D6.2 Simplified Model to Reach Broader Stakeholders Audience

Symbiosyst

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Acronyms and Abbreviations

3D	Three-dimensional
Agri-PV / agri-PV	Agrivoltaics / agri-photovoltaics
BTDF	Bidirectional Transmittance Distribution Function
BNI	Beam Normal Irradiance
CAP	Common Agricultural Policy
CAPEX	Capital Expenditure
CINEA	European Climate, Infrastructure and Environment Executive Agency
CPT	Cone Penetration Test
CSV	Comma-Separated Values
D6.2	Deliverable 6.2
DEM	Digital Elevation Model
DHI	Diffuse Horizontal Irradiance
DLI	Daily Light Integral
DNI	Direct Normal Irradiance
EC	European Commission
EIA	Environmental Impact Assessment
EPW	EnergyPlus Weather file
EU	European Union
GA	Grant Agreement
GPU	Graphics Processing Unit
GSE	Gestore dei Servizi Energetici
HV	High Voltage
Kd	Diffuse reflectance coefficient
Kp	Effective number of surface passes
Ks	Specular reflectance coefficient
Kt	Total transmittance
kV	Kilovolt
LCOE	Levelized Cost of Energy
LED	Light-Emitting Diode
LiDAR	Light Detection and Ranging
MASE	Ministry of the Environment and Energy Security
MTL	Material Template Library / material file
MV	Medium Voltage
MW	Megawatt
NOCT	Nominal Operating Cell Temperature
Ns	Shininess coefficient
OBJ / .obj	Wavefront OBJ file
OPEX	Operating Expenditure
PAR	Photosynthetically Active Radiation
PNRR	National Recovery and Resilience Plan
PPFD	Photosynthetic Photon Flux Density
PR	Performance Ratio
PV	Photovoltaic
PVGIS	Photovoltaic Geographical Information System
SANDIA	Sandia National Laboratories

SPT	Standard Penetration Test
USCS	Unified Soil Classification System
VPD	Vapour Pressure Deficit
WACC	Weighted Average Cost of Capital
WEA	Weather file format for Radiance workflow
WP6	Work Package 6
$W \cdot m^{-2}$	Watts per square metre
$\mu mol \cdot m^{-2} \cdot s^{-1}$	Micromoles per square metre per second
$mol \cdot m^{-2} \cdot d^{-1}$	Moles per square metre per day
°C	Degree Celsius
m / m²	Metre / square metre
h	Hour

Executive Summary

This deliverable presents the simplified agrivoltaics modelling approach developed in SYMBIOSYST to support early-stage stakeholder understanding of agri-PV design options. The deliverable documents two complementary components: the EURAC early-design tool (*DualHarvest*), which supports rapid screening of agri-PV configurations, and the public LUSIM demo provided by LUCISUN, which enables more detailed visualisation and analysis of irradiance distribution in selected open-field and greenhouse scenarios.

The objective is not to replace detailed engineering, agronomic validation, grid studies, or permitting assessments. Instead, D6.2 provides an accessible modelling layer that helps farmers, agronomists, PV designers, and other stakeholders understand the main trade-offs between crop-light availability and PV electricity generation at an early stage of project development.

The report first explains the purpose, target users, inputs, outputs, and assumptions of *DualHarvest*, the EURAC early-design tool. It then presents the LUSIM public demo, including the available scenarios, user journey, heatmap/time-series outputs, and export options.

Finally, it explains how irradiance outputs can be interpreted in agronomic terms through PAR, PPFD, DLI, and crop-light reference values and provides guidelines for the responsible usage of these tools for early-design.

Introduction

The deliverable is structured around two modelling tools, complemented by a final section on limitations and boundary conditions. The first section presents the agrivoltaics modelling tool developed within the project by EURAC (*DualHarvest*), detailing its underlying methodology, key functionalities, and the parameters used to simulate both the electrical performance of the PV system and the impact on crop irradiance. The second section is dedicated to the presentation of the free version (Demo Version) of the *LUSIM* software developed by Lucisun. The section provides an overview of the tool's main functionalities, user interface, and intended applications, highlighting the features currently available in the demonstration release. The third section focuses on the critical enabling conditions for agrivoltaics deployment, with specific emphasis on geotechnical constraints, legal and regulatory aspects, electrical interconnection requirements, and the strategic importance of on-site self-consumption.

Agrivoltaics systems introduce additional structural, agronomic, electrical, and regulatory complexity compared to conventional ground-mounted photovoltaic plants. For this reason, early-stage feasibility assessments must be conducted with greater rigour than for the more conventional PV plants. A project that initially appears viable may later prove non-viable once soil characteristics, agricultural productivity, grid constraints, or legal classifications are analysed in detail. The following considerations summarise the most critical factors that should be evaluated during the initial screening phase.

In the early-design phase, it is also essential to rely on a modelling tool capable of quickly and flexibly representing the agrivoltaics system under development. Such a tool should allow the designer to simulate both the reduction of irradiance on crops and the expected electrical production of the PV plant. This capability is crucial because every agrivoltaics project must be supported by a specific agronomic plan, ensuring that crop health, agricultural productivity, and long-term land stewardship are preserved. Without a robust early-stage modelling, it is not possible to compare and select the most suitable Agri-PV configuration while ensuring compatibility with agricultural requirements.

Moreover, the stakeholders involved in an Agri-PV initiative must be fully committed to operating the combined energy generation and agricultural activities over the long term. Attention should be given to ensuring that, within this synergy, agricultural objectives remain the primary driver of system design and operation. This includes safeguarding agricultural productivity, maintaining crop quality, and preserving environmental performance, while simultaneously enabling renewable energy generation.

This requirement stems from the fact that maintaining the agricultural component is essential to preserve the authorisation granted for the construction and operation of the PV plant. In other words, if agricultural performance declines, it is not possible to discontinue farming activities while continuing only the energy-selling business.

This condition also has implications for the asset's financial value: while a conventional utility-scale PV plant generally maintains a clear and straightforward valuation, the resale of an agri-PV installation is inherently more complex. The coexistence of two interdependent business models—energy production and agricultural operations—introduces additional uncertainty for potential buyers and may reduce asset liquidity compared to standard PV projects.

DualHarvest (Agri-PV Early Design Tool)

The tool developed by Eurac is designed to provide an initial assessment of the potential electricity yield and the amount of light reaching the various parts of the plant, the ground and the photovoltaic modules. As this tool is specifically designed for users with no prior experience of 3D modelling or light simulation, it is designed to be user-friendly. The target user is primarily a farm owner or an agronomist. This is because, when speaking with these professionals, we realised that in the early stage of designing an Agri-PV system, the two main questions asked upfront are: the potential for electricity generation, and, most important, the amount of light reaching the plants and the soil near the plants (the latter to assess soil evapotranspiration).

Methodology: how the *DualHarvest* model works

To achieve the intended simulation results, the model carries out the following main steps:

User Inputs

1. The user is first asked to provide some parameters to build the 3D model of the Agri-PV system. The parameters are:
    a. The shape of the plant's foliage, to be chosen among 4 options:
        i. Hexagonal pyramid
        ii. Hexagonal prism
        iii. Hexagonal bipyramid
        iv. Inverted hexagonal pyramid
    b. Total height of the plant and height of the trunk.
    c. Canopy width of the plants.
    d. Distance between two rows of plants.
    e. Distance between two plants in the same row.
    f. The height of the vertical posts of a single tracker and the length of the horizontal beam of a tracker.
    g. The thickness of the vertical and horizontal posts of the tracker structure.
    h. Number of vertical posts per tracker.
    i. Number of rows of plants between each tracker.
    j. Geolocation of the Agri-PV plant and direction of the Trackers respect to North.

    The optical characteristics of the plants and photovoltaic modules models – such as the transparency percentage of the modules and the canopy, or the colour of the canopy or ground – can also be adjusted quite easily by editing a text file. In any case, the tool provides default values so that even a non-expert user can still run a simulation.

2. Module specifications:
    a. Efficiency
    b. Width
    c. Length
    d. Thickness
    e. Bifaciality factor
    f. Transparency

g. Temperature coefficient (default value if not entered by the user)

3. Input of weather data from a file (EPW format)

4. The user decides on the parameters of the simulation.
   These parameters are:
   a. Timestep
   b. Start and end date and time of the simulation
5. Optional inputs:
   a. Context OBJ file
   b. CAPEX and OPEX values
   c. Lifetime of the plant
   d. WACC (Weighted Average Cost of Capital)

   These inputs are defined as optional because the code can run even without these values being provided by the user. Specifically, the simulation can be run even without context files, in which case only the geographical location is taken into account, rather than the shading caused by the topographical profile of the area surrounding the Agri-PV plant. As regards CAPEX, OPEX and lifetime values, the code uses default values generated by the Symbiosyst project, which are therefore close to realistic figures.

3D Model Generation

Once the user-defined inputs have been acquired, the first stage of the workflow consists of the generation of the 3D Model of the Agri-PV system and its surrounding environment. This model represents the geometric basis for the simulation and includes photovoltaic modules, trackers, crops, and the surrounding that may influence solar radiation distribution.

6. Generating a 3D model of a single crop.

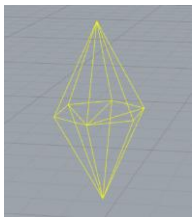


Figure 1. Single Crop Model

7. Generating a 3D model of a single tracker with PV modules.
8. Generating a 3D model of a complete trackers field with PV modules.

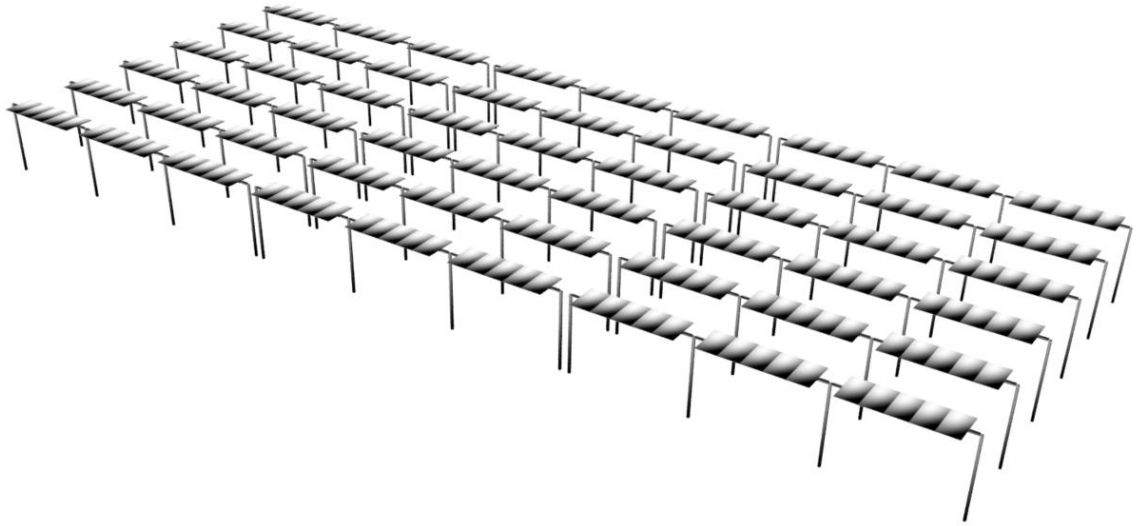


Figure 2. 3D Model of the complete tracking System

9. Generation of geometries for each tilt angle adopted by the tracker.
10. Generating a 3D model of a complete Agri-PV Plant.

