standard RatedPower model. The front-side POA estimates are relatively well aligned between the tools, while large differences are found for the rear-side contribution. We find that tools implementing raytracing are well aligned, and estimate higher total and rear POA irradiance, while the view factor tools estimate a lower total irradiance. PVsyst also provides significantly lower estimates for the rear side irradiance.

Comparing simulations for the site with terrain included and a flat reference, we find that PVCase, PVsyst, and CDT estimate a reduced total irradiance for the plant in terrain relative to the flat case. The reduction is mainly associated with the front-side contribution, while the rear-side response clearly separates the raytracing tools, PVCase and CDT, from PVsyst which employs view factor modelling. PVCase and CDT both estimate that introducing terrain reduces the rear side contribution to the POA, while PVsyst estimates an increased POA for the terrain compared with the flat case. This work demonstrates that even when user inputs and the PV plant layout are largely consistent across tools, significant differences in EYA remain due to differences in implemented irradiance models and layout simplifications. This highlights the importance of careful evaluation of model assumptions when applying EYA tools to evaluate bifacial PV plants in complex terrain.

5. Acknowledgements

The authors thank Endra for sharing data and information regarding the PV plant simulated in this work.

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