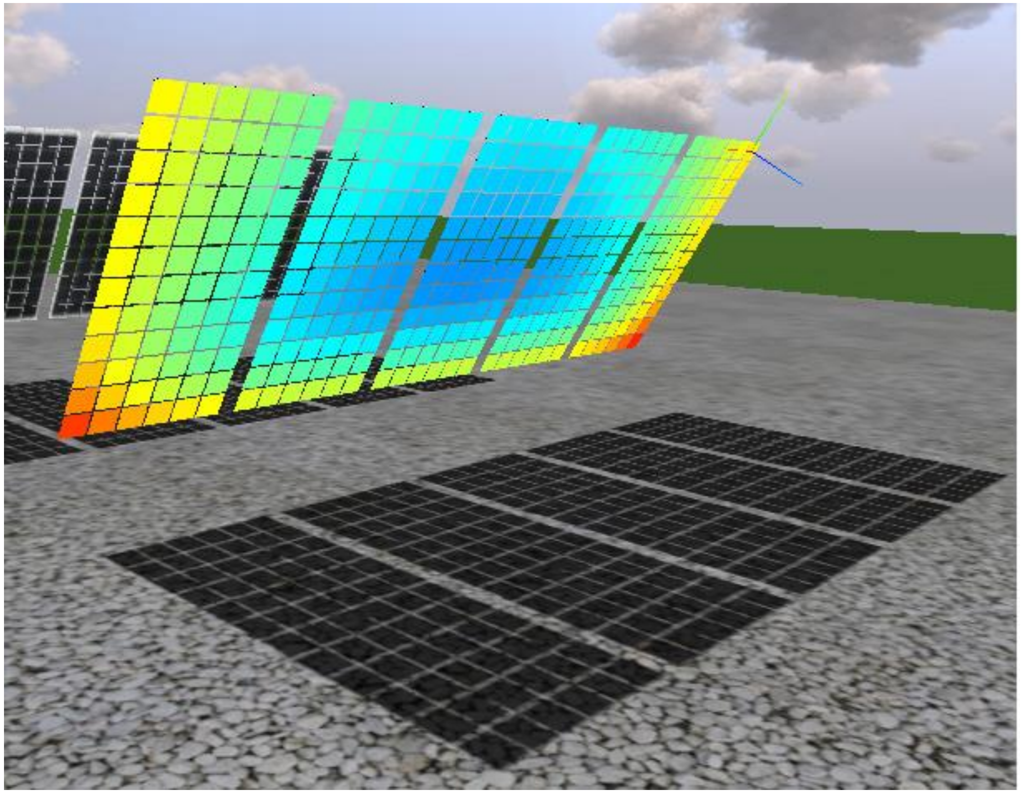
Simulation of the bifacial energy gain for photovoltaic plants using the Graphics Processing Unit (GPU)

Training School, University of Brasov, Romania

EU COST Project Pearl PV

08/07/2021



Jonathan Leloux
Jesús Robledo
Babacar Sarr

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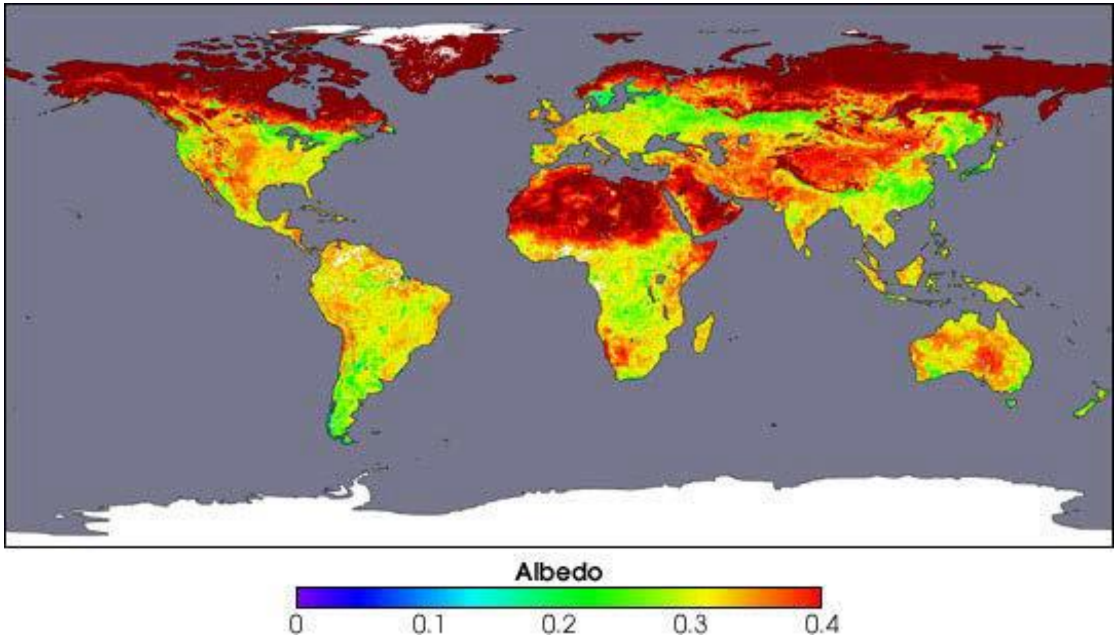
Bifacial PV simulation: some key points

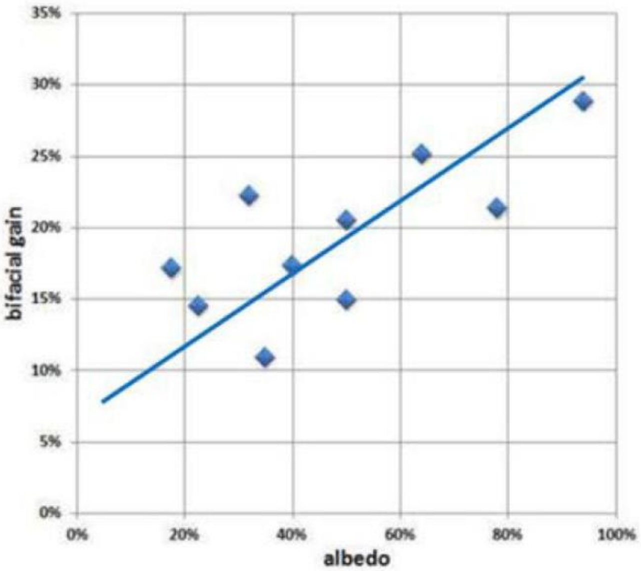
- What potential for bifacial PV? Why?
- Bifacial Energy Gain (BEG) to be expected?
- Parameters influencing BEG
- Uncertainties
- Risk assessment
- Current status of simulation tools
- Practical solutions for Energy Yield Assessments (EYA)

General concepts on bifacial PV applications

High solar resource + albedo → Bifi paradise



NASA Earth observation, 2019



Kopecek, 2015

surface	albedo [%]
water	8
dry dark soil	13
grass	17-28
dry sand	35
dune sand	37
old snow	40-70
reflective roof coatings	80-90
fresh snow	75-95

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Bifacial PV plants

PV plant with 1-axis trackers in Egypt

PV plants in Canada

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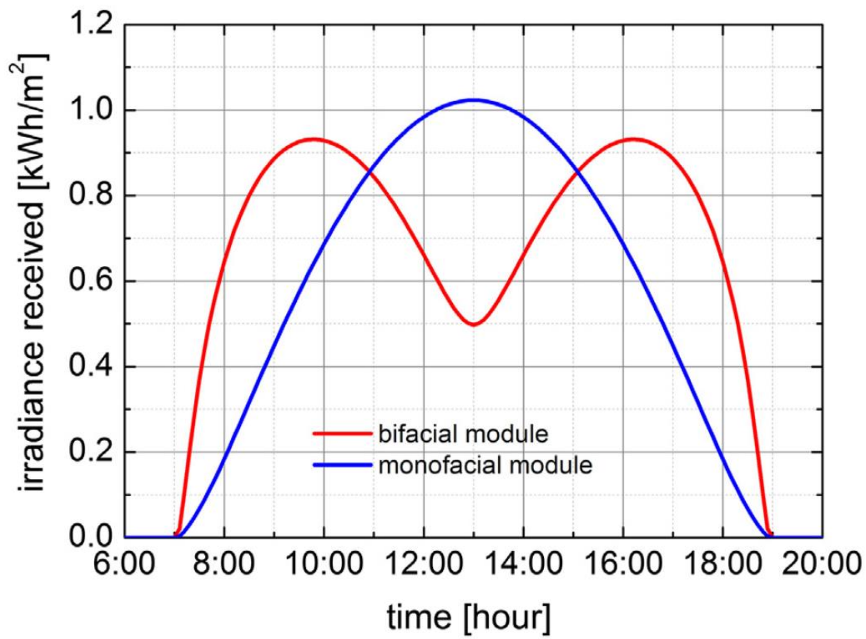
Vertical bifacial PV



Guo, 2013

Bifacial PV in agrivoltaics

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High uncertainties might slow down bifacial

QUICKPOLL

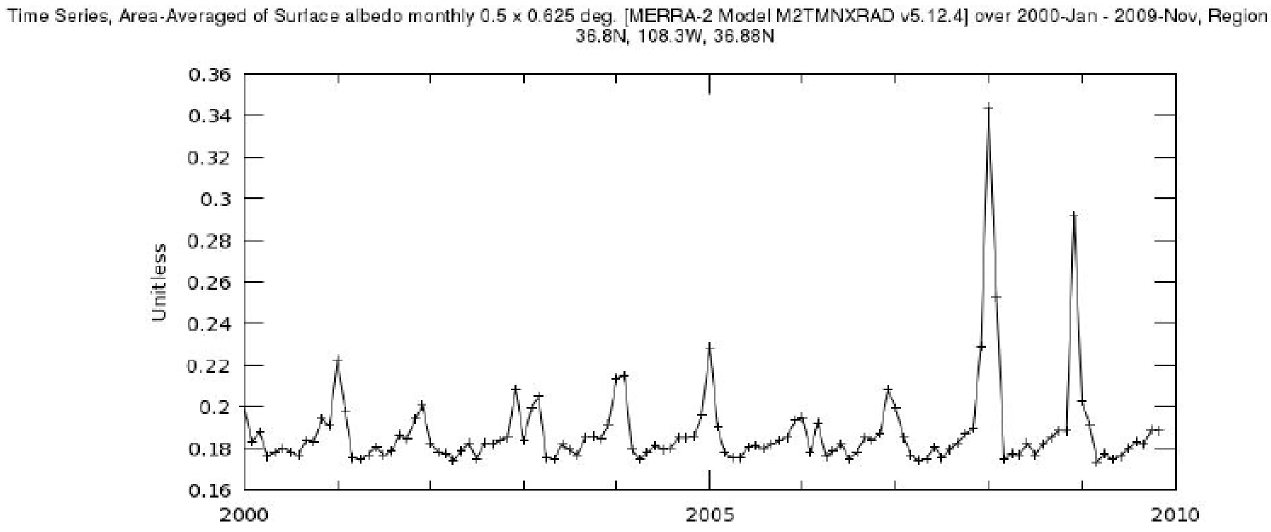
3. Bifacial promises a significant yield advantage. Why would you delay using bifacial?

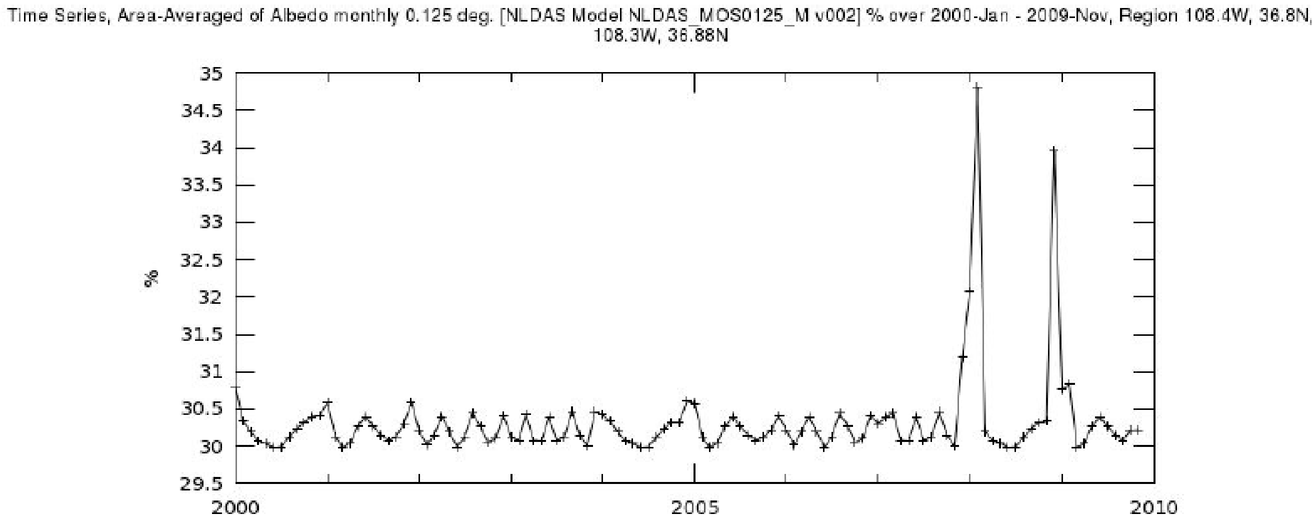
Poll Results (single answer required):

a. Uncertainties about yield gains	41%
b. It requires changes in the BOS	10%
c. Unsure/negative feeling about Glass-glass	8%
d. For other reasons	15%
e. I am ready to use bifacial now!	26%

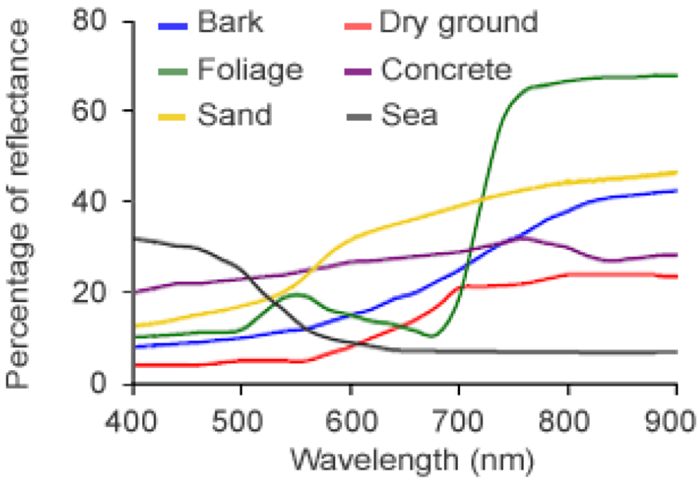
Webinar PVTech, 2019

Assessing the albedo? Databases do not agree!