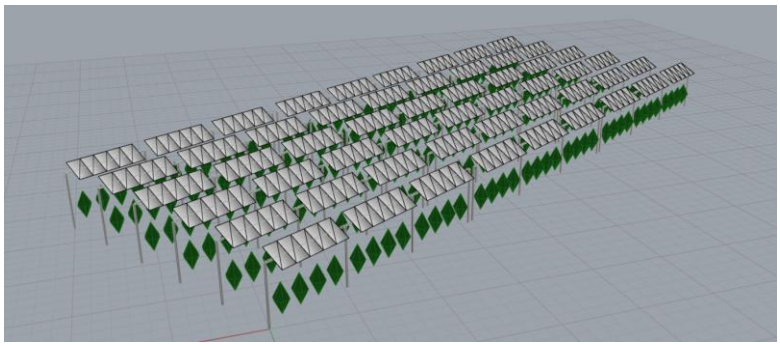


Figure 3. Complete Agri-PV Plant Model

11. The model of the geographical context is imported into the simulation environment and preserves the original geometry and mesh structure of the source file. Contextual 3D models can be generated through several approaches, including both open-source and commercial platforms providing terrain and landscape data. Depending on data availability and the required level of accuracy, the surrounding environment may be reconstructed using Digital Elevation Models (DEMs), photogrammetric datasets, LiDAR surveys, or online 3D mapping services. Once generated, the contextual OBJ model is imported into the workflow without any modification of the original mesh. The purpose of this model is to represent the surrounding topography and landscape features that may affect the solar resource through horizon obstruction and shading effects. Since the contextual environment is primarily used to capture large-scale shading phenomena rather than detailed local interactions, the geometry is typically maintained at a relatively coarse level of detail. This approach ensures an appropriate balance between simulation accuracy and computational efficiency, allowing the model to accurately reproduce the influence of the surrounding landscape while limiting computational costs.
12. Placing the 3D model of the Agri-PV plant in the correct location, together with the context.

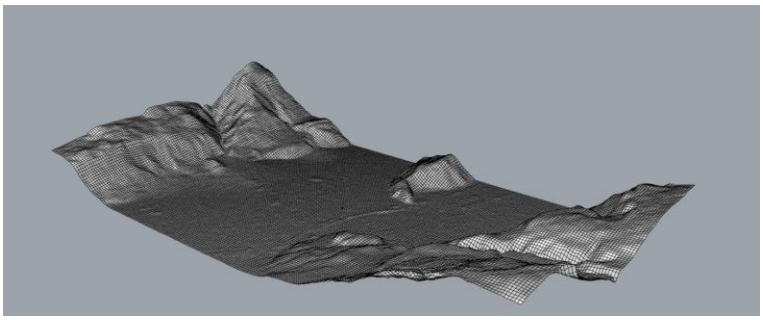


Figure 4. Context Model (landscape)

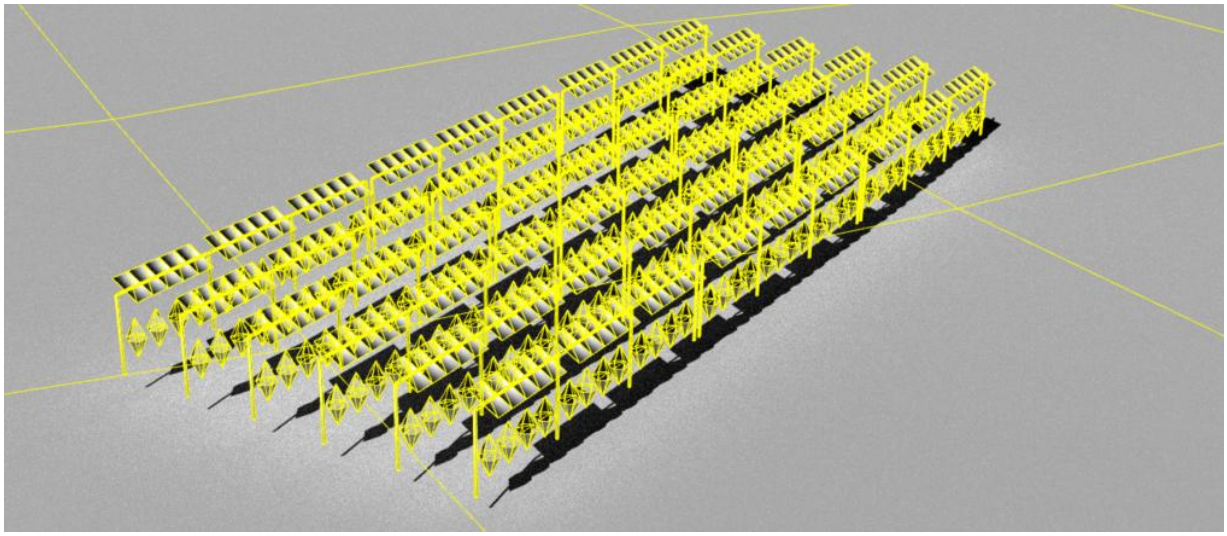


Figure 5. Complete model of an Agri-PV included in the Context (Close View)

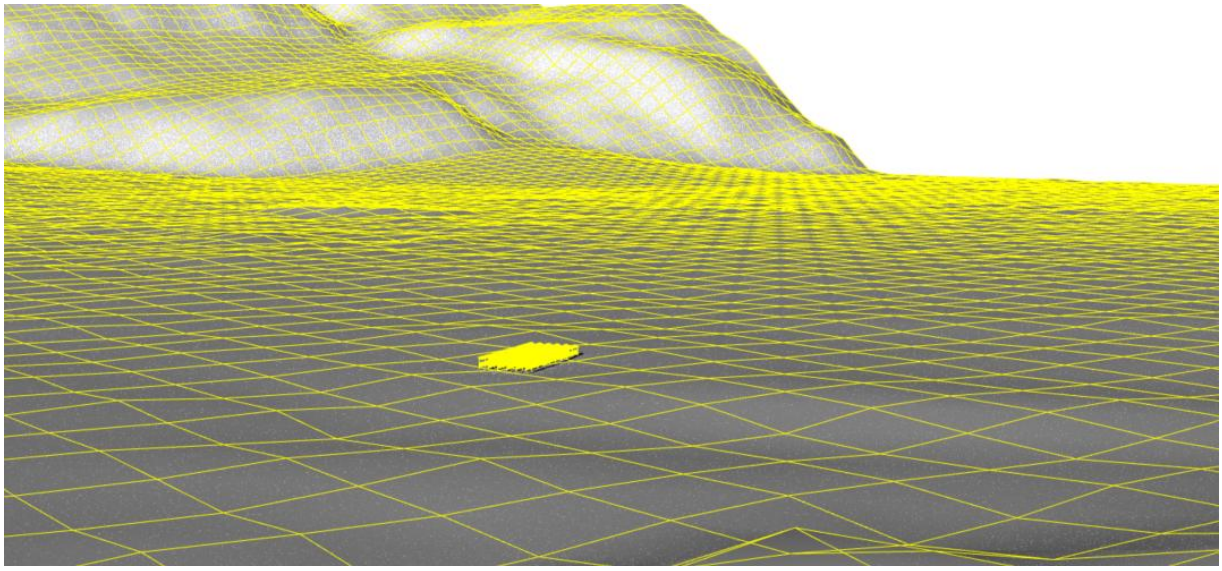


Figure 6. Complete model of an Agri-PV included in the Context (Large View)

13. Generation of the mesh of the Agri-PV system.
    Module meshes are derived from the tracker geometry and consist of one measurement surface above the PV module and two below it. These meshes are generated using a user-defined spatial resolution, rotated according to the tracker orientation, and offset from the module surfaces to enable accurate irradiance calculations while avoiding geometric overlap.
    Ground meshes are represented by simplified rectangular sampling surfaces located on both sides of a selected tracker. Positioned slightly above the ground and discretized into structured triangular grids, they are designed to evaluate irradiance distribution at ground level.
    Plant meshes are generated from parametric representations of tree canopies, such as hexagonal pyramids, prisms, bipyramids, and inverted pyramids. The workflow includes the identification of external canopy faces, removal of internal surfaces, outward offsetting of measurement surfaces, triangulation, and optional mesh refinement through recursive subdivision.
    Across all mesh types, the tool ensures consistent normal orientation, user-controlled spatial resolution, and the use of offset measurement surfaces to improve the robustness and accuracy of Radiance-based irradiance simulations.
14. Materials.
    Surface optical properties are defined in a single MTL library. The library assigns named materials to each component type: PV module, tracker horizontal axis, vertical poles, tree canopies, measurement planes, and context elements.
    During 3D model generation, each OBJ exporter tags faces with the corresponding material. The same file is copied into the 3D output folder and, later, into each tracker-angle geometry set used for irradiation simulations. Context OBJ files imported from external models are remapped to these canonical material names where needed.
    For Radiance simulations, the MTL library is converted at run time into a .rad material file. Diffuse (Kd), specular (Ks), shininess (Ns), and opacity parameters are translated into Radiance plastic, glass, or trans models according to material type: PV modules are treated as opaque plastic; tree canopies as translucent layers with total transmittance (Kt) and an effective number of surface passes (Kp). Technical measurement surfaces as fully transparent trans materials that do not block light paths. This ensures consistent material definition from configuration through 3D geometry to ray-tracing.
15. Sky generation: is performed dynamically at each simulation timestep using the weather file and Radiance tools. The workflow first converts the EPW file to WEA format, then reads the direct normal and diffuse horizontal irradiance corresponding to the selected date and hour. For each timestep, the model computes the solar time correction (including longitude and equation of time) and builds an instantaneous sky with gendaylit[1], so the sky condition is physically consistent with location, time, and meteorological data. This means the sky is not static: a new sky is generated for every timestep, and the Radiance scene is re-evaluated accordingly.

[1] https://github.com/NatLabRockies/Radiance/blob/master/src/gen/gendaylit.c

Simulation/Optimization

At this stage, the workflow is ready to perform the irradiance simulation. The user is asked to select the operating mode, namely either standard solar-tracking operation or irradiance-optimized tracking based on crop light requirements.