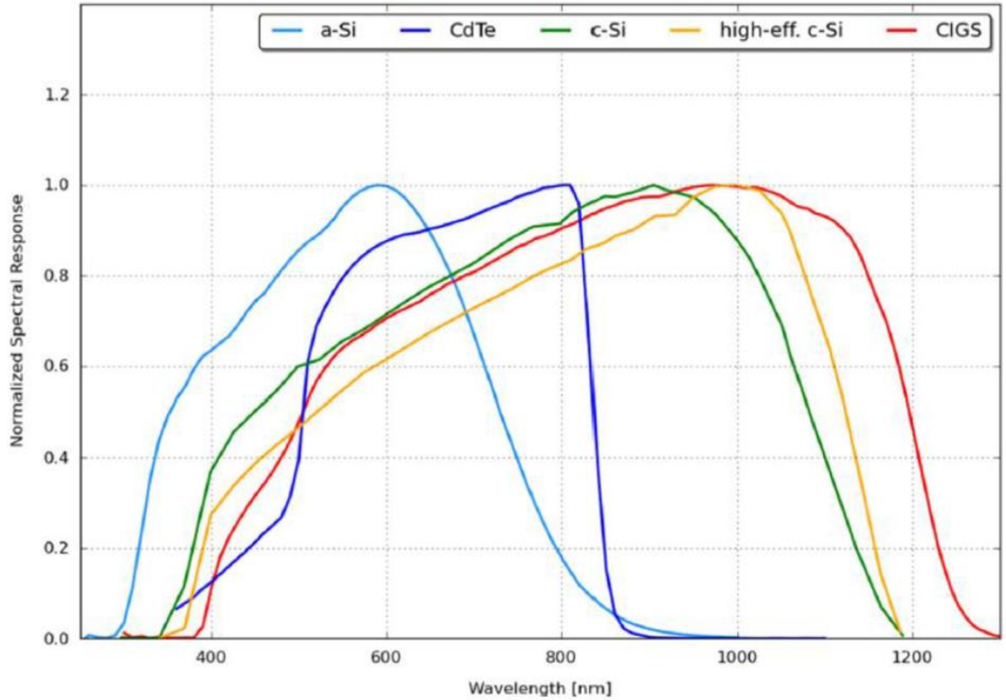




Spectral considerations on albedo? Complex



Luxorion, 2017



Dirnberger, 2015

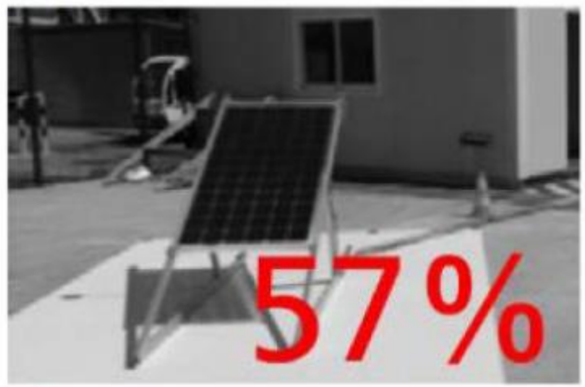
Reported BEG values: quite a wide range!

bSolar 2014

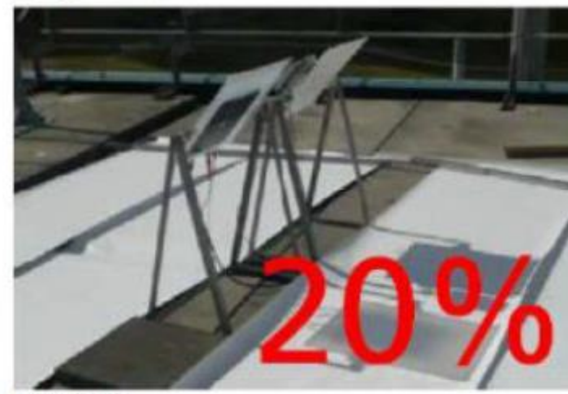
bSolar 2014

Sanyo 2009

ISC Konstanz 2014



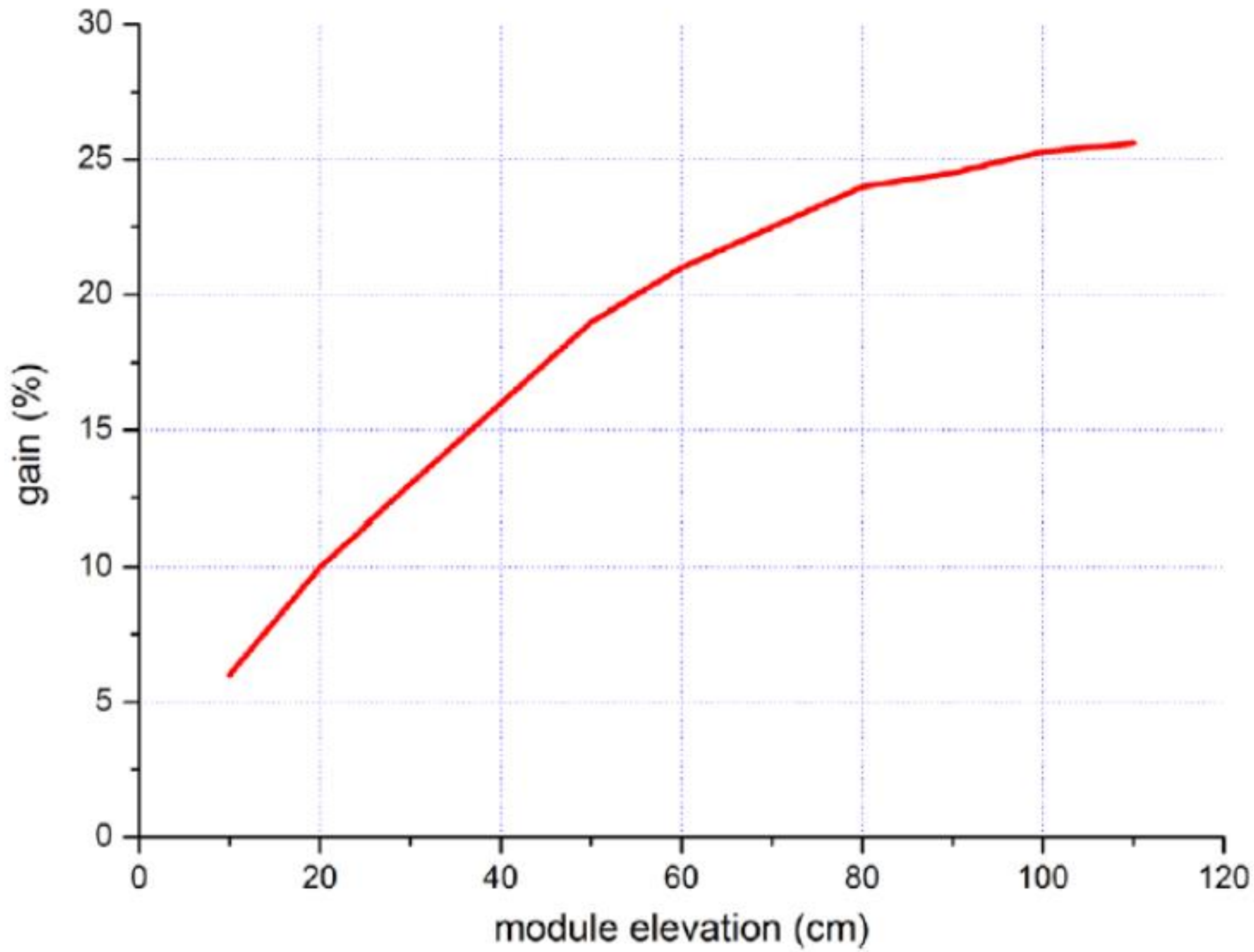
EdF R&D 2014



ECN 2014

Toor and others, 2016

Ground clearance plays a major role on BEG



PV system in Tenerife, Guerrero-Lemus, 2016

BEG 1 PV module > 2 x BEG PV plant

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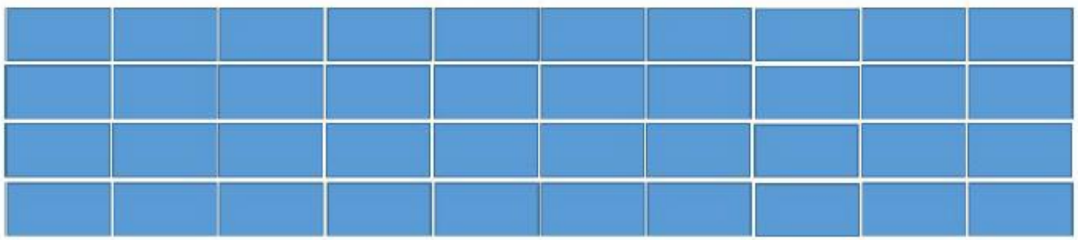
Irradiance model

Rear irradiance heterogeneity

- Rear side irradiance heterogeneity for HSAT or fixed-tilt ($kWh/m^2/year$)



239	165	131	120	116	116	120	131	165	239
214	138	109	101	98	98	101	109	138	213
188	111	90	84	82	82	84	90	111	187
185	116	106	103	101	101	103	106	116	184

176
123
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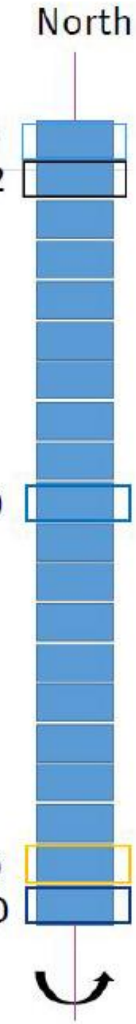
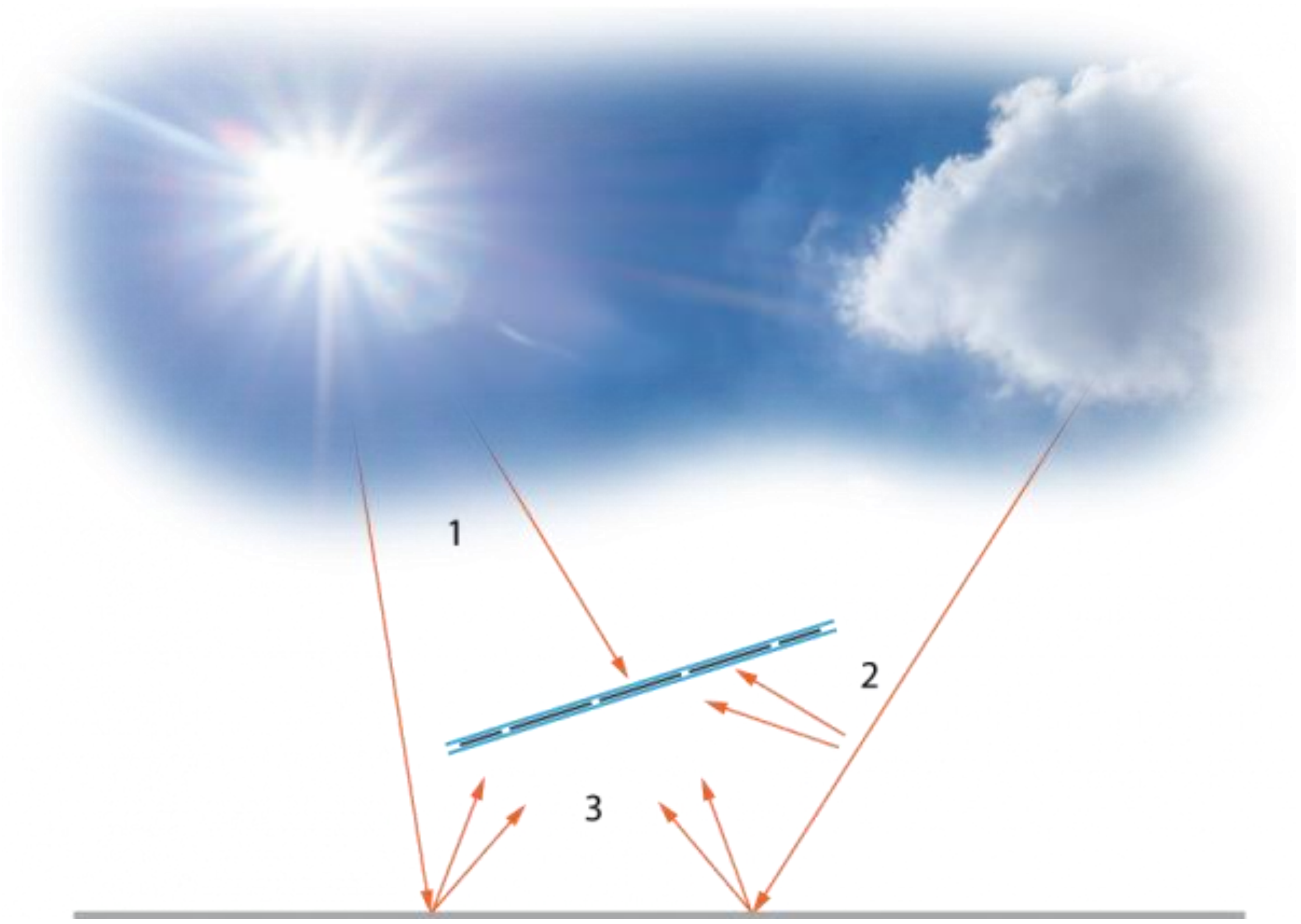
215



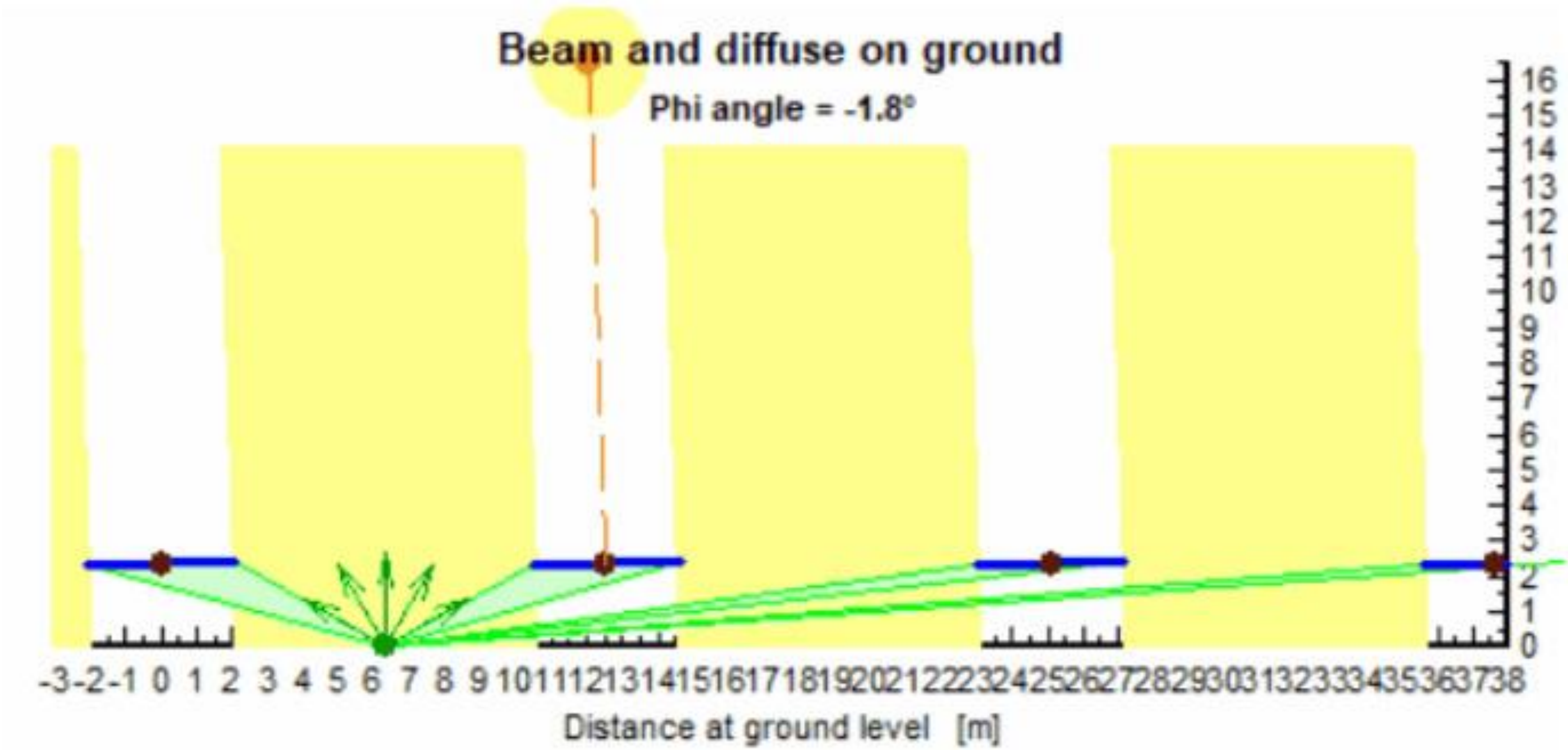
- Illustrations for Cairo (DNI=1760 kWh/m^2), albedo=0.2, equivalent GCR=63%, fixed-tilt=30° , elevation=60cm