In the case of standard solar tracking, the tool directly performs the irradiance simulation (step14) using the tracker positions determined solely by the sun-following algorithm. Conversely, when the irradiance-optimized mode is selected, an additional optimization step is executed after the simulation. In this configuration, the tracker positions are adjusted to meet the predefined crop irradiation targets while minimizing deviations from the reference solar-tracking trajectory

16. Run the Simulation.
17. Optimization. In the optimization mode, the tool requires as input a set of target daily irradiation values defined for each month of the year, together with the desired intra-day distribution of the received irradiation. Based on these inputs, the algorithm generates a target irradiation profile for every day of the year, considering the corresponding meteorological conditions. For each day, the optimization routine determines the tracker positions that best achieve the prescribed irradiation target, whenever the available solar resource allows it. Simultaneously, the algorithm minimizes deviations from the reference solar-tracking configuration, thereby limiting unnecessary tracker movements and preserving energy yield. The resulting output consists of a complete annual sequence of optimized tracker positions that balances compliance with crop-specific light requirements and adherence to conventional solar-tracking operation.

Generation of the Outputs

18. Energy production calculation. The electrical energy production of the photovoltaic system is estimated by means of a simplified module-level energy balance. Two alternative approaches are implemented within the tool, allowing the user to select either a standard irradiance-based model or a temperature-corrected formulation.
    In the first **irradiance-based model**, the electrical power generated by each bifacial PV module is calculated from the simulated irradiance values obtained in the previous modelling step. The average rear-side irradiance is determined as the arithmetic mean of the irradiance values calculated on the left and right sides beneath the module:

$$G_{rear} = \frac{G_{below,left} + G_{below,right}}{2}$$

    The front-side module power is then calculated as:

$$P_{front} = G_{above} \cdot A_{front} \cdot \eta \cdot PR$$

    where $G_{above}$is the incident irradiance on the front surface, $A_{front}$is the active module area, $\eta$is the module conversion efficiency, and $PR$is the performance ratio accounting for system-level losses. The contribution from the rear side of the bifacial module is calculated as:

$$P_{rear} = G_{rear} \cdot A_{rear} \cdot bifaciality \cdot \eta \cdot PR$$

    where *bifaciality* represents the rear-side performance factor provided by the module manufacturer.

The total module power output is obtained by summing the front-side and rear-side contributions:

$$P_{mod} = P_{front} + P_{rear}$$

The energy generated during each simulation timestep is then calculated as:

$$E_{step} = P_{mod} \cdot \Delta t$$

where Δtrepresents the timestep duration expressed in hours.
Finally, the total plant power and energy production are obtained by scaling the module-level results according to the total number of modules installed.

To account for the effect of operating temperature on PV conversion efficiency, a second modelling option includes a **temperature corrected model** [1]**,** based on the Nominal Operating Cell Temperature (NOCT) approach.
First, the total irradiance effectively received by the bifacial module is calculated as:

$$G_{poa} = G_{above} + G_{rear}$$

The cell temperature is then estimated as:

$$T_{cell} = T_{amb} + (NOCT{-}20)\frac{G_{poa}}{800}$$

where $T_{amb}$is the ambient air temperature and NOCT is the nominal operating cell temperature specified by the module manufacturer.
The temperature-corrected module efficiency is computed as:

$$\eta_T = \eta \cdot (1 + \gamma \cdot (T_{cell} - 25))$$

where $\gamma$is the module temperature coefficient.
The corrected efficiency $\eta_T$is subsequently used in place of the nominal efficiency η in the front-side and rear-side power calculations, allowing the model to account for performance variations associated with changing operating temperatures.

The main parameters required by the electrical energy model are:

- G: irradiance values [Wm^{-2}] derived from the irradiance simulation workflow;
- A_{front}, A_{rear}: active front-side and rear-side module areas [m²];
- η: nominal module efficiency [-];
- PR: performance ratio [-];
- *bifaciality*: rear-side performance factor [-];
- γ: temperature coefficient [°C^{-1}];
- $NOCT$: Nominal Operating Cell Temperature [°C];
- T_{amb}: ambient air temperature [°C];
- Δt: simulation timestep duration [h].

This methodology provides a computationally efficient estimation of PV energy yield while allowing users to include first-order temperature effects when higher modelling accuracy is required.

19. When a full-year simulation is performed, the tool also calculates the Levelized Cost of Energy (LCOE). The calculation is based on the annual energy yield estimated by the simulation and enables a preliminary economic assessment of the proposed Agri-PV configuration. The LCOE is computed using the following formula:

$$\mathrm{LCOE} = \frac{\mathrm{CAPEX} + \sum_{t=1}^{N} \frac{\mathrm{OPEX}_t}{(1+r)^t}}{\sum_{t=1}^{N} \frac{E_t}{(1+r)^t}}$$

Economic inputs are set in the configuration file:

- CAPEX — total installed cost of the system [€]
- OPEX (year 1) - annual operating and maintenance cost in the first year [€/year]
- WACC — discount rate [%]
- Lifetime — analysis period [years]
- Energy degradation — optional annual reduction in PV output [%/year]; year *t* energy: $E_t = E_1 \times (1-d)^{(t-1)}$ (d − annual degradation rate)

20. The output from the Early Design Tool is text-based (e.g., an Excel spreadsheet), ensuring that it does not rely on 3D visualisers. Furthermore, text-based outputs are more immediate to interpret and can be more easily integrated into subsequent analysis and decision-making workflows.

datetime	angle_deg	angle_str	module_top_\	module_bottom_'	plant_upper_east_V	plant_upper_west	plant_lower_e	plant_lower_v	ground_far_p	ground_mid	ground_near	ground_left_f	ground_lef	ground_lef	ground_rig	ground_rig	ground_rig	electrical_production_kWh
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01.06.24 07:00	22	-22deg	278.0896546	2.890547344	268.0288333	2.3559	0.041033333	2.35583333	258.76705	258.767	258.76705	258.7513	258.7586	258.766	258.7828	258.7754	258.7681	2.91447
01.06.24 07:30	28	-28deg	365.1456012	8.526003805	0.074566667	0.185833333	0.074666667	0.1858	374.0657	187.71615	1.3665	374.0688	1.3682	1.3667	374.0626	374.0641	1.3663	3.86159
01.06.24 08:00	34	-34deg	379.5896283	15.32187378	0.046133333	0.030133333	0.0462	0.03016667	440.2501	440.2501	1.8356	440.254	440.2522	1.8359	440.2462	440.248	1.8353	4.06177
01.06.24 08:30	38	-38deg	405.1731998	24.07329747	0.050233333	0.0869	0.050333333	0.08696667	530.6838	267.1785	3.67325	530.7075	530.6964	3.6748	530.6601	3.6606	3.6717	4.39222
01.06.24 09:00	44	-44deg	380.7285853	36.04361876	0.066533333	0.086566667	0.0666	0.08666667	587.5148	294.676	1.8372	587.524	587.5197	1.8378	587.5056	1.8323	1.8366	4.2258
01.06.24 09:30	50	-50deg	355.2447702	50.50951585	0.1346	0.146733333	0.1346	0.14686667	673.13645	673.1364	1.4371	673.1415	673.1391	1.4374	673.1314	673.1337	1.4368	4.06691
01.06.24 10:00	50	-50deg	359.1199067	55.4232829	0.401166667	0.1284	0.401	0.12853333	722.70305	363.6632	363.6632	722.7325	722.7187	722.7049	722.6736	4.6077	4.6215	4.14331
01.06.24 10:30	50	-50deg	379.8152448	62.08933166	0.366433333	165.0489667	0.3664	0.1816	798.33475	402.56335	402.56335	798.376	798.3568	798.3375	798.2935	6.7699	6.7892	4.40758
01.06.24 11:00	50	-50deg	382.5232554	64.97463357	0.421966667	175.7884	0.4218	0.1553	826.87065	416.54535	416.54535	826.9117	826.8925	826.8733	826.8296	6.1982	6.2174	4.45695
01.06.24 11:30	50	-50deg	359.6396142	62.4387641	0.213133333	170.9911333	0.2132	0.20026667	791.0956	398.3975	791.0956	791.1286	791.1132	791.0977	791.0626	5.6818	791.0935	4.20024
01.06.24 12:00	44	-44deg	433.8170623	53.81849767	0.2572	173.5784333	0.257166667	0.1436	798.15245	401.88045	798.1525	798.1892	798.1721	798.1549	798.1157	5.5888	798.1501	4.90868
01.06.24 12:30	22	-22deg	652.2905285	7.214618184	91.58736667	329.4394333	0.302166667	0.17323333	788.68005	397.24925	788.68005	788.7189	788.7007	788.6826	788.6412	5.7978	788.6775	6.83941
01.06.24 13:00	-12	-12deg	713.9048118	80.3618861	155.3336333	347.1320667	0.4225	0.28236667	774.856	390.08645	774.85605	774.8859	774.8719	774.858	774.8261	5.301	774.8541	8.01764
01.06.24 13:30	-30	-30deg	579.2354123	21.489514	187.8469	425.6794667	0.4596	0.16773333	774.44735	390.4494	390.44945	774.486	774.4679	774.4499	774.4087	6.4309	6.449	6.18418
01.06.24 14:00	-38	-38deg	489.5605898	36.1023192	219.3149	396.3186	4.330066667	0.27043333	739.49825	372.39105	372.39105	739.5317	739.5161	739.5005	739.4648	5.266	5.2816	5.35852
01.06.24 14:30	-40	-40deg	442.8690222	35.11295969	0.2213	356.0314667	0.2212	0.12743333	671.67255	671.6725	2.28405	671.6857	671.6795	2.2849	671.6594	671.6655	2.2832	4.86548
01.06.24 15:00	-40	-40deg	428.5578914	30.92899216	0.104066667	110.9079	0.1041	0.10636667	621.00015	621.00015	311.26875	621.0042	621.0023	621.0004	620.9961	620.998	1.5371	4.68586
01.06.24 15:30	-38	-38deg	404.0571615	22.77590671	0.075433333	0.072733333	0.0755	0.0728	537.92855	270.69915	3.46975	537.9507	537.9404	3.4712	537.9064	3.4579	3.4683	4.37108
01.06.24 16:00	-36	-36deg	393.2980111	16.88328326	0.045133333	0.055633333	0.045133333	0.0557	476.1161	476.1161	2.2508	476.1283	476.1226	2.2516	476.1039	476.1096	2.25	4.21586

Table 1. Example of the output for the Electrical Production Simulation

Table 1 shows an example of the output. In this case, the irradiance is calculated at the centre of the front face of a module and at two points on the back, because the backside of the photovoltaic module is in practice divided into two by the tracker's axis of rotation; it is therefore useful to distinguish between these two values. In this case, the step between two discrete angles that the tracker can take is 10 degrees, and a backtracking function is also present. This significantly limits the positions that the trackers can take. The power output of the front and rear sides of the PV module (considering the bifaciality factor) is then calculated, as well as that of the entire plant.

LUSIM: 3D irradiance simulation on the demonstrators

While the early design tool developed by EURAC as described in the previous section supports rapid screening of configurations, LUCISUN has developed LUSIM, which allows users to dive deeper on specific configurations of Agri-PV, providing detailed irradiance analysis. Through this analysis, it is in the interest for agricultural purposes to assess how much irradiance that the crops will receive in different spatial and temporal configurations. LUCISUN has provided free access to a limited version of its LUSIM 3D simulation tool through its website. Being an online tool, it is not necessary to perform any kind of installation but a simple registration on the site to get access. The steps to do that are described in a later section.

The demo version includes the following information:

- A precomputed scenario corresponding to one of the Symbiosyst demonstrators, located near Bolzano in Italy (open installation)
- A precomputed scenario corresponding to a generic agri-PV greenhouse (closed installation).
- A configurable scenario where the user can define some basic parameters and perform a simulation, including some variants over it to compare the results. This configurable scenario is based on an elevated tracker installation (as the one in Bolzano) and it includes:
    - A set of predefined locations, with irradiance obtained from PVGIS database
    - Overall azimuth orientation of the installation
    - From an agricultural point of view:
        - Crop model (from a predefined list)
        - Number of rows and number of crop elements per row
        - Distance between the rows and between the elements in a row
        - Ground and crop Lambertian albedo
        - Crop size
    - From PV installation point of view
        - PV module used (from a predefined list)
        - Tracker elevation from the ground (trackers are installed over the crop rows, so the pitch distance is controlled in the crops definition)
        - Rotation law for the trackers (from a predefined list of them)

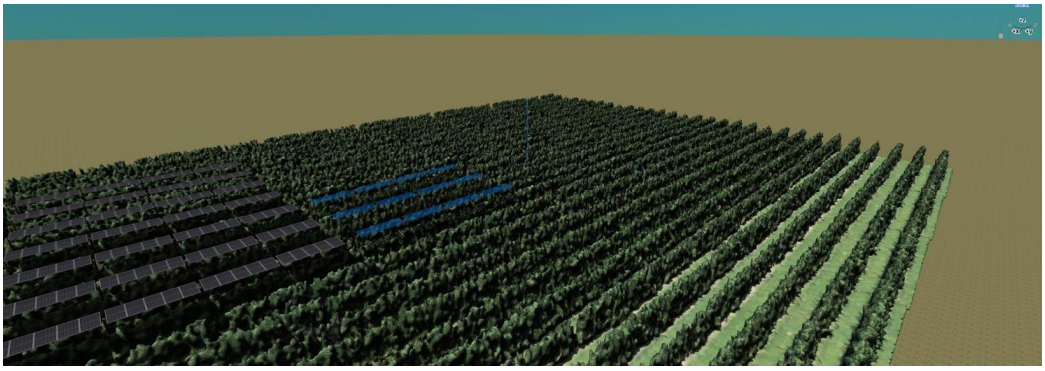


Figure 7. Screenshot of the precomputed Bolzano and greenhouse scenarios and an example of a user-configurable scenario.

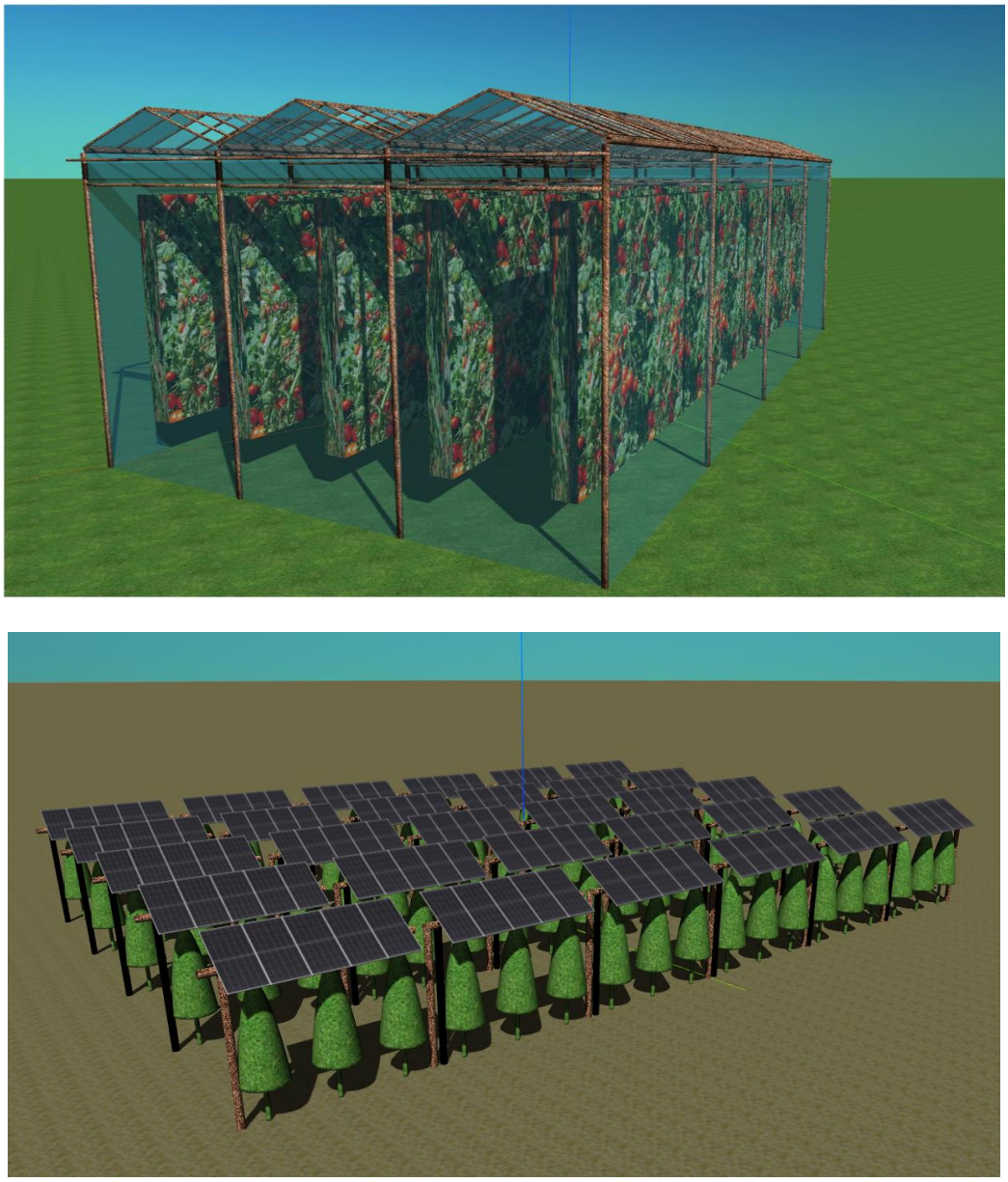


Figure 8. Screen shots of different scenarios simulated in LUSIM: Top – Bolzano site, Middle – Greenhouse, Bottom - example of customized agrivoltaic installation

LUSIM provides an analysis of the irradiance received on different areas of the crops, broken down by irradiance components and displayed as heatmaps for a specific date and time or as a time series graph for a point, a zone or a complete object in the scene. Additionally, the same level of detail is used to evaluate the irradiance received on the modules at cell level, module level or string level, using that information to provide additional PV related information as power generated or bifacial gain.

An example of the kind of outputs generated by LUSIM can be seen in Figure 9 (the controls and display options could vary on the demo version)

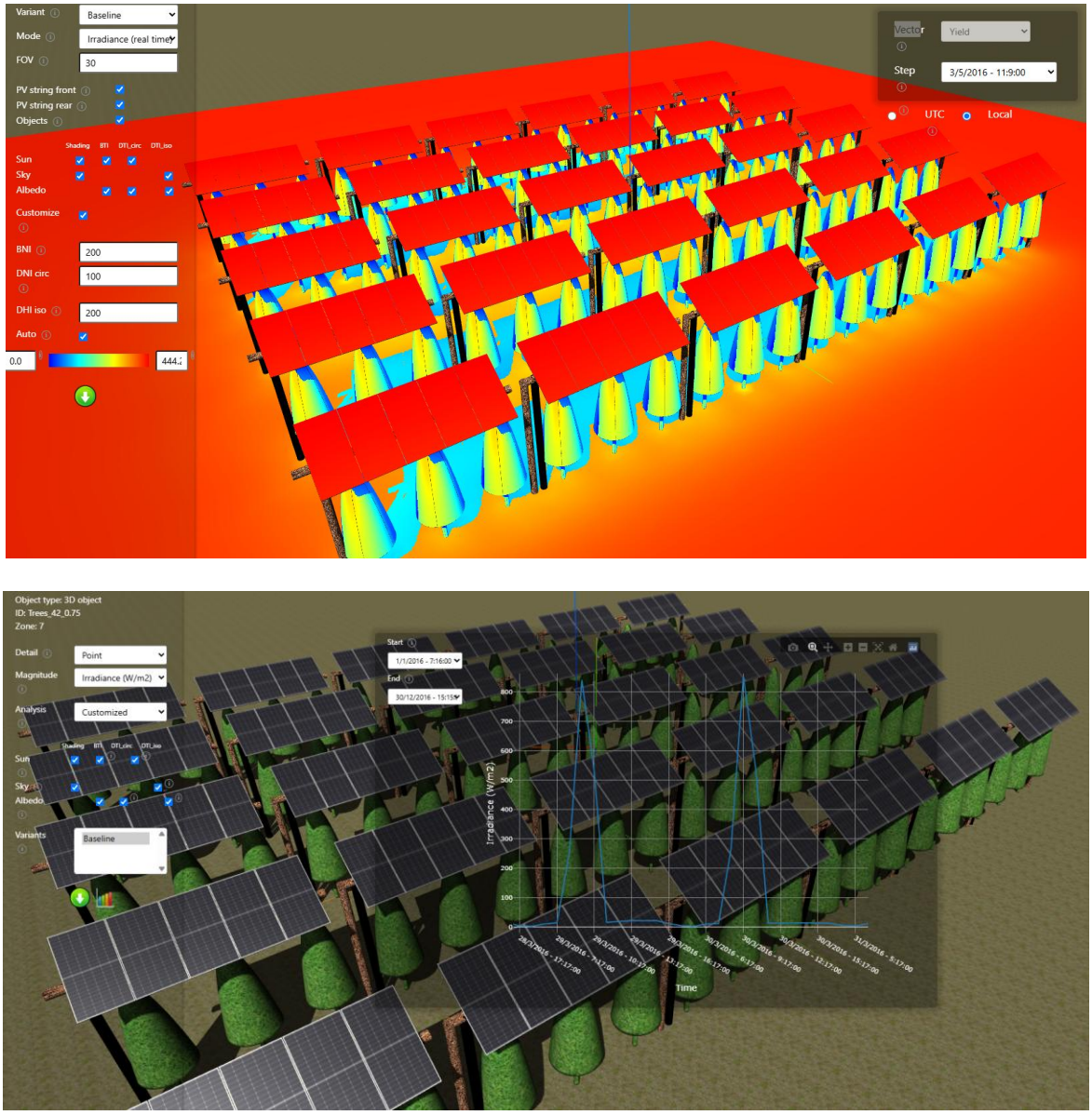


Figure 9. Screen shots of irradiance output through heatmaps or time series in LUSIM

The time series results can be exported on CSV files in case it is needed for some post-processing in an external software.