Simulations for Cairo, Dupuis, 2016

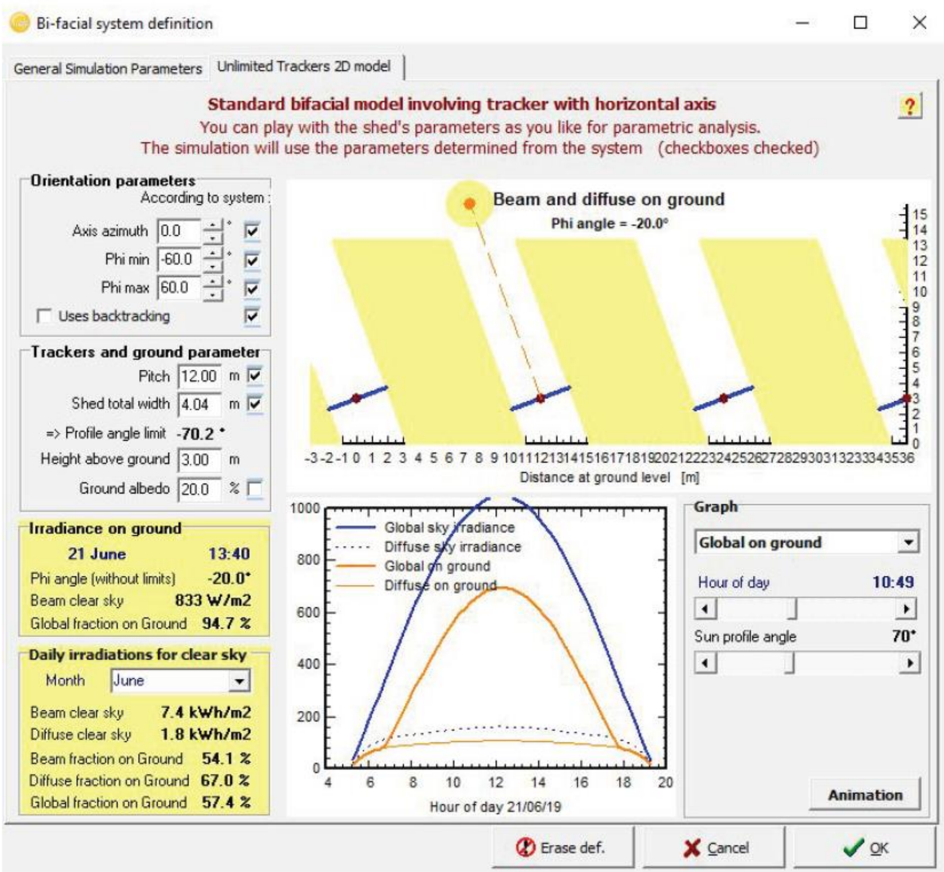
Bifacial PV simulation: state of the art

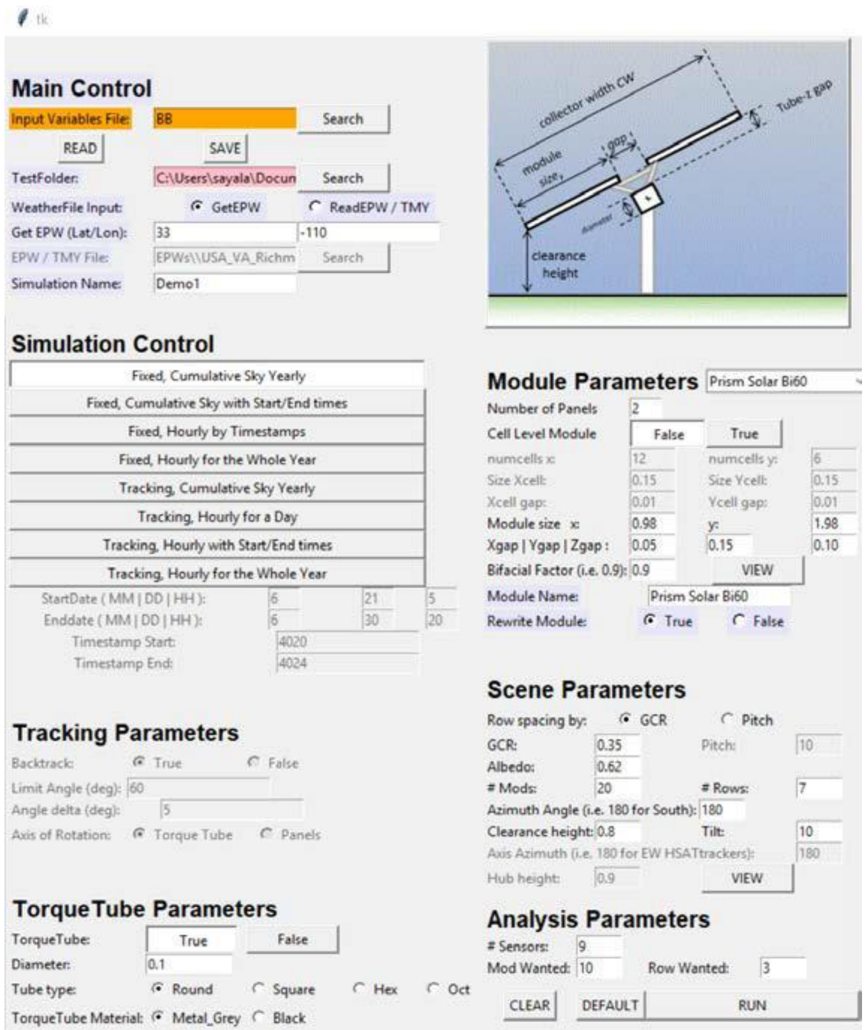


Simulation tools: PVSyst, SAM → view field

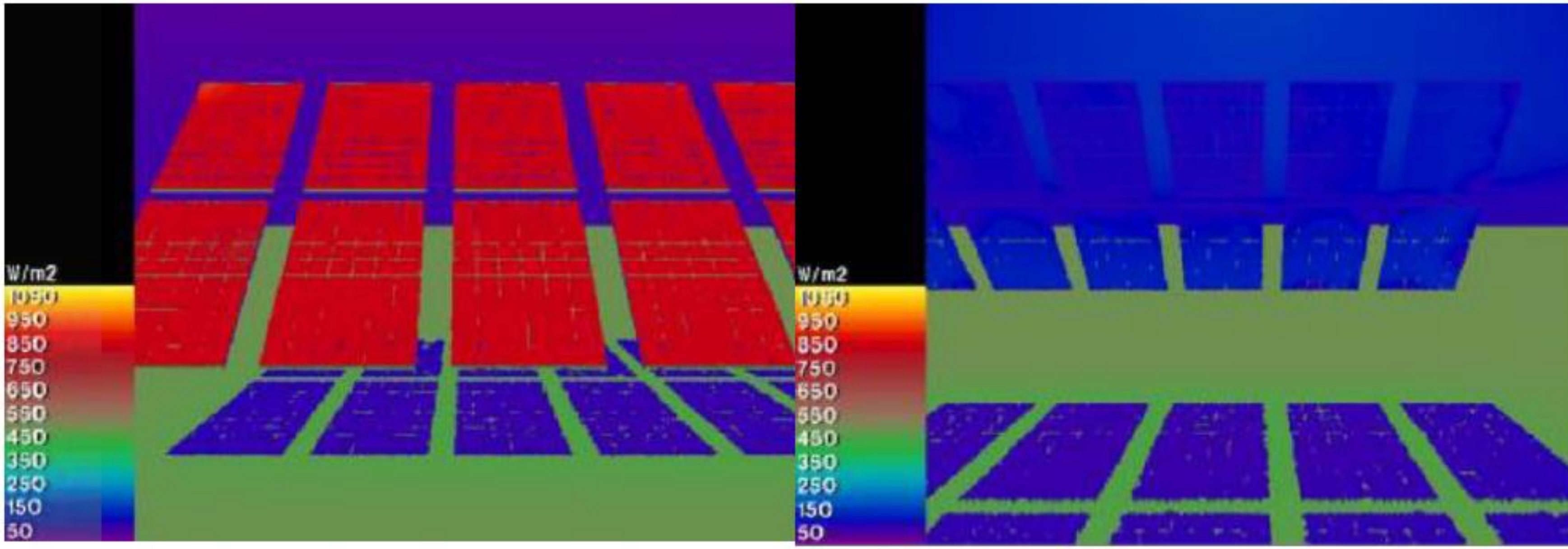


Interfaces from PVsyst and SAM



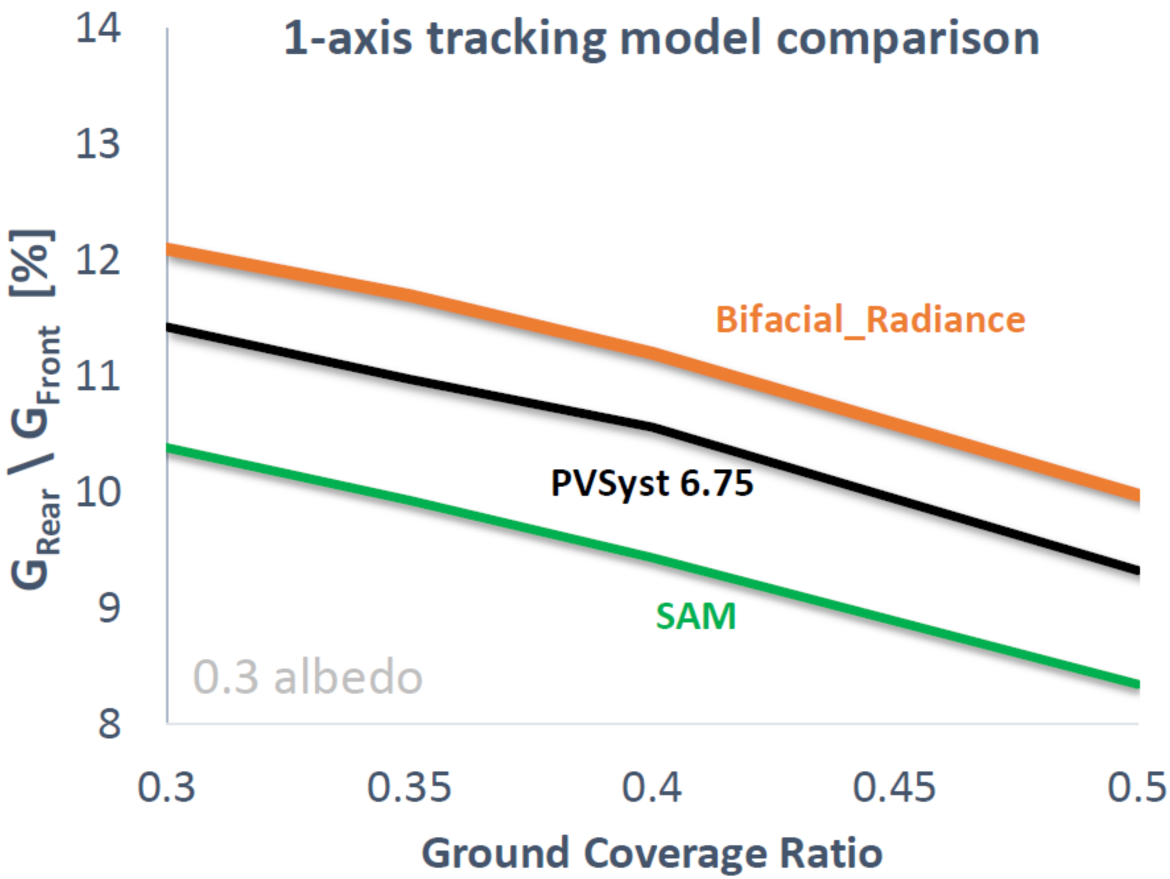


NREL/SANDIA + Imec/PVcase → Ray tracing



Radiance /PVlib, NREL/SANDIA, Deline, 2016

Ray tracing vs view fields: high differences



S. Ayala Pelaez, C. Deline, S. MacAlpine, B. Marion, J. Stein, R. Kostuk, "Comparison of bifacial solar irradiance model predictions with fieldvalidation" IEEE Journal of Photovoltaics, 2019, vol 9 no. 1, pp. 82-88.

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Ray tracing is time/resource consuming

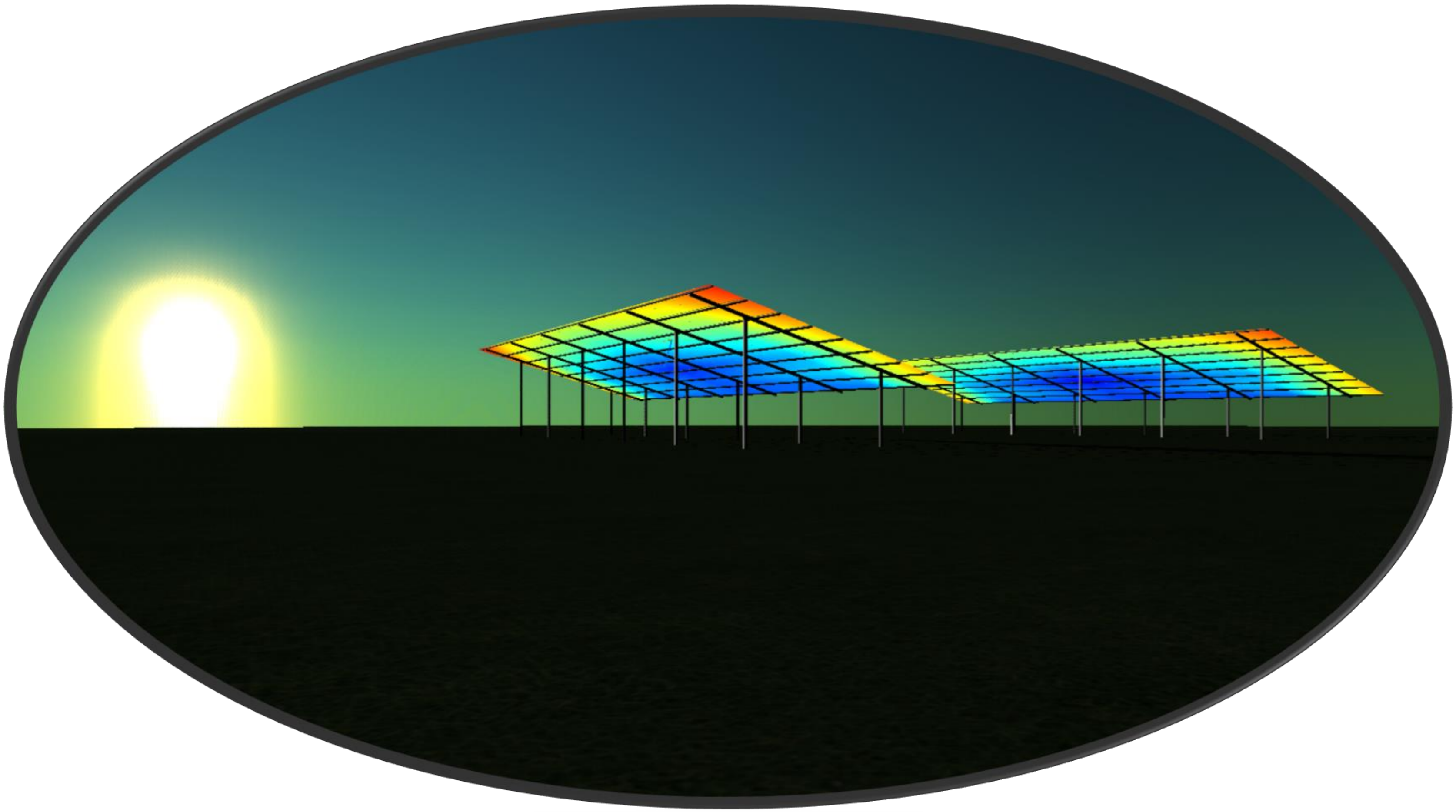
Timing

Rendering time depends strongly on the output image resolution, the number of light sources, scene complexity, the importance of indirect illumination, and the desired accuracy. Rendering time depends weakly on the materials used, emitting surface dimensions and output distributions, and the number of images rendered under the same lighting conditions (since diffuse indirect values may be reused just like radiosities).

A low resolution rendering of an empty space with a single light source will take a few seconds on a modern workstation (eg. Silicon Graphics IRIS or Sun SPARCstation). A high resolution rendering of a moderately complex office space with a direct lighting system will take about 1 hour on the same machine. The same rendering with daylight entering through venetian blinds will take about 2 hours. If the direct lighting system is replaced by an indirect hanging system, the rendering time will increase to about 4 hours. A large auditorium with 100 pendant fixtures will take about 12 hours to render at high resolution. An atrium space with significant indirect illumination could take as long as 20 hours. Such a rendering could be distributed among 20 workstations and be done in close to 2 hours. A 30 second walk-through animation of a large auditorium would take approximately 3 weeks to compute on a single workstation. This work could be distributed among 10 workstations and be done in a little more than 2 days.

https://www.radiance-online.org/about/detailed-description.html

Bifacial PV simulation based on GPU: Lusim from LuciSun

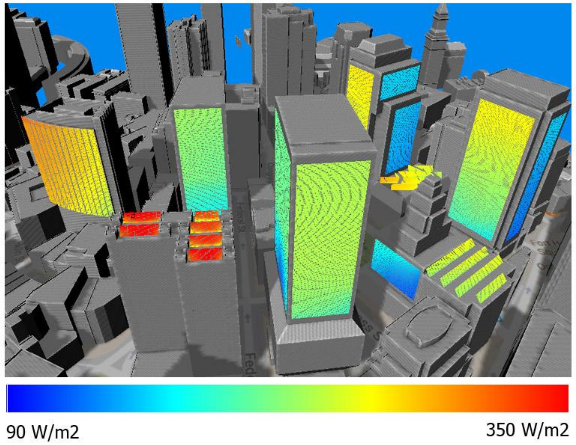


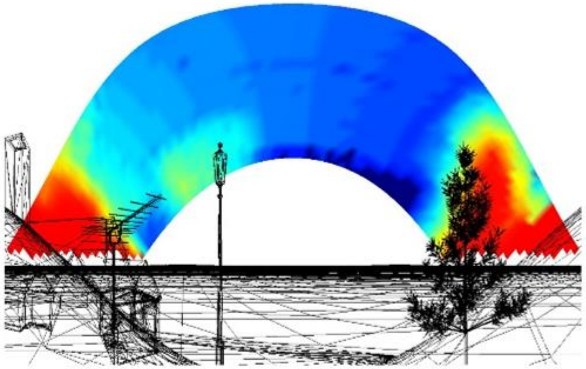
GPUs developed for video games can help bifi!

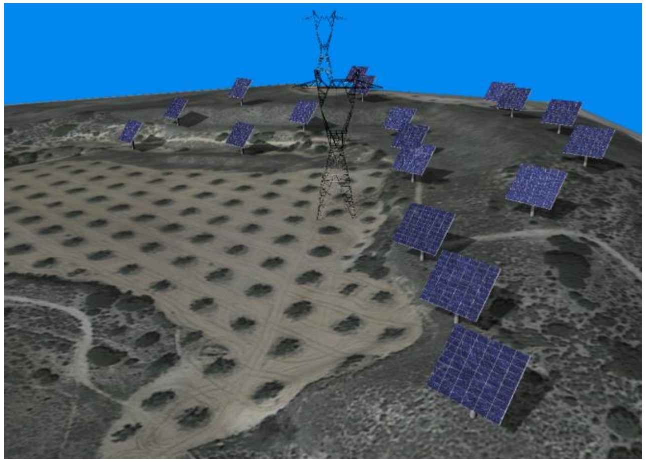
Evolution in Lara Croft (Tomb Raider) in 2 decades

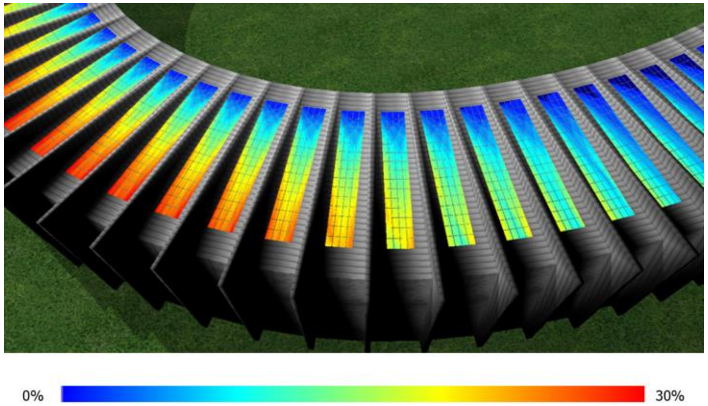
First person shooter (Battlefield)

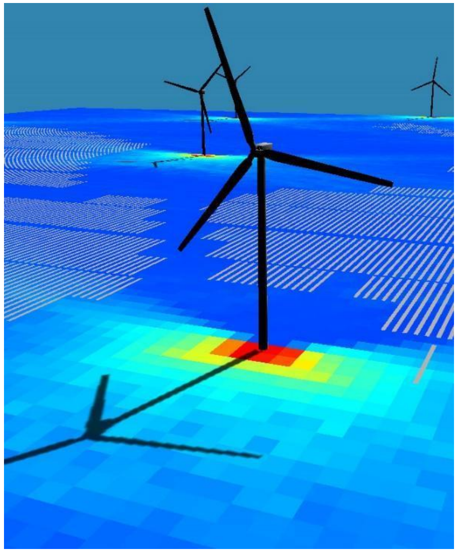
GPUs applied to shading evaluation





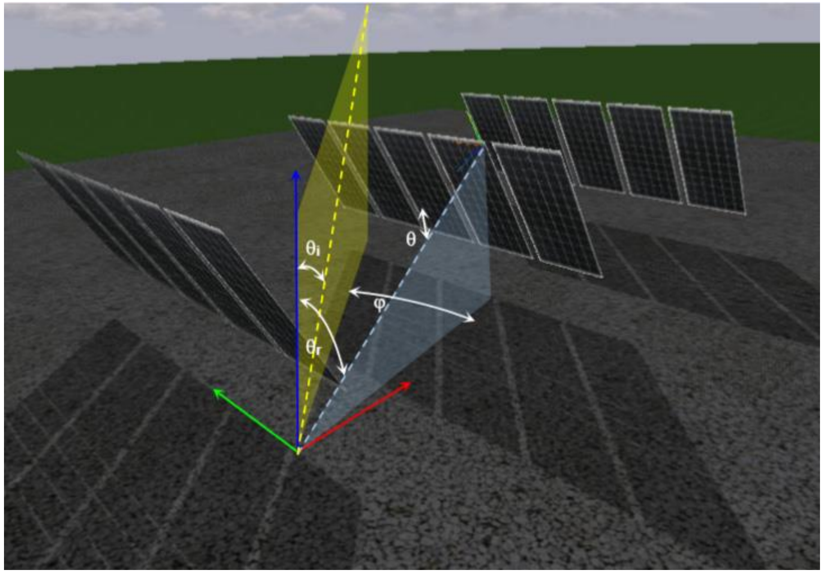




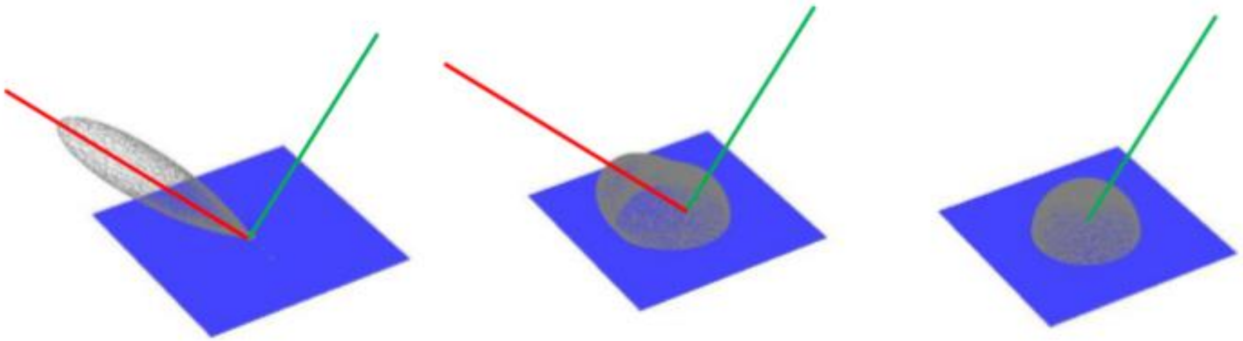


Robledo et al., From video games to solar energy: 3D shading simulation for PV using GPU, Solar Energy, Elsevier, 2019

Implementation of BRDF in GPU for bifacial

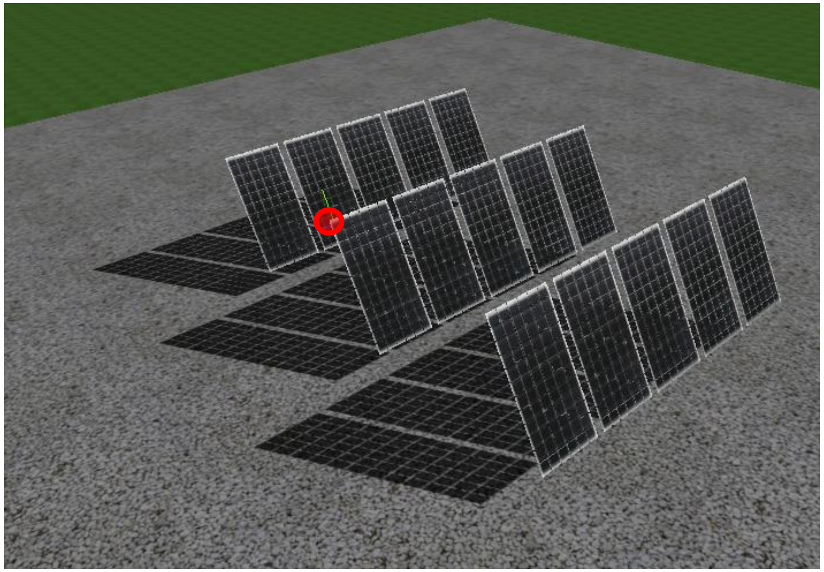


Albedo functions programmed into to the GPU

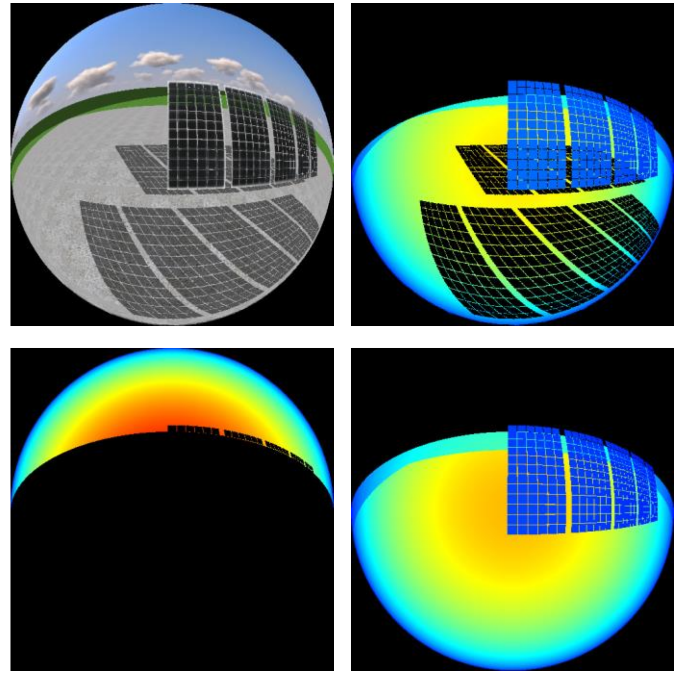


Specular Intermediate Lambertian

BEG vs irradiance components



Selection of on PV cell among PV generator



Backside irradiance from
direct, diffuse and reflected components

- 3D view generation for whole PV generator
- 206,000 rays
- 10 to 20 ms per picture

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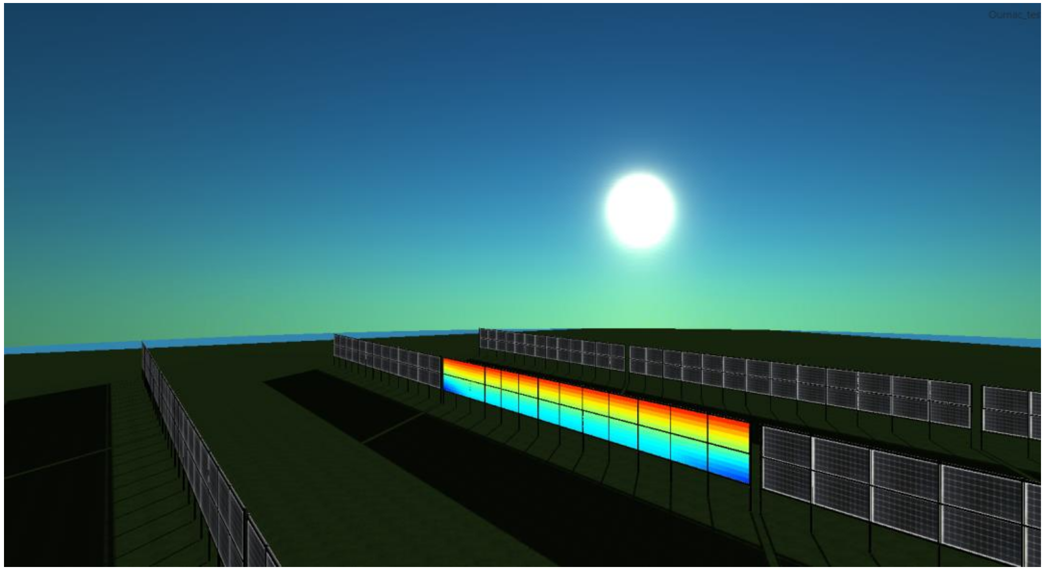
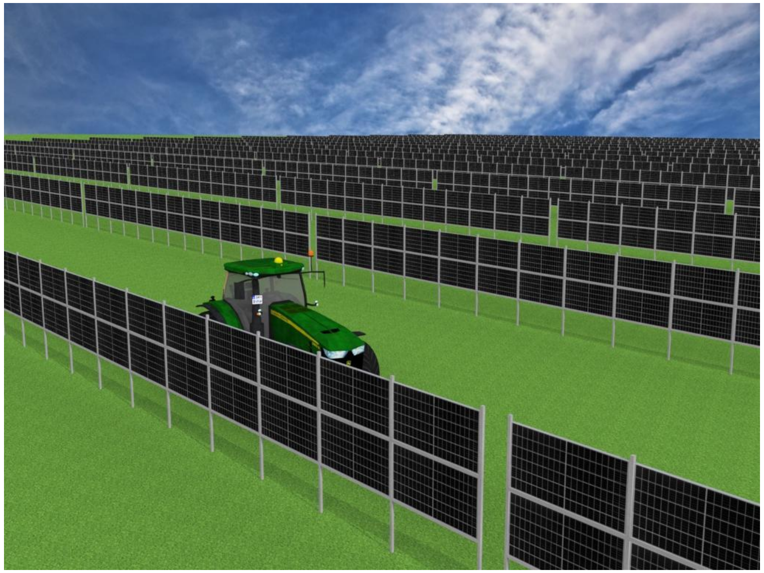
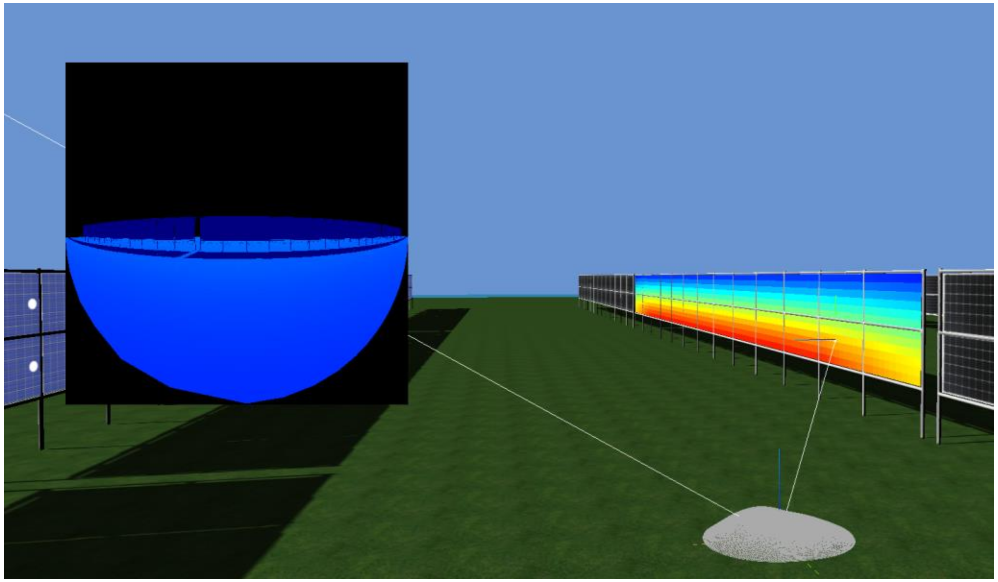
Bifacial for vertical agrivoltaic plants







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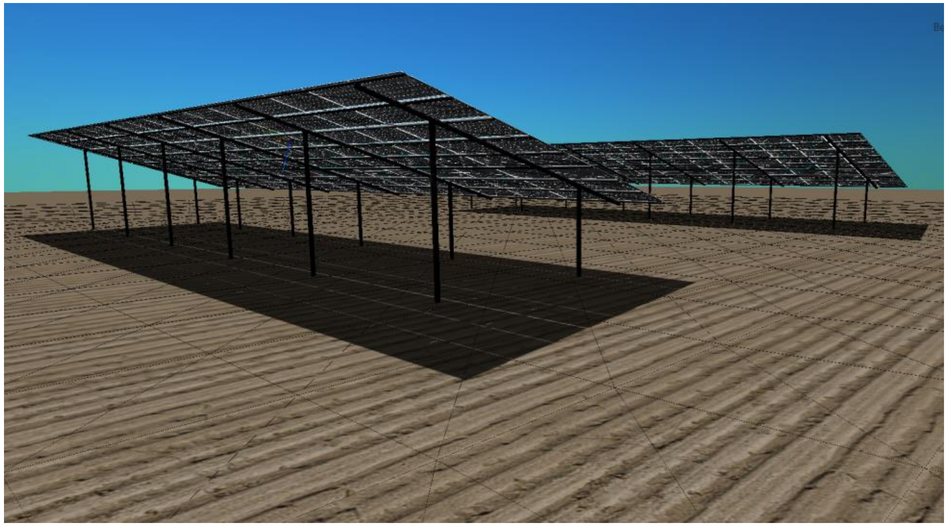
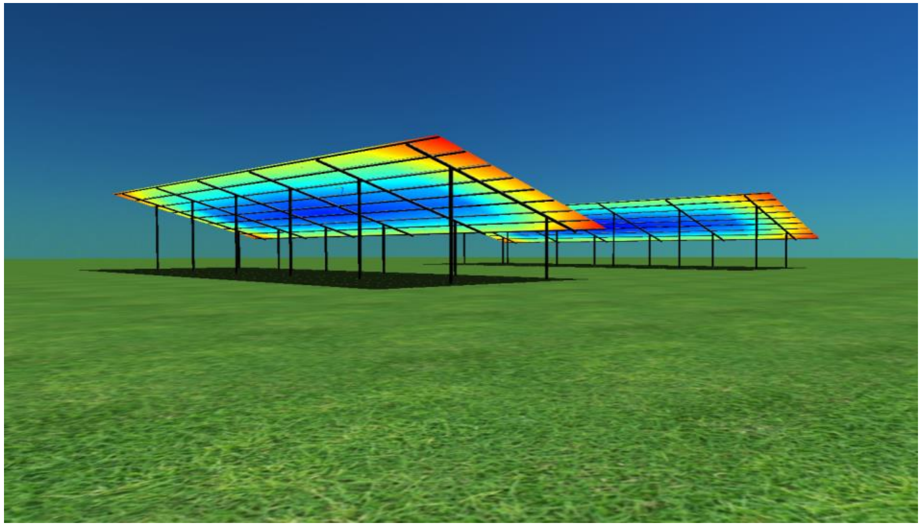
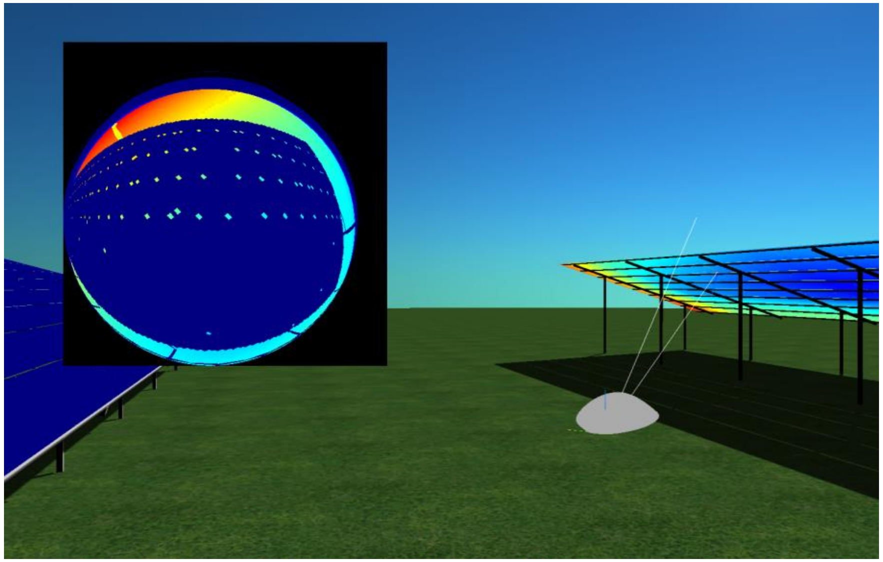
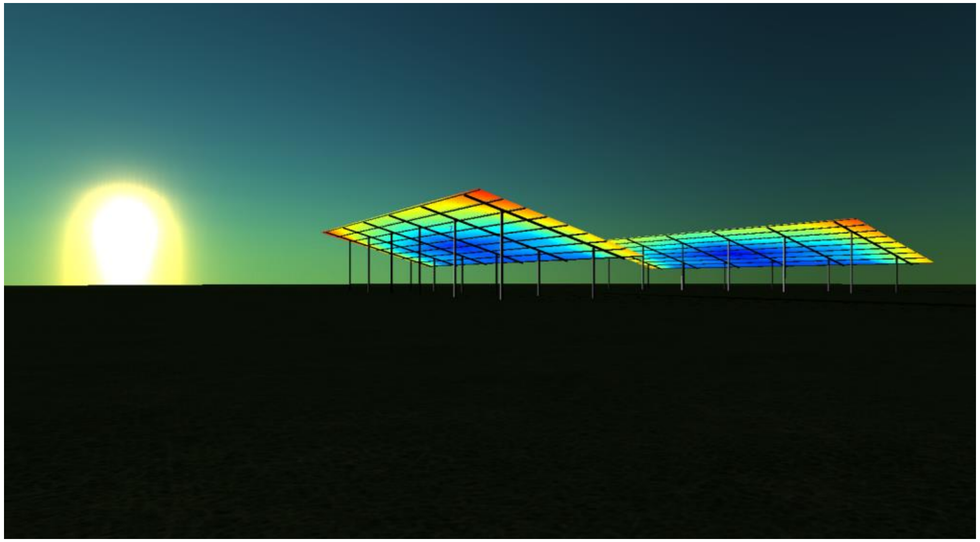
Bifacial for agrivoltaics and carports









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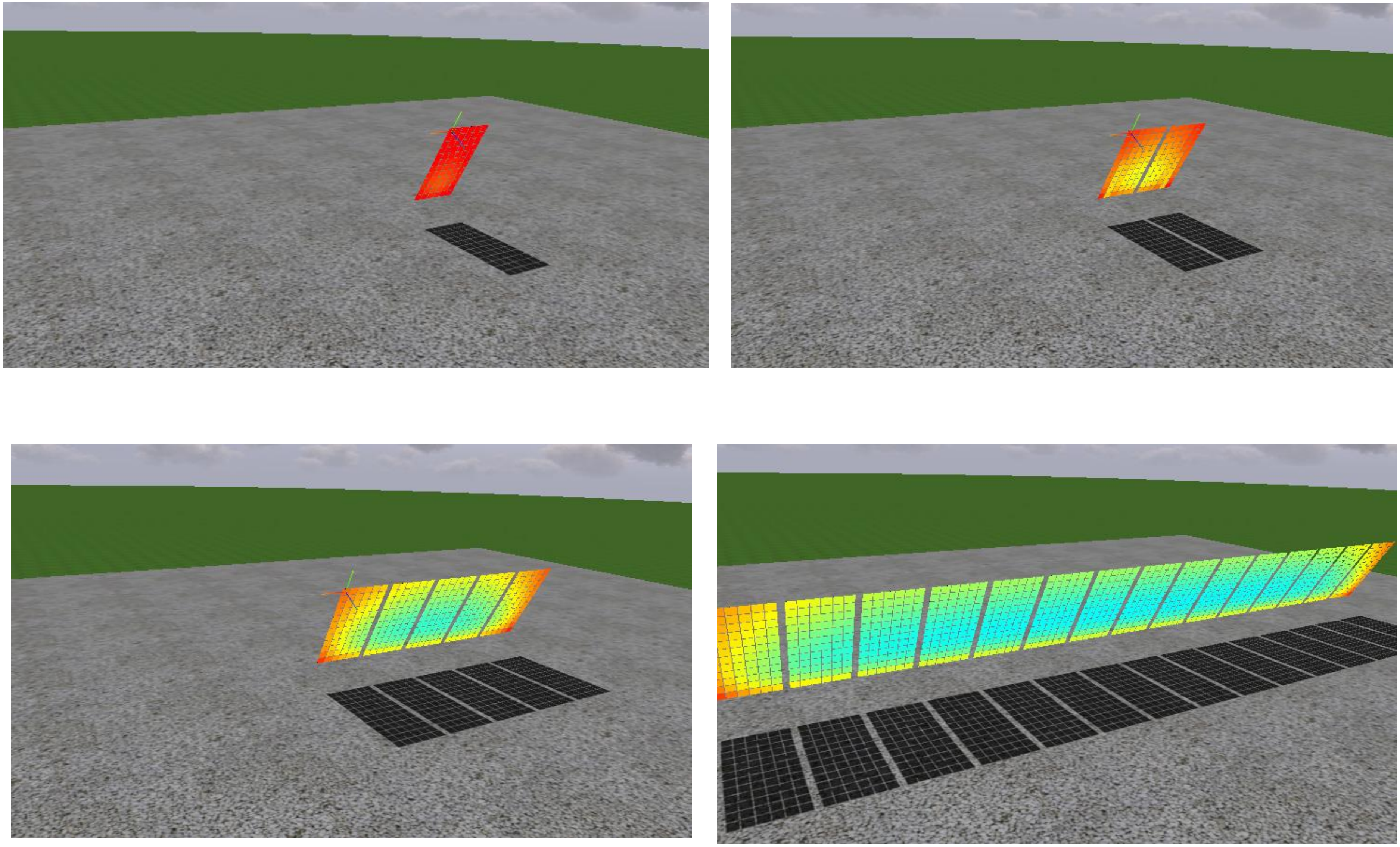
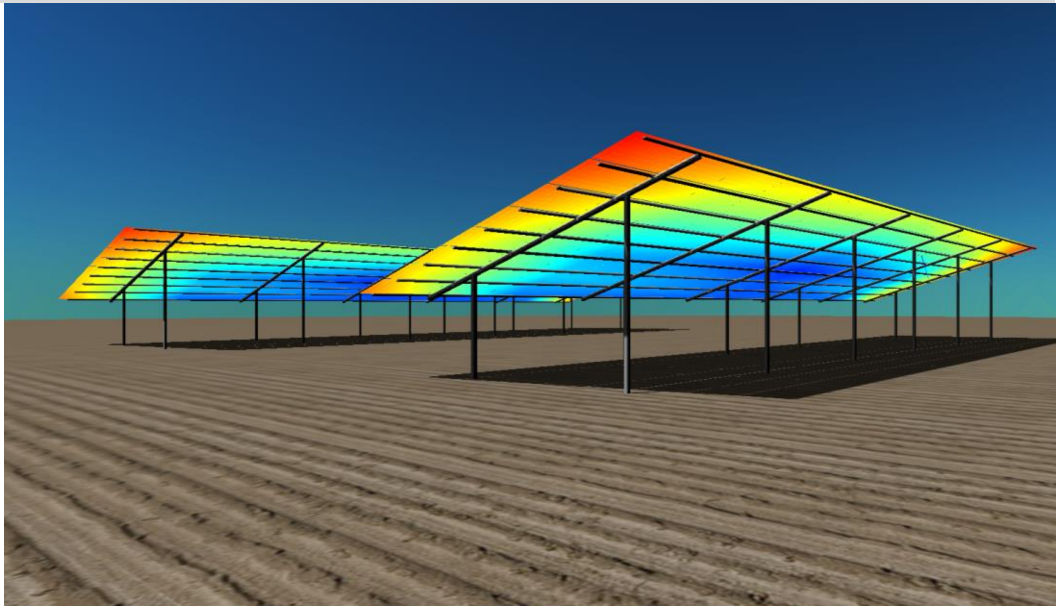
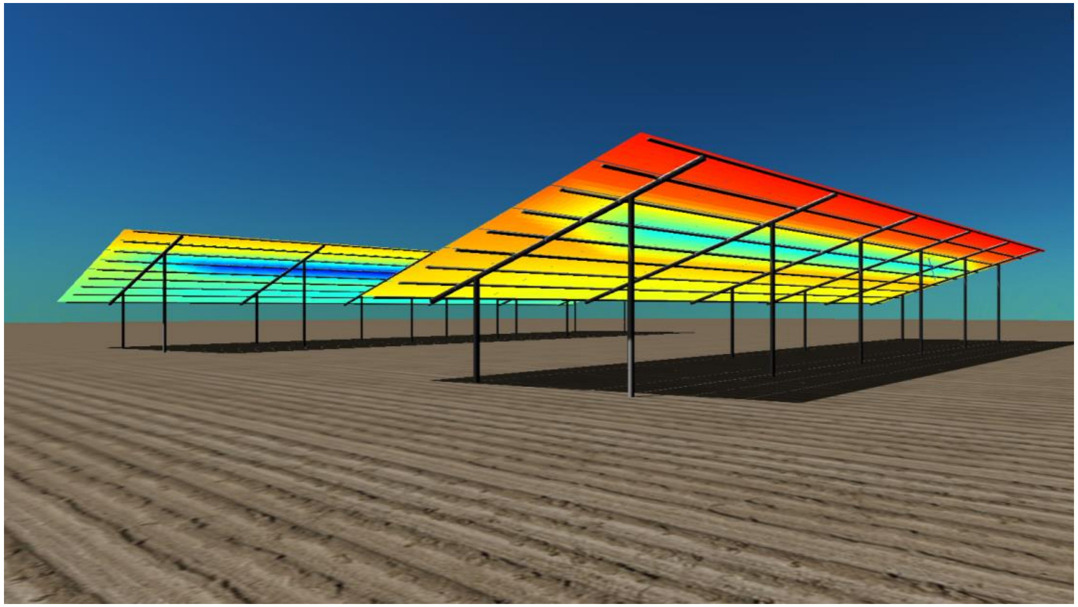
Comparison BEG 1 module vs 1 row



Irradiance gains depend on components

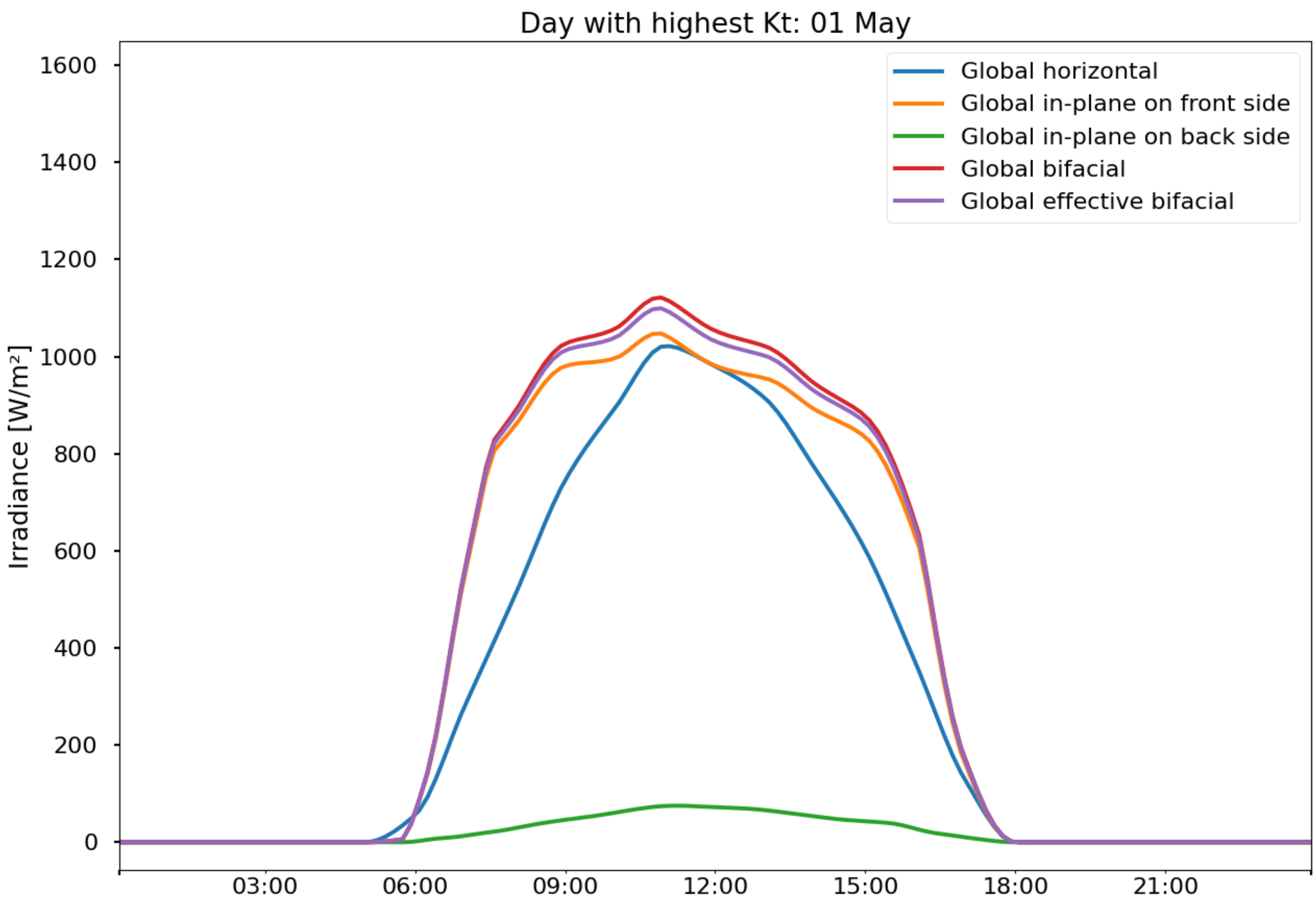
Direct reflected irradiance on back side



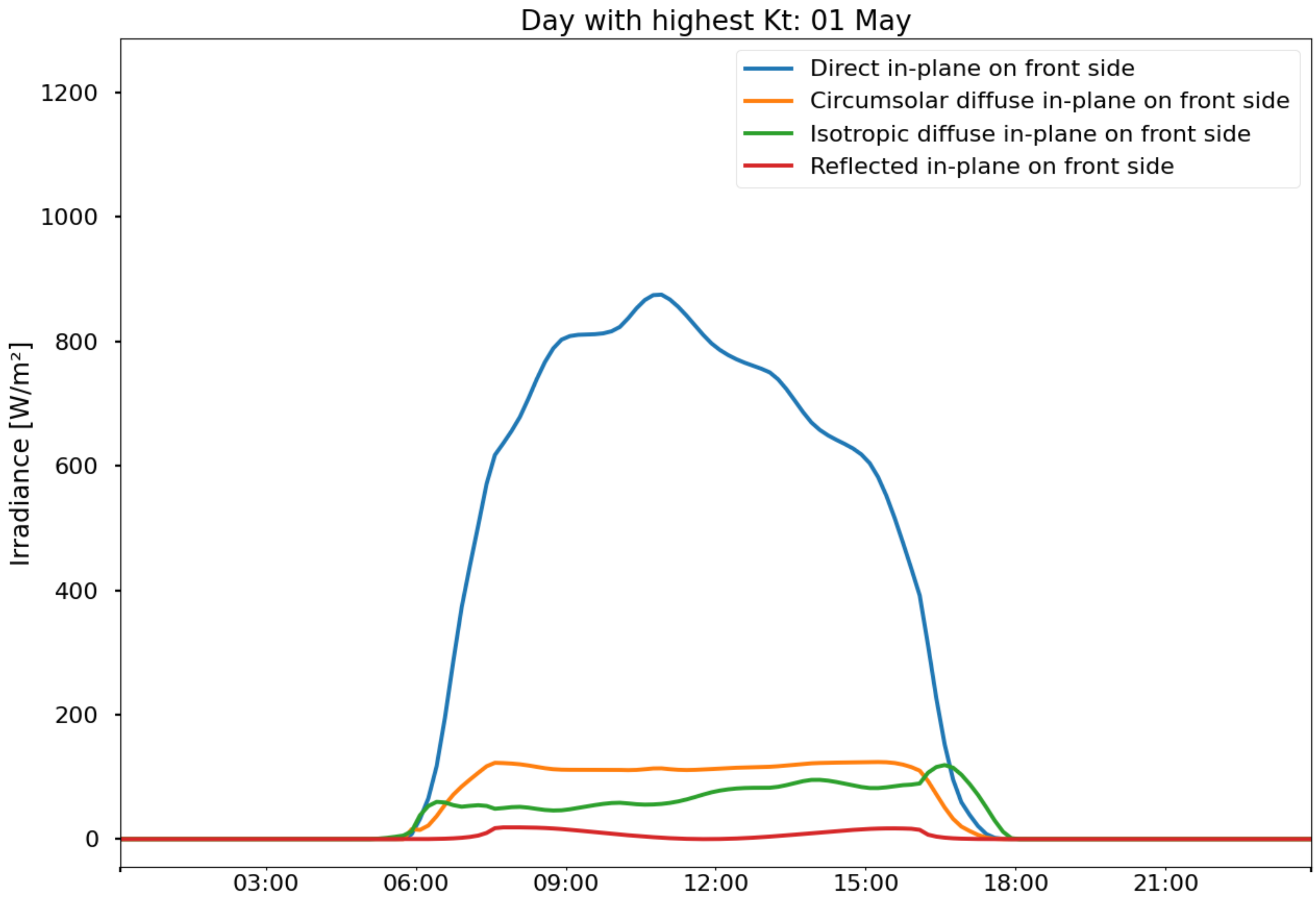


Isotropic diffuse sky irradiance on back side

Global irradiance on front and back side



Solar irradiance components on front side



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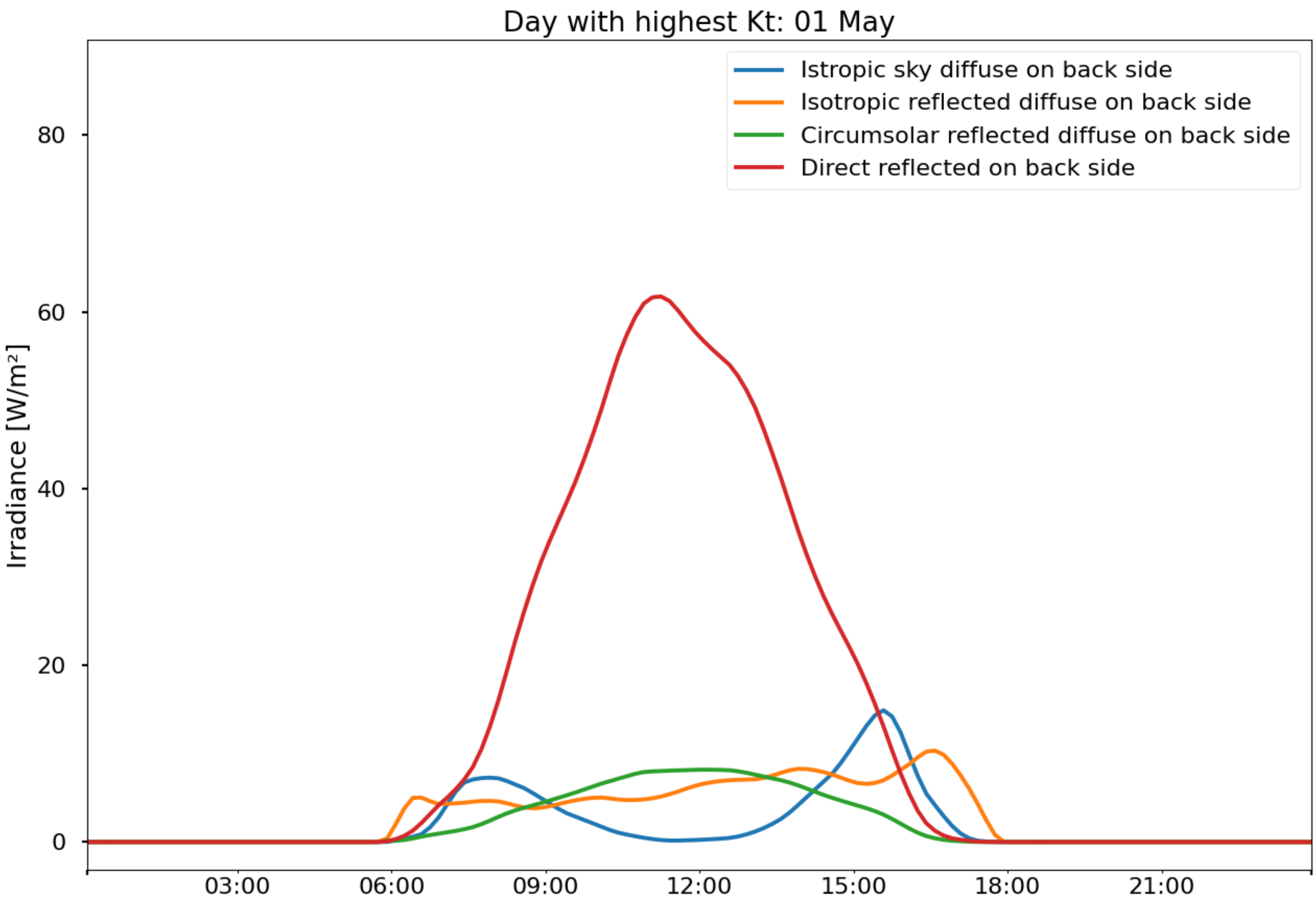
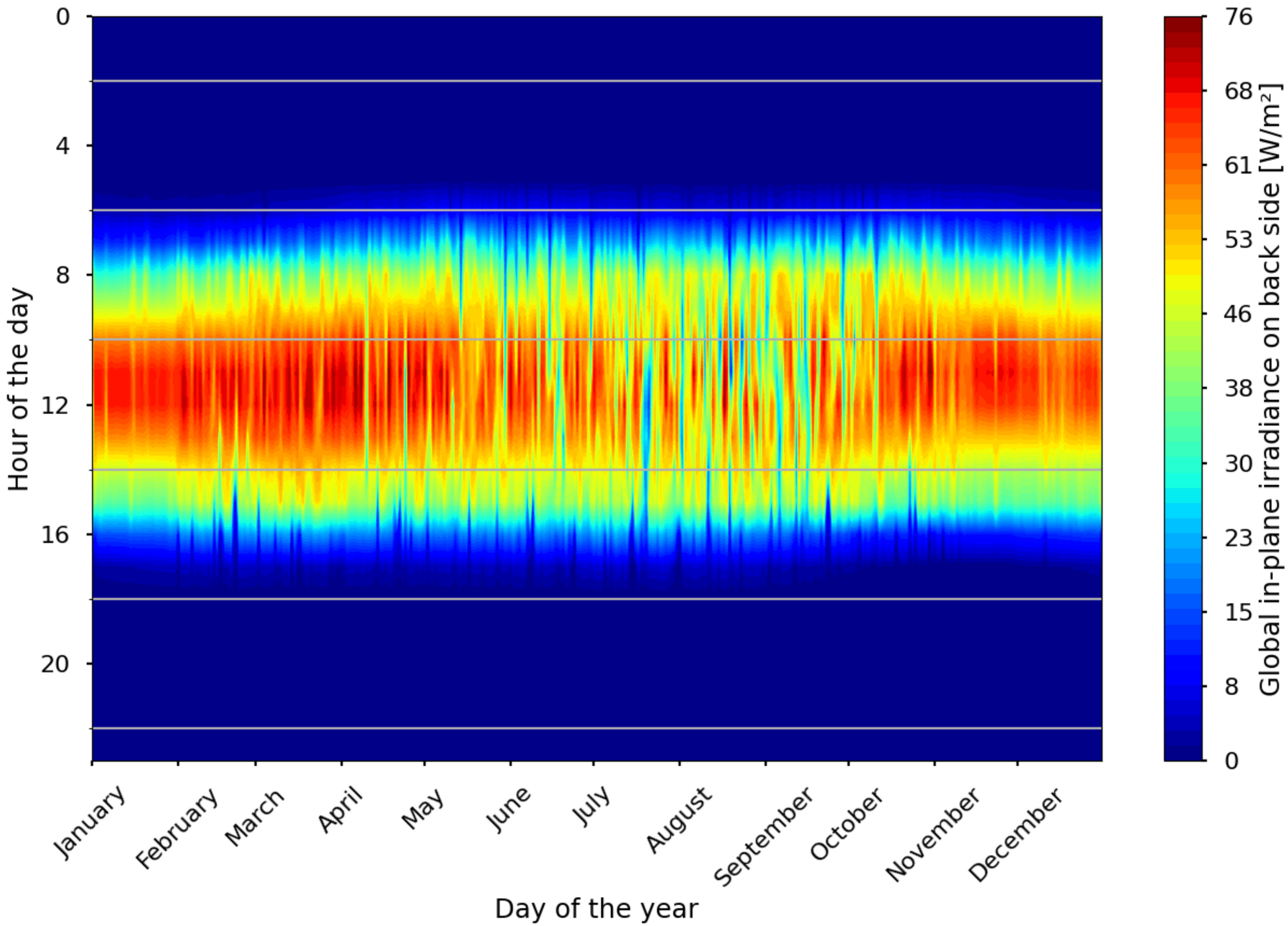
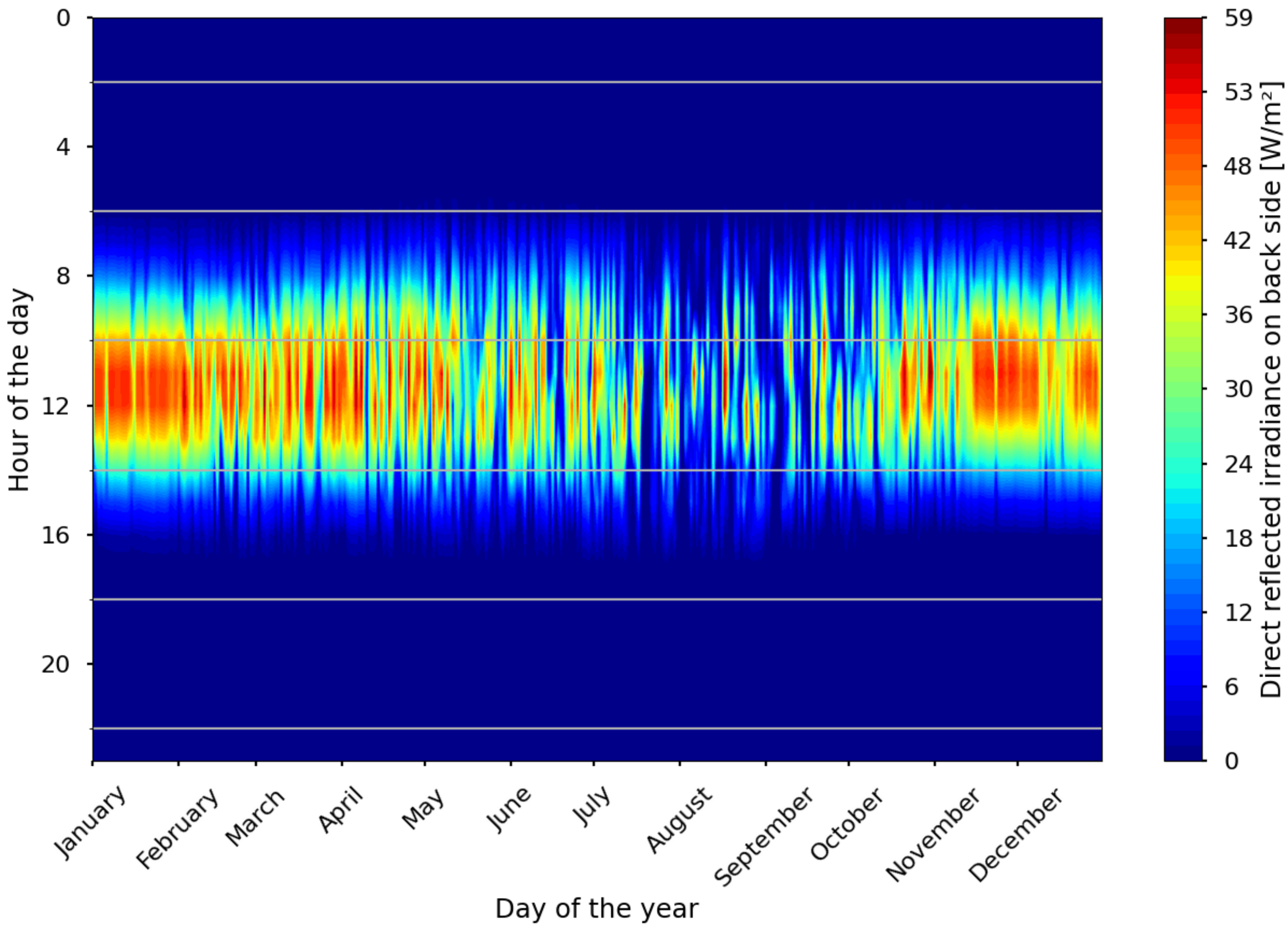
Solar irradiance components on back side



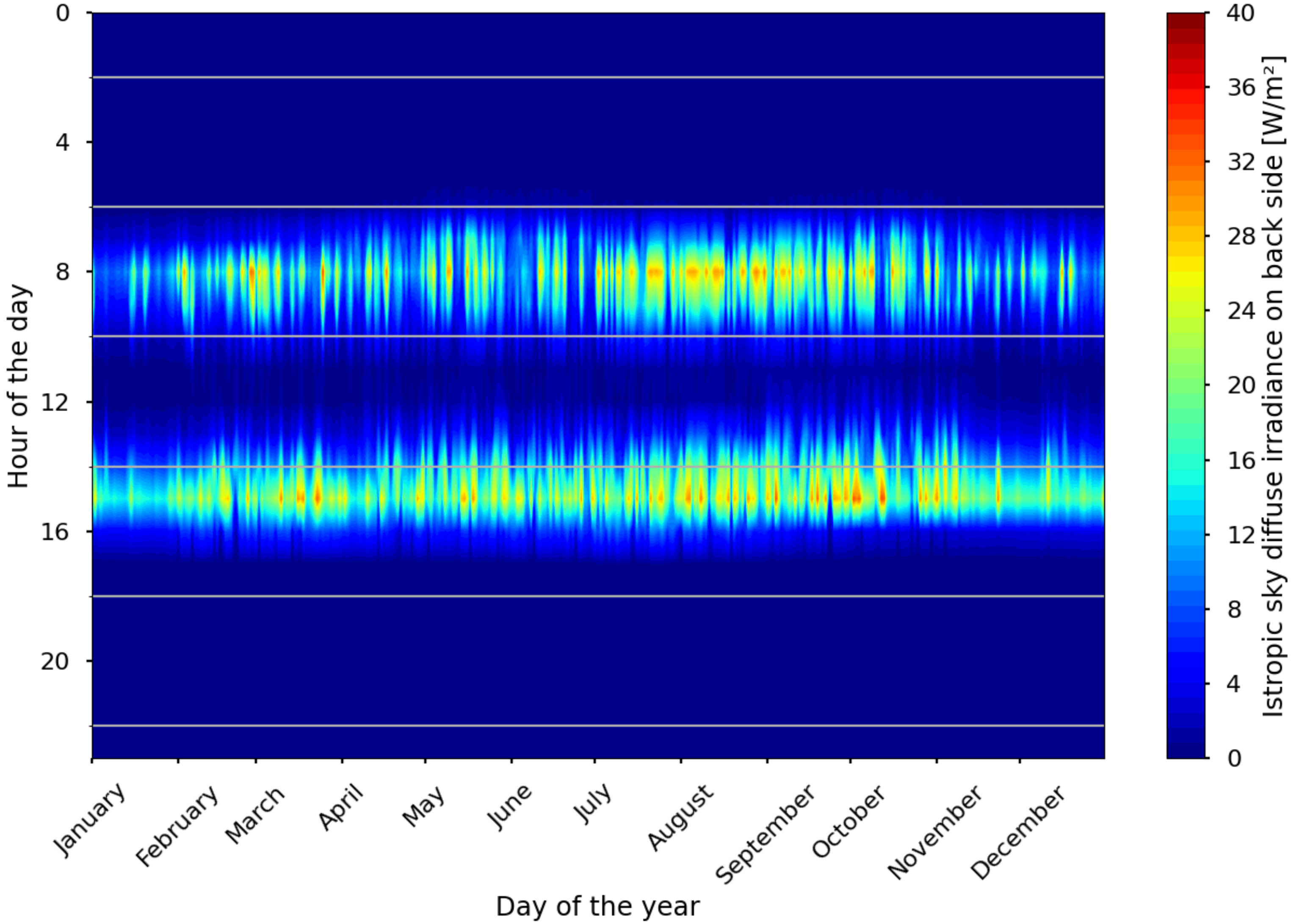
Global irradiance on back side



Direct reflected irradiance on back side



Isotropic diffuse sky irradiance on back side



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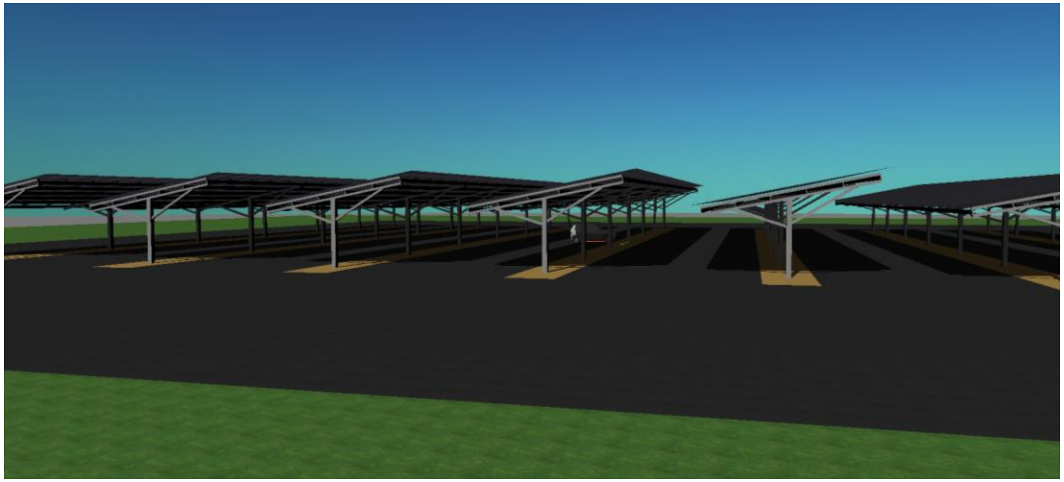
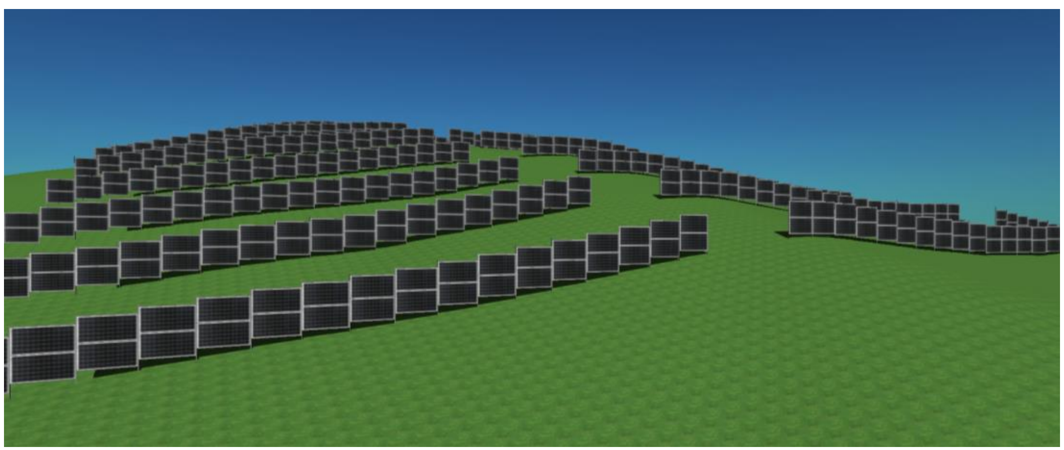
Carports and vertical agrivoltaics



- Different materials and albedos
- Complex structures on the back side
- Impact of other elements than ground
- Reuse of evaluation meshes



- Installation over irregular terrains
- Undefined “front/back” sides

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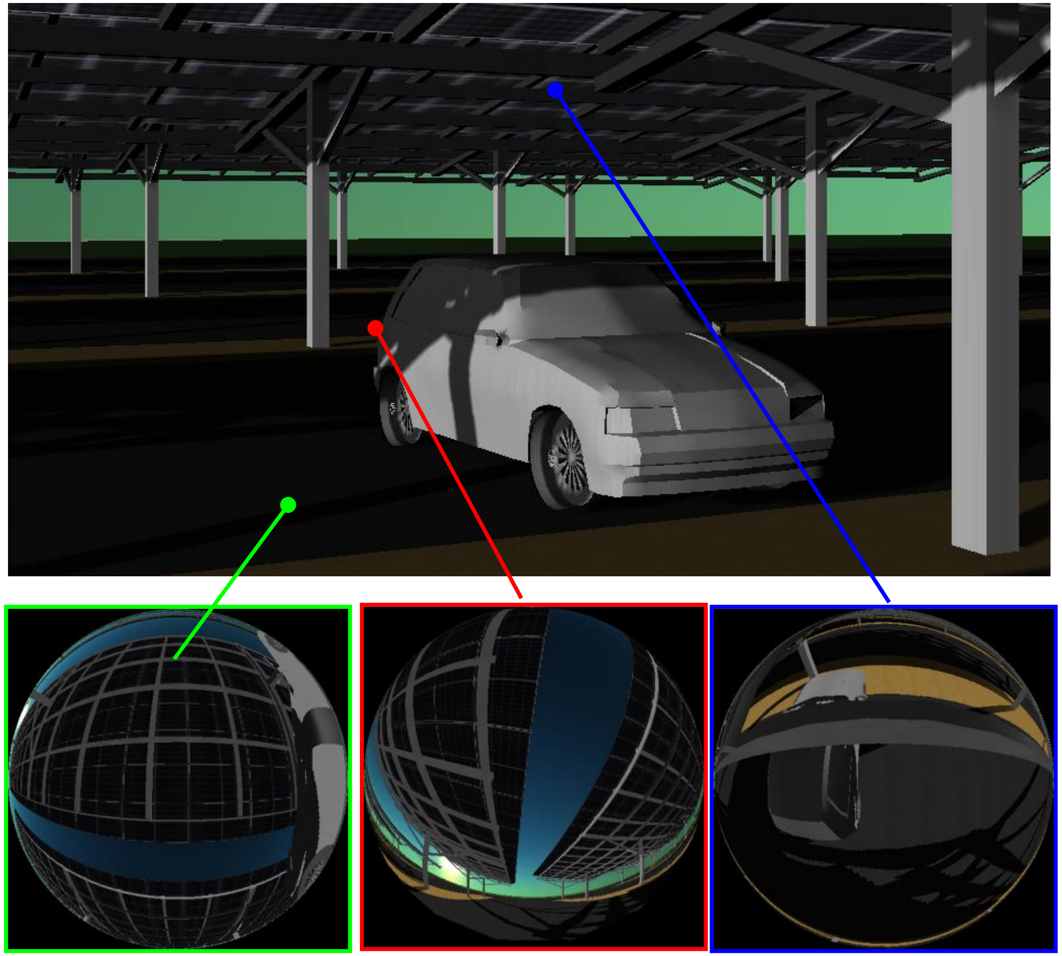
Carports with detailed 3D elements



- Current resolution 512x512 pixels
- Pictures generated at different places for different purposes
- Support for debugging analysis
- Scenario evolution capture (sky conditions, sun position, trackers, etc.)
- Evaluation points linked with auxiliary meshes

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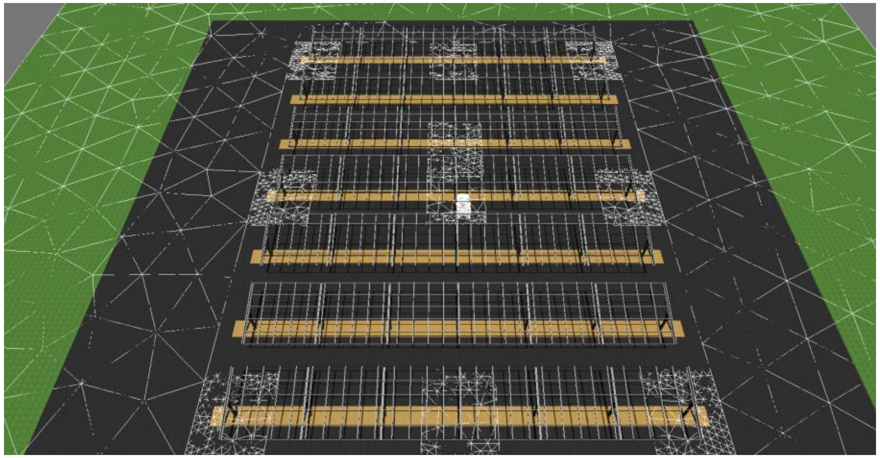
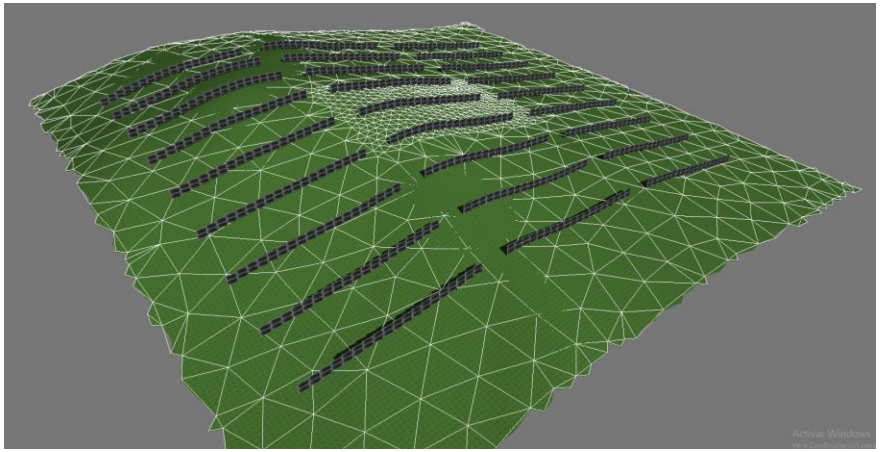
Setting up the meshes





- Support definition for spherical view generation
- Generation through customized software, but standard format
- Adaptable to real surfaces
- Resolution vs computation time control
- Possibility for reuse of areas under a specific pattern (scalability)
- Easy identification of the sources of errors for debugging

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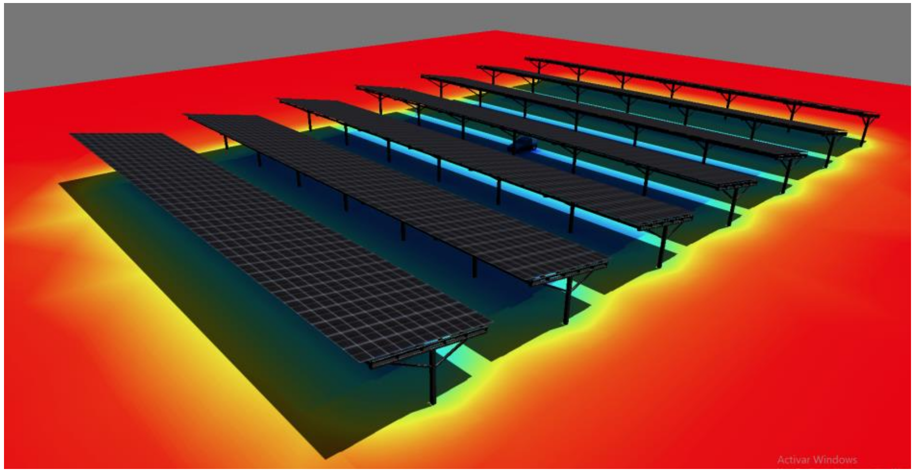
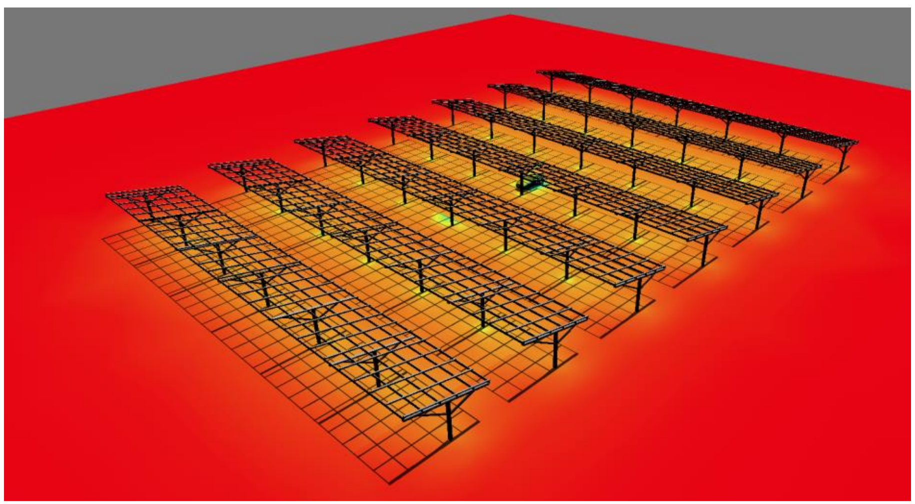
Irradiance distribution on the ground





- Objects in the scenario partially block sky visibility (diffuse shading), reducing diffuse irradiance contribution
- Preliminary step to evaluate sky diffuse reflectance potential
- Needs to be adapted to the shape of the objects
- One step calculation for fixed structures, but module rotation dependent for trackers

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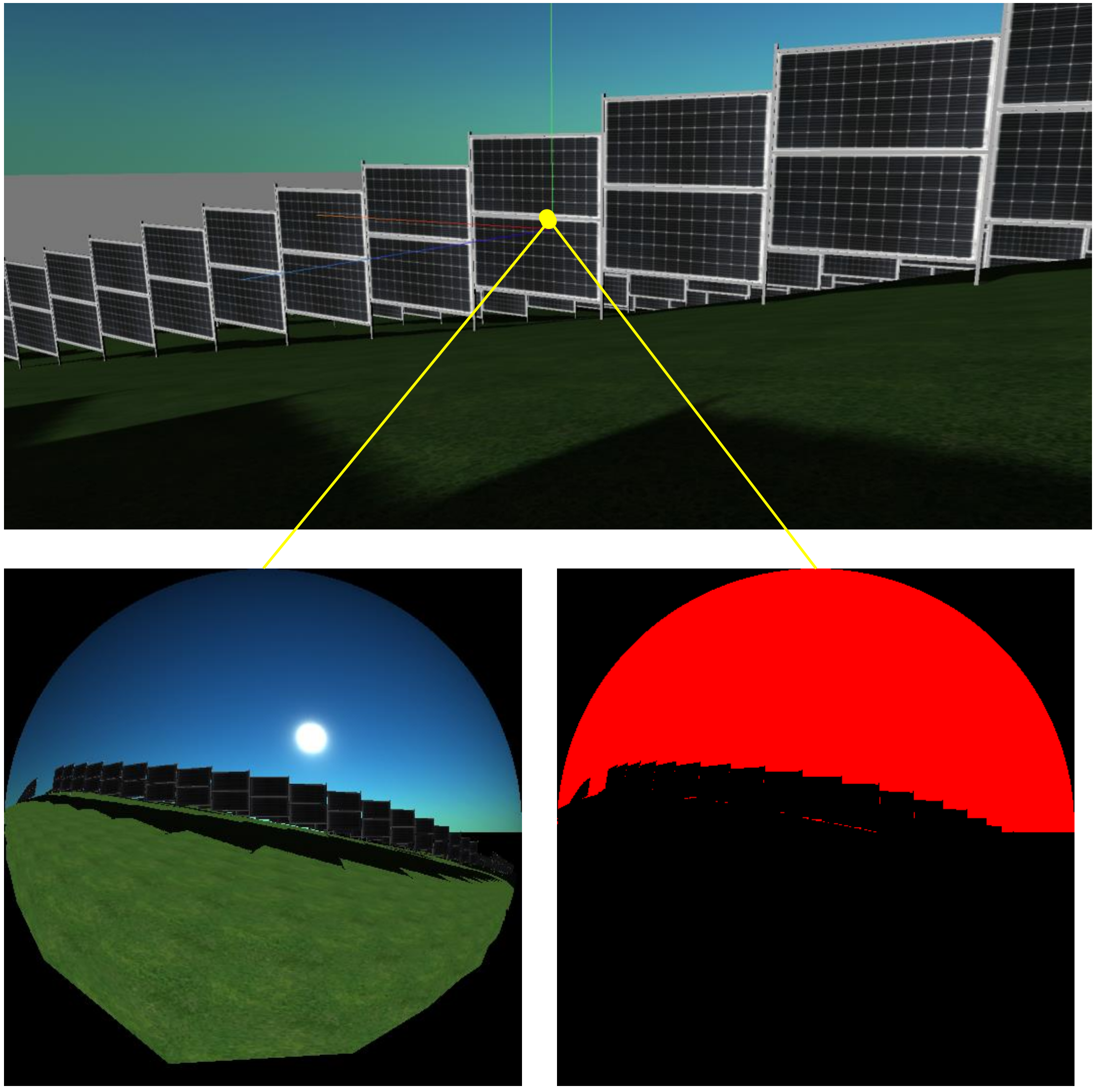
Application to vertical bifacial PV



- Identification of the contribution of the pixels in the picture with direct sight of the sky
- Non-uniform irradiance scenarios from sky possible (at pixel level)
- Easy identification of other elements blockage (diffuse shading)
- Larger effect with high tilt angles (maximum for agrivoltaics, marginal for carports)

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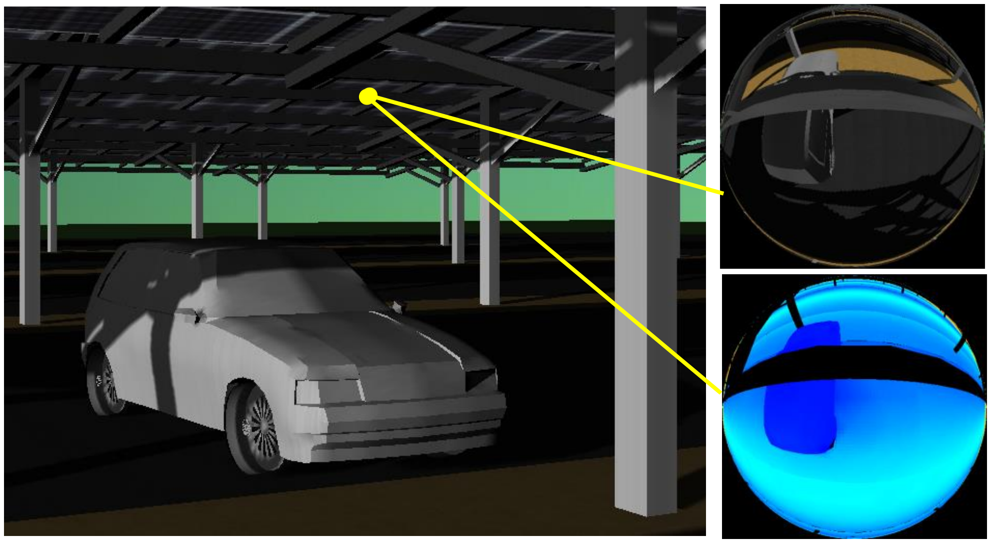
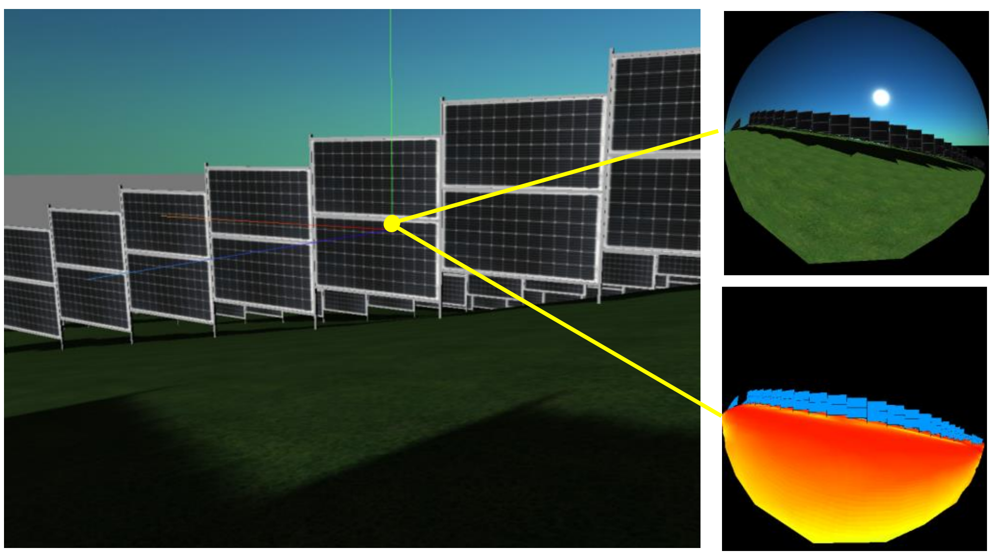
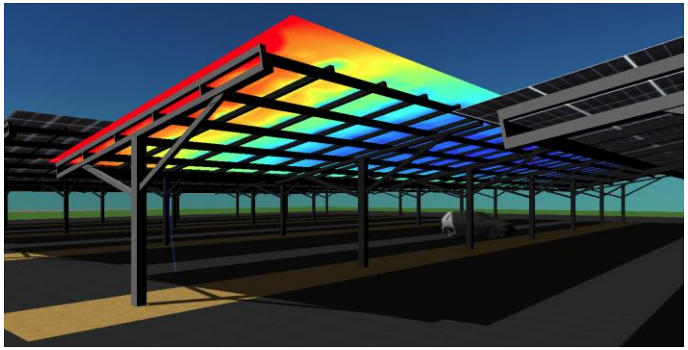
View factors for carports and vertical PV

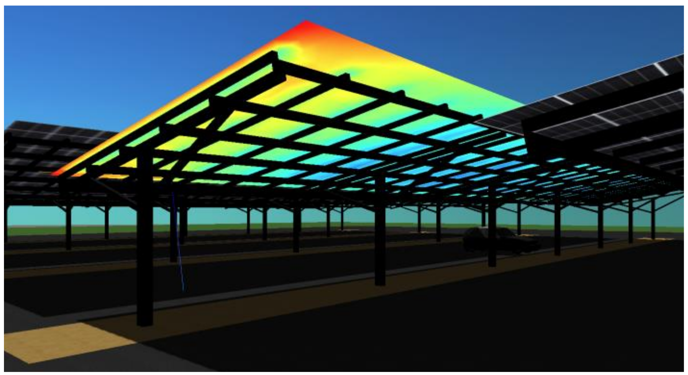


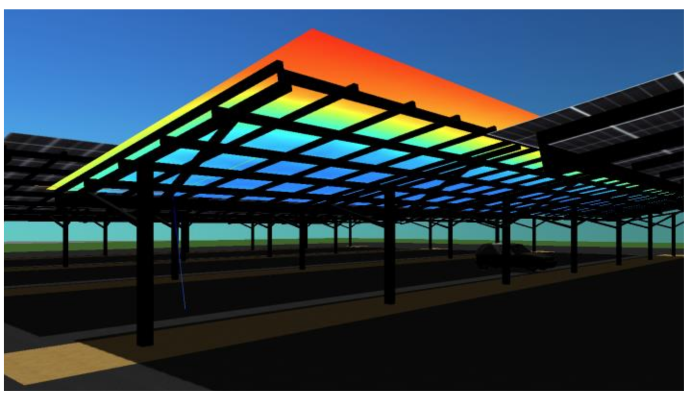


- Identifies the contribution of the pixels in the picture with reflection of the irradiance from sky
- Includes stationary albedo effects
- Takes into account objects orientation (previous step needed)
- Takes into account possible structure obstructions
- Not dependent on Sun position (computation acceleration; one-step computation for fixed structures)

Irradiance distribution on back side of carports







- Set of spherical view contribution pictures computed per vertex of auxiliary mesh to obtain the local view factor
- After multiplication by different irradiance contributors, we obtain the detailed irradiance breakdown on one side of the PV module
- Information transferred at PV cell level to compute non-homogeneities (mismatch)
- Detailed of structure blockage captured depending on mesh resolution (versus computational time)

Contact

Jonathan Leloux

Email	jonathan.leloux@lucisun.com
Phone	(+32) 468 08 37 38
LinkedIn	www.linkedin.com/in/jonathanleloux