Methodology: How LUSIM works

LUSIM is based on a proprietary GPU computation engine. The setup of a scenario requires some knowledge of the tool's workflow, so for the demo version that is provided, a simplified interface is used, where most of the configuration setup is done in the background to make the user experience easier.

Being a GPU-based simulation environment, the computation time is very dependent on the hardware used (because as it is a web-based tool, that operation is performed in the user's GPU, not in LUSIM's servers). The

existing demonstrators are precomputed scenarios, and the simulation is not intended to be run online on them, only being possible to visualize the results.

The customizable example uses predefined elements (crops and modules) with a certain freedom for the user to combine them and arrange different geometrical configurations (crop grow, etc.). In that sense, LUSIM is equipped with a batch mode that allows to execute several scenario variants in the same simulation and compare the results between them. The demo version provides a limited option on that batch mode.

The process for the user is defined in the following steps:

1. Select the case to work with (preconfigured or customized)

2. If customized, an empty scene (or previously saved) is displayed
3. If customized, there is a button to open a dialog box to create/modify the existing scenario. If pressed, it displays a modal dialog as shown below (Figure 10).

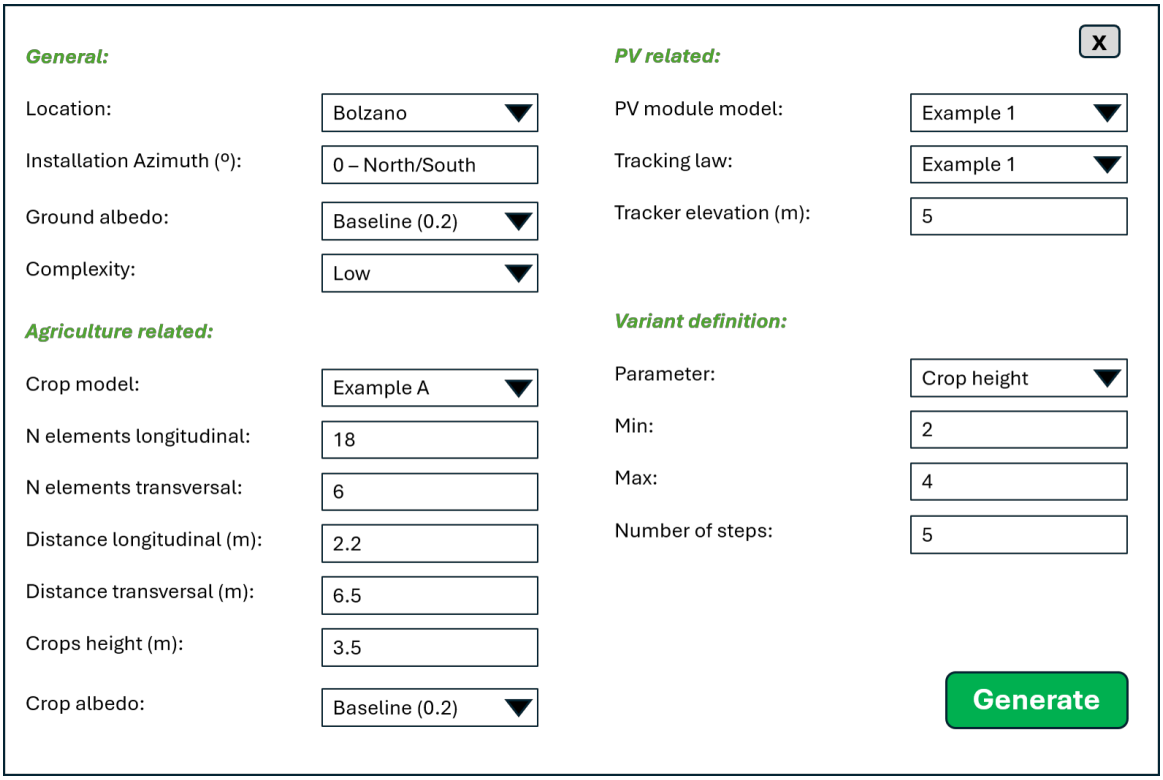


Figure 10. Dialog Box

This dialog includes the different options for the scene definition and the variants to be evaluated. When "generate" is pressed, the scene is displayed as shown in the bottom picture of the figure above.

4. Once the scenario is generated, a "play" button  is activated in the middle of the menu bar. Pressing that button starts the simulation.

5. Once the simulation is finished, a “save” button  is activated in the left side of the menu bar in case we want to save the simulation to be displayed the next time we log in to the tool.

6. To visualize the heatmap mode, press the “heatmap” button  on the right side of the menu bar. Pressing the button again turns the user back to the visualization mode.
In heatmap mode, the irradiance is displayed over the crops, ground, and both sides of the modules. The control of the information displayed can be done with the menu on the left side, like this picture (final version of the demo version can differ), where the following parameters can be controlled:



Figure 11. Parameters Control Menu

- Variant displayed
- Irradiance components from PVGIS database or manually entered by the user (with the customized box checked in)
- Color scale limits or auto mode for the display

7. To visualize the irradiance time series, the user can select a point in the scene and open the menu with the “Analytics” icon  on the right side of the menu bar. This will open a menu on the right side as the one in the following picture, that will include the following elements:

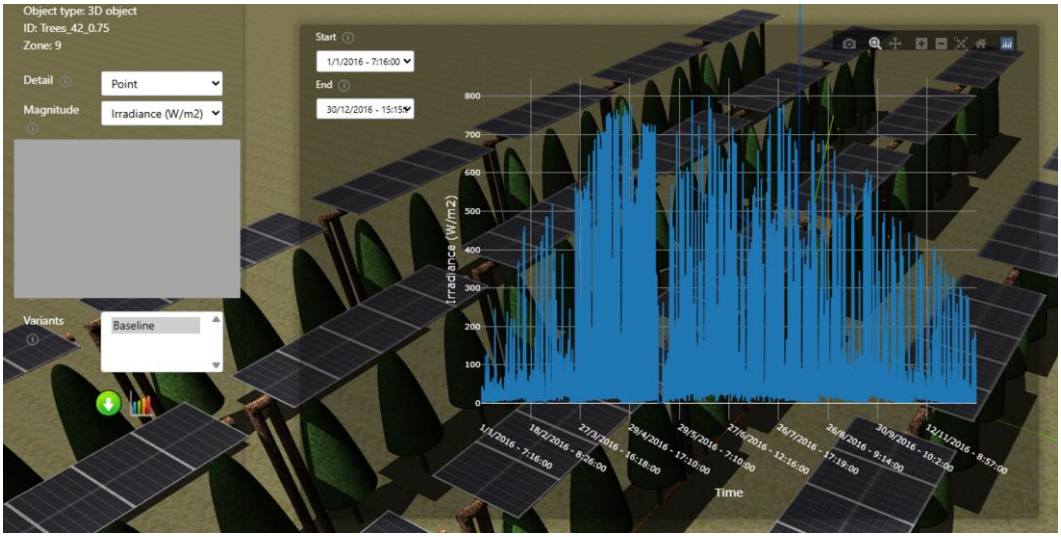


Figure 12. Analytics Menu

- Detail displayed – Depending if done for PV modules or objects, the value could be as cell or point, zone or module and object or string.
- Magnitude displayed – Irradiance or irradiation (in case of irradiation, another input to select the grouping level as hourly, daily, monthly or yearly is displayed).
- Variants displayed on the graph.
- Two buttons for displaying the graph ( ) or download the data as CSV ( ) once at least one variant is selected.

For the precomputed cases of Bolzano and the greenhouse, there is only the option to display the results as described in the points 6 and 7

Bolzano demonstrator: open-field overhead Agri-PV

Bolzano is the open-field case where bifacial panels stand on posts above field crops located in South Tyrol, Italy. There are two PV module configurations installed that share the site: a semi-transparent bifacial system that passes part of the direct irradiance through the module, and an opaque bifacial system that completely blocks direct irradiance. Running both over the same orchard vineyard, under the same sky, on the same terrain lets the project measure how each technology affects the total irradiance going to the crop below.

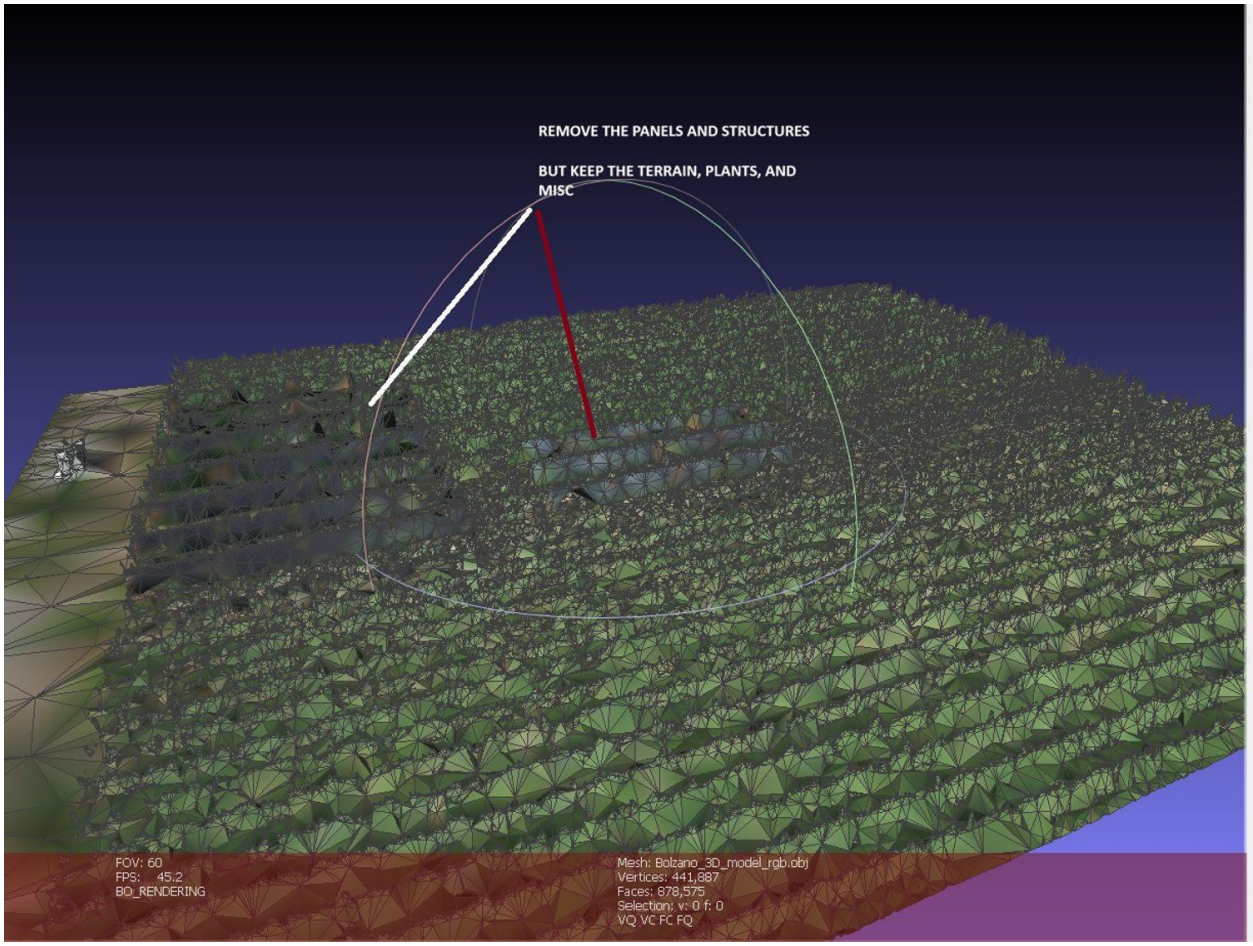


Figure 13. Raw .obj mesh of the Bolzano cutout. The on-screen note records the editing rule applied during cleaning: keep the terrain, plants, and other objects, and remove the panels and structures. The vertex and face counts show why the model stays a cutout rather than the full site.

The figure above shows the raw file in which ABOVE has provided through their drone imaging in which it was further processed by LUCISUN to remove artefacts present in the raw file**.** The cleaned plant as shown in the next figure is then imported in LUSIM with the opaque bifacial system on one side, the semi-transparent system on the other, and the crop rows running between them.

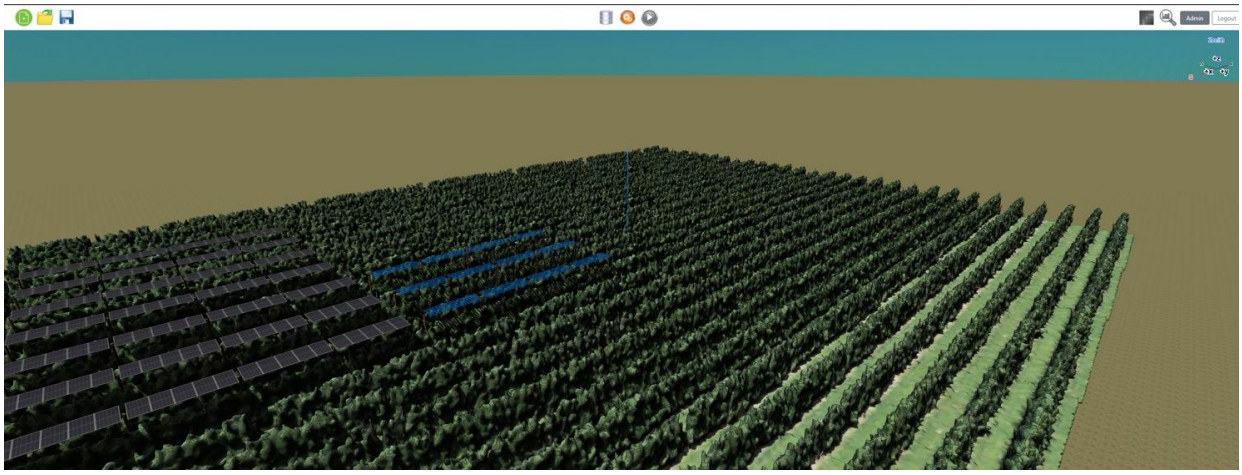


Figure 14. The cleaned Bolzano cutout in LUSIM. Opaque bifacial on the left, semi-transparent bifacial in the centre, crop rows throughout. The PV structures are parametric objects that move inside the model.

Surfaces under measurement

The model reads irradiance on six types of surfaces across the scene:

- the crops under the opaque panels,
- the crops under the semi-transparent panels,
- a reference crop strip beside the systems, with no panels above it,
- the front of each PV array,
- the rear of each PV array,
- the poles and beams.

The reference strip carries the whole comparison. Measured on the same site, under the same sky, at the same hour, it sets the baseline for every shaded reading: the light the crop would have received with no panels above it.

Irradiance and heatmaps

LUSIM separates the irradiance on each surface into direct, diffuse, and albedo, then paints the result across the geometry as a heatmap. The Bolzano analysis reports the front of both PV systems, the rear of both systems, where the bifacial gain and the albedo off the crop appear, and the crop under each system. The opaque and semi-transparent PV modules produce the three different zones in which the share of light that reaches the crop under each one of the systems, and the open-sky reference field. The semi-transparent module passes part of the direct beam through its surface, while the opaque module passes light to the crop only through the row gaps and from the diffuse sky.

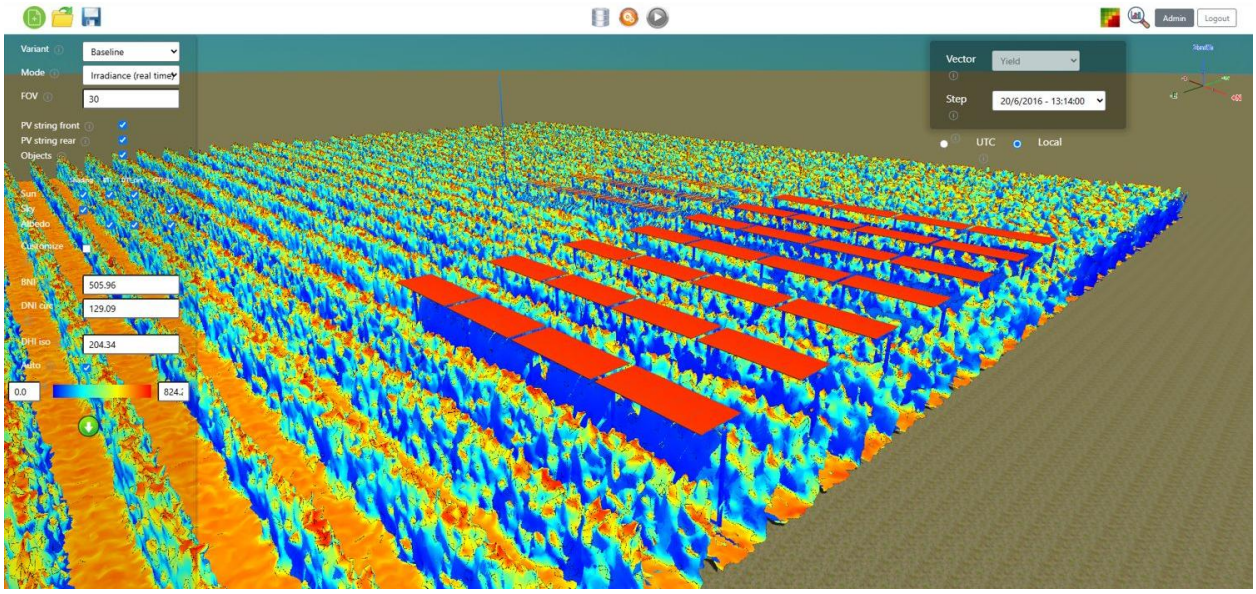


Figure 15. Irradiance heatmap on the Bolzano scene. The left panel shows the sun, sky, and albedo components, the BNI, DNI, and DHI values, and the timestep.

As shown in the reference field, these surface-level numbers give the crop-light answer that the early-design tool can only estimate at archetype level. The early-design tool points a designer toward a configuration. LUSIM then tests that configuration on the geometry of the plant as it stands.

Greenhouse demonstrator: closed agri-PV

The greenhouse demonstrator covers the closed archetype. The geometry is a simplified Venlo greenhouse, with crops grown inside the frame and PV mounted across the roof. The same model carries the characterisation of the cover material, so the irradiance results pass straight from that work into the LUSIM web tool.

LUSIM splits the irradiance into a direct and a diffuse part and represents the cover with a Bidirectional Transmittance Distribution Function (BTDF). The BTDF records a ray of light that meets the cover at one angle leaves it spread across a range of directions, which is the physical source of the softening that a glazing or a diffusing coating produces. LUCISUN characterised the function from the FOTONIQ material set, which covers bare glass, polycarbonate, FOTONIQ latest PAR coating on bare glass and polycarbonate, and the Redufuse diffusing coating, and added an ideal Lambertian cover as the upper bound on diffusion.

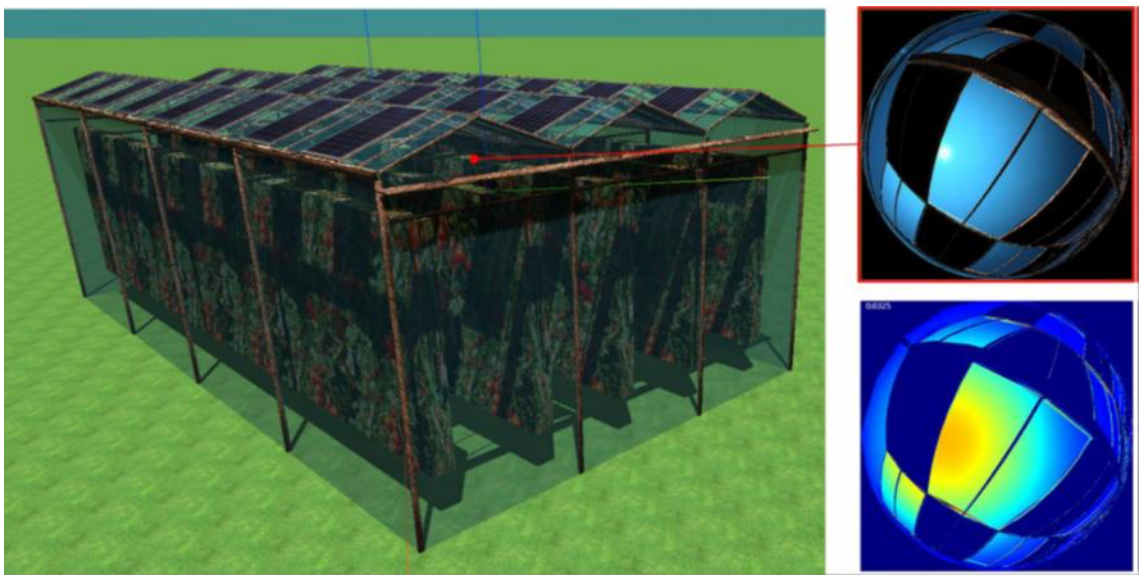


Figure 16. Simplified greenhouse in LUSIM, with roof PV over the enclosed crops. The hemispherical insets on the right show the characterised BTDF of the cover: the transmitted light spread over direction for a given angle of incidence.

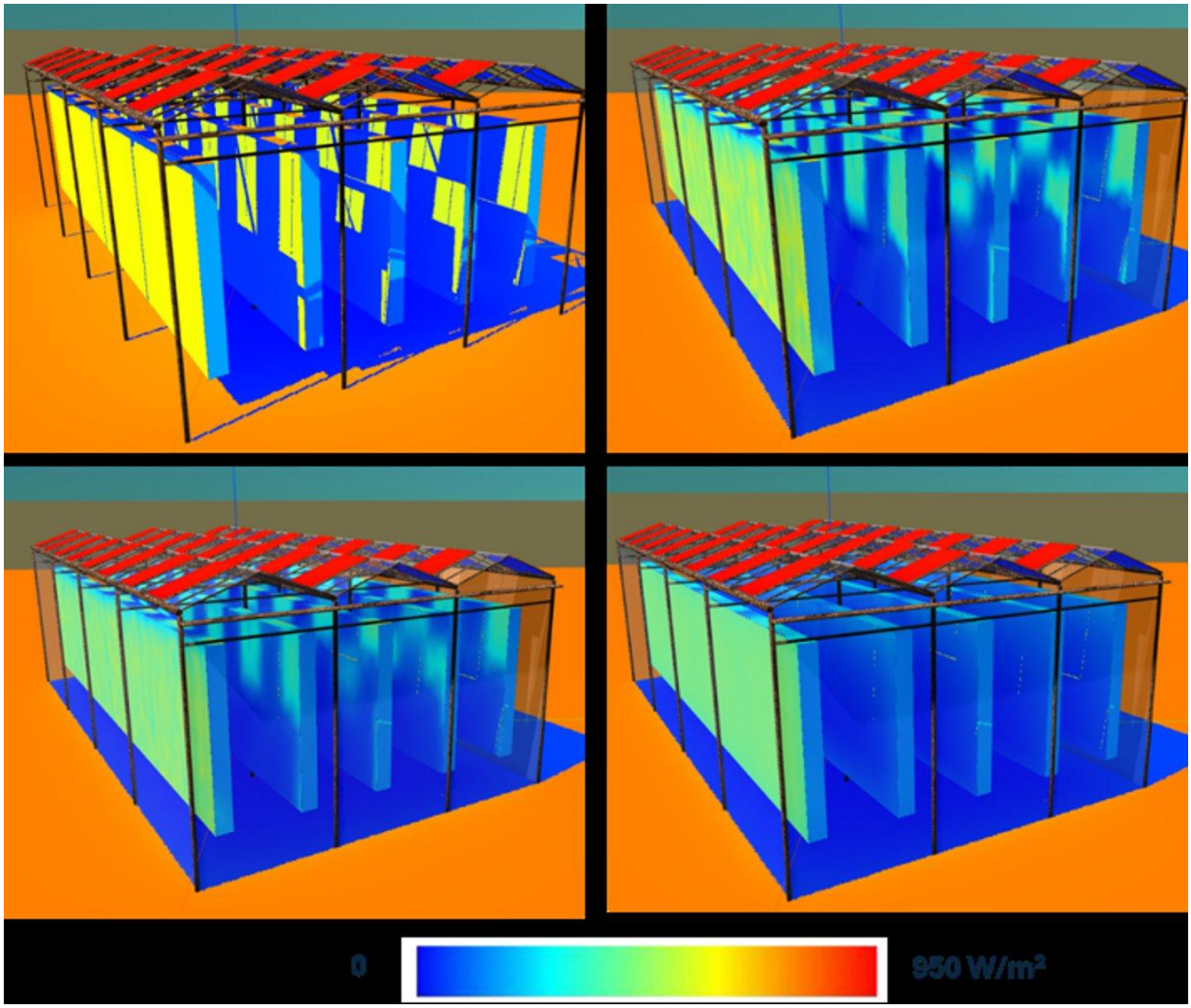


Figure 17. Crop-level irradiance in the greenhouse (W/m²) under four covers: no glass (top left), bare glass (top right), Redufuse coating (bottom left), and an ideal Lambertian material (bottom right). The shared scale runs from 0 to 950 W/m².

As a complement to the Bolzano case, the greenhouse completes the different cases: one tool, an open and a closed archetype. The crops are represented as a rectangular block for simplification of irradiance analysis.

Accessing the tool: the user journey

The tool reaches its users through the SYMBIOSYST website, which links to the LUSIM landing page. The link to LUSIM landing page can be accessed through here: LUSIM
The figure below shows the path from the public link to the irradiance analysis.

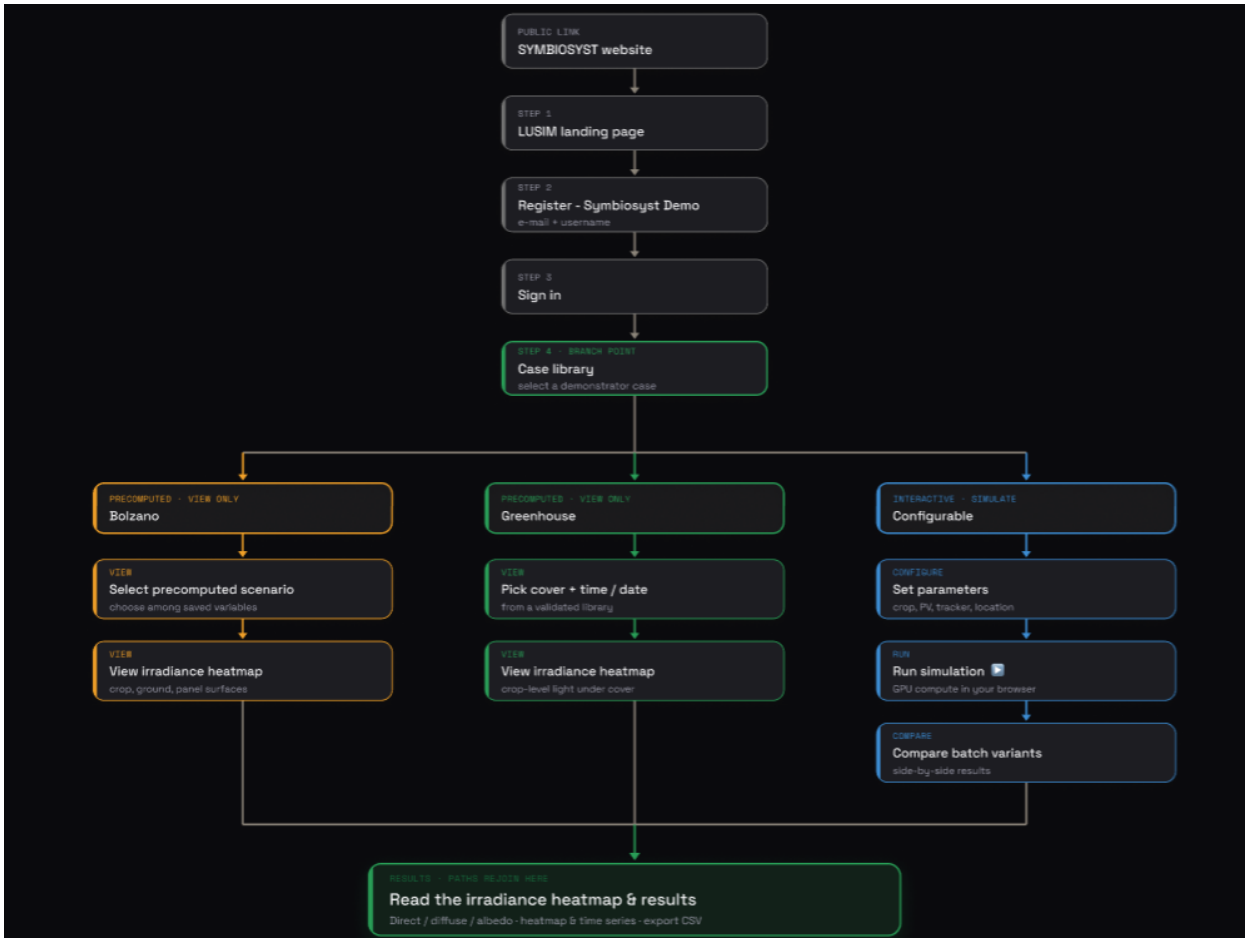


Figure 18. User journey through the LUSIM web tool, from the public link on the SYMBIOSYST website to the analysis of the irradiance heatmap. The path branches at the case selection into the Bolzano and greenhouse demonstrators and rejoins at the parameter and results stage.

For both demo cases, the users are able to select the pre-computed cases with different variables as described in the previous section. A simple built-in walkthrough is available to guide users into each step, which meets the training aim set for the web tool in Task 6.3.

Irradiation Conversion (agronomic interpretation)

It should be noted that both tools presented in this work provide outputs in terms of irradiance expressed in $W \cdot m^{-2}$. This unit is widely adopted in the photovoltaic domain for the characterization of solar radiation, but it is less commonly used in agronomic applications, where radiation is typically expressed in terms of photosynthetic photon flux density (PPFD), i.e. $\mu mol \cdot m^{-2} \cdot s^{-1}$.

In this context, the present section provides a brief clarification on the conversion between these two units when considering photosynthetically active radiation (PAR). It is first important to underline that PAR does not refer to the total solar radiation but only to the fraction of the spectrum comprised between 400 and 700 nm, which is effectively utilized by plants for photosynthesis

The conversion from global solar irradiance expressed in radiometric units ($W \cdot m^{-2}$) to photosynthetically active radiation (PAR) expressed in quantum units ($mol \cdot m^{-2} \cdot s^{-1}$) requires the adoption of empirical assumptions due to the different physical nature of the two quantities. Global irradiance represents the total incoming shortwave radiation over a broad spectral range (approximately 300–2800 nm), whereas PAR refers only to the photon flux density in the 400–700 nm wavelength interval that drives photosynthesis.

A standard approach consists of two sequential steps. First, a fixed fraction of global irradiance is assumed to fall within the PAR spectral range. Under typical atmospheric conditions, this fraction (f_PAR) is commonly approximated as 0.5, implying that about 50% of incoming solar radiation is photosynthetically active. Second, the energy-based PAR component is converted into photon flux using an average energy-to-quanta conversion factor. Empirical studies suggest that 1 $W \cdot m^{-2}$ of PAR corresponds to approximately 4.6 $\mu mol \cdot m^{-2} \cdot s^{-1}$[2].
Combining these two factors, the conversion from global irradiance (G, in $W \cdot m^{-2}$) to photosynthetic photon flux density (PPFD, in $\mu mol \cdot m^{-2} \cdot s^{-1}$) can be expressed as:

$$PPFD = G \cdot f_{PAR} \cdot 4.6$$

which results in a simplified combined coefficient of approximately 2.3. This yields the widely adopted approximation:

$$PPFD \approx 2.0\text{–}2.3 \cdot G$$

Finally, conversion to molar units is obtained by dividing by 10^6, given that 1 mol equals 10^6 µmol.
It should be noted that this approach provides an approximation suitable for modelling and large-scale assessments. More accurate conversions would require spectral irradiance data and wavelength-resolved integration, as the photon energy depends on wavelength and atmospheric conditions.

Limitations and Responsible Use of the Agri-PV Early-Design Tools

Certain factors that influence real agri-PV deployment — such as geotechnical suitability, grid connection, permitting, and national regulatory frameworks — are outside the modelling scope of D6.2. They are mentioned here only as boundary conditions, outside the modelling scope of the 2 early-design tools, that users should consider before moving from early-stage screening to project development. Detailed treatment of these aspects belongs to the relevant technical, demonstration, regulatory, or business-model deliverables.

Moreover, the results provided by the Agri-PV early-design tools should be interpreted as preliminary, simplified estimates intended to support early-stage decision-making. Their responsible use requires integration with prior agronomic knowledge of the target crops and agricultural practices, as local conditions, crop physiology, and management strategies play a critical role in determining actual performance. In particular, translating simulated irradiance outputs into meaningful agronomic indicators demands an understanding of crop-specific light requirements, phenological stages, and stress responses. The following section therefore also provides guidance on linking radiation modelling outputs to agronomic performance, helping users contextualise the tool results within real-world agricultural systems.

From Radiation Modelling to Agronomic Performance: Defining Crop Light Requirements

This section aims to define a set of guiding principles and conceptual elements to support the user in developing an initial, simplified, yet coherent representation of crop-specific light requirement curves. Such guidance is intended to facilitate the construction of a first, preliminary parametrisation aligned with the overall objective of the tool, namely to serve as an early-stage design support instrument for agrivoltaic systems.

Apple and Pear Cultivation

Regarding apple and pear cultivation, and considering the annual distribution of irradiance across the canopy, a first approximation for defining a crop light-demand curve can be based on the different phenological stages of the plants. In general:

- High light requirements can be assumed during the flowering, fruit set, and fruit development stages, when adequate solar radiation is essential to support photosynthetic activity, fruit growth, and final yield quality.
- Medium light requirements can be associated with the bud break phase and the post-harvest period, during which the trees continue to accumulate reserves for the following growing season.
- Low light requirements can be considered during the dormancy period, when physiological activity is significantly reduced and light availability has a limited influence on crop performance.

In addition, for both apple and pear orchards, it is generally advisable to maximise shading during periods of excessive heat. Therefore, under conditions where ambient air temperatures exceed 30°C, a full solar-tracking configuration is recommended, as it can provide the highest level of shading while helping to mitigate heat stress and reduce the risk of sunburn damage on fruits.

With specific reference to pear cultivation, experimental observations have reported yield reductions of approximately 15% when solar irradiance was reduced by around 24% (this reduction in terms of irradiation affects also the microclimate, with an increase of humidity and lowering the air temperature)[3].

These findings are consistent with the results obtained for apple cultivation within the SYMBIOSYST project during the first year of monitoring activities, where similar relationships between irradiance reduction and crop productivity were observed. These preliminary observations suggest that moderate shading levels may be tolerated by both crops; however, excessive reductions in light availability could negatively affect productivity and should therefore be carefully considered during the design and operation of agrivoltaics systems.

Open-Field Vegetables: Tomato, Lettuce, Broccoli, and Spinach

For the crops considered within the Barcelona demonstrator (lettuce and tomato are actively cultivated and monitored within the demonstrator, while broccoli and spinach are not currently included in the experimental activities but are commonly grown in the surrounding area and have been identified as potentially suitable crops for agrivoltaic applications), crop-specific irradiance demand curves across the different phenological stages are currently not available. A review of the scientific and technical literature indicates that this type of information is rarely reported in a form that can be directly translated into daily irradiance requirements,

particularly for open-field cultivation and agrivoltaic systems. Consequently, a different approach is proposed for the preliminary parameterisation of crop light requirements within the early-stage design tool.
At this stage, physiological reference values describing the response of crops to photosynthetically active radiation (PAR) can be used. In particular, the light compensation point and the light saturation point provide useful information for characterising crop responses to light availability. These parameters should not be interpreted as direct daily irradiance requirements or as complete crop-specific irradiance demand curves. Nevertheless, they represent a scientifically sound basis for approximating crop light-response functions. The values are expressed as photosynthetic photon flux density (PPFD, µmol m^{-2} s^{-1}) within the photosynthetically active radiation range (400–700 nm).

Table 2. Examples for Crops physiological reference values

Crop	Light Compensation Point (µmol m^{-2} s^{-1})	Light Saturation Point (µmol m^{-2} s^{-1})
Lettuce	29.5	857
Spinach	45	889
Broccoli cultivars	81	1070
Tomato	53.1	1985

A potential implementation strategy within the early design tool consists of defining crop-specific light preference functions rather than fixed irradiance thresholds. Under this approach, irradiance levels below the compensation point would be considered limiting for net photosynthesis, as carbon assimilation would be insufficient to offset respiratory losses. Irradiance levels between the compensation and saturation points would represent the effective operating range, where increasing light availability is expected to enhance photosynthetic activity and support crop growth. Above the saturation point, additional irradiance would provide progressively smaller photosynthetic benefits, indicating diminishing marginal returns with respect to light availability.
Regarding the temporal distribution of irradiance during the day, the information currently available does not support the definition of crop-specific preferences for morning or afternoon radiation. In general, solar radiation received throughout the entire photosynthetically active period contributes positively to crop development. However, under Mediterranean summer conditions, excessive irradiance occurring simultaneously with high air temperatures, elevated vapour pressure deficit (VPD), and water stress may negatively affect plant performance. In these circumstances, reducing peak irradiance during the warmest hours of the day may be beneficial. Such considerations should be interpreted as responses to environmental stress factors rather than as intrinsic crop-specific light requirements.
Therefore, for the crops considered in the Barcelona demonstrator, the proposed methodology is to use light compensation and saturation points as boundary conditions for defining preliminary crop-response functions. These functions can support early-stage agrivoltaic design decisions while awaiting the availability of more detailed experimental datasets capable of describing crop irradiance requirements throughout the growing cycle.

Closed AgriPV: Greenhouse – Tomatoes

A key difference between greenhouse and open-field cultivation is the availability of supplemental lighting systems, typically based on LED technology, which can compensate for insufficient natural radiation. The tools developed within this task consider solar radiation as the sole source of light and therefore do not account for artificial lighting.

Nevertheless, for completeness, this section also provides indicative guidance for greenhouse tomato cultivation. The aim is to identify irradiance conditions that can support crop growth while minimising the need for supplemental lighting, thereby offering a useful reference for evaluating agrivoltaic configurations in protected cultivation systems. These values should be regarded as supporting guidance rather than direct modelling inputs.

For tomato cultivation, additional guidance can be derived from crop lighting recommendations commonly adopted in controlled-environment agriculture. While these values should not be interpreted as strict requirements for open-field agrivoltaics systems, they provide useful reference points for defining preliminary crop-response functions within the early-stage design tool.

A lower threshold of approximately 20 mol m^{-2} d^{-1} of Daily Light Integral (DLI) can be considered as the minimum level required to sustain satisfactory crop development.

It should be noted that the Daily Light Integral (DLI) corresponds to the integral of PAR over an entire day. Therefore, DLI combines both the instantaneous PAR intensity and the duration of daylight (photoperiod), providing a measure of the total amount of photosynthetically active radiation received by a crop during a 24-hour period. While the concept is applicable to both outdoor and indoor cultivation systems, it is more commonly used in controlled-environment agriculture and greenhouse production. Within the project, DLI can be readily calculated from the PAR measurements collected at the different demonstration sites, enabling a more comprehensive assessment of light availability for crop growth.

For high-yield production targets in mature tomato crops, a DLI in the range of 22–30 mol m^{-2} d^{-1} is generally recommended. Values exceeding 30 mol m^{-2} d^{-1} are not necessarily detrimental and can further support crop productivity; however, under such conditions, appropriate climate management becomes increasingly important to avoid excessive vapour pressure deficit (VPD), water stress, and heat stress[4], [5].

From an agronomic perspective, tomato plants also require a daily dark period to maintain normal physiological processes. Continuous or excessively prolonged light exposure may result in plant stress, reduced performance, and physiological disorders. Consequently, a photo period including approximately 6 hours of darkness per day is generally considered beneficial for crop health and productivity.

For the purposes of the agrivoltaic design tool and preliminary simulation activities, a reference value of 25 mol m^{-2} d^{-1} may be adopted as a baseline target, representing a compromise between satisfactory crop development and high-production conditions. This value can subsequently be adjusted according to local climatic conditions, crop management practices, and project-specific objectives.

Geo-Technical and Site Constraints

The starting point for any agrivoltaics project must be a thorough geotechnical and hydrogeological analysis. Unlike standard photovoltaic installations, agrivoltaics systems may require elevated structures with greater spans and increased wind exposure. This amplifies foundation demands and structural sensitivity to soil behaviour. A full campaign should ideally include borehole tests, Standard Penetration Tests (SPT), Cone Penetration Tests (CPT) where appropriate, soil classification under the Unified Soil Classification System (USCS), bearing capacity calculations, groundwater level assessment, and corrosion risk analysis through pH, resistivity, and sulphate content testing. Pull-out tests for driven steel piles should be carried out with local licensed technicians. On sandy, silty, recently tilled, or irrigated agricultural soils, particular care should be

taken. Fields should be pre-seeded >6 months before construction to ensure a vegetative cover that's resistant to the passage of construction machinery.

Topography is another decisive constraint. Agrivoltaics tolerates less aggressive grading than standard photovoltaic systems because soil preservation and erosion control are essential to maintain agricultural productivity. Sites with slopes below five percent are ideal. Between five and ten percent is generally manageable with optimised layout and drainage design. Beyond fifteen percent, mechanised farming becomes difficult and structural costs escalate sharply. Slopes exceeding twenty percent make agrivoltaics systems particularly challenging, though not necessarily impossible. However, due to the increased technical complexity, higher installation and maintenance costs, and potential limitations for agricultural activities, agrivoltaics applications on such steep terrain are generally not recommended.

Electrical interconnection & Offtake

Electrical interconnection must be evaluated in parallel with soil and structural considerations. Many projects fail due to grid distance rather than technical design. Small projects must consider a low-voltage electrical interconnection in a building or available point ideally less than 100 m away. Costs increase with every linear meter of cable trench. For projects over a few MW, connection to medium voltage (MV, typically fifteen to thirty kilovolts) lines within three kilometres is generally feasible. Distances between three and ten kilometres remain feasible but become cost sensitive. Beyond fifteen kilometres, connection costs frequently jeopardise viability unless project scale exceeds twenty megawatts. Interconnection to high voltage (HV, typically sixty-six kilovolts or greater) substations introduces multi-year permitting timelines and higher infrastructure costs. Early grid impact studies are essential, especially in regions with increasing congestion and curtailment risk.

Where possible, agrivoltaics systems benefit from matching generation to local agricultural consumption. Irrigation pumps, cold storage, agro-processing facilities, and energy communities (for example under Spain's collective self-consumption (autoconsumo colectivo) framework can stabilise revenues). A structure that maximises output to be locally consumed improves bankability and mitigates exposure to wholesale price volatility. When grid export will be the dominant revenue source, this business plan should be reviewed early in the project life cycle. Any curtailment risk exceeding ten to fifteen percent should be treated as a significant warning signal, possibly mitigated with batteries.

Structural design must preserve viable crop production. Clearance height directly affects steel intensity and cost. Tractor-compatible systems typically require clearances of 2.1 to 2.5 meters, orchard systems 3.5 to 4.5 meters, and certain tree-based or specialty systems may require five meters or more. Above three meters, structural steel requirements increase substantially, often driving significant CAPEX premiums compared to conventional ground-mounted photovoltaic installations. "Interrow cultivation" systems (lower than 2 meters) are possible, and although direct overhead weather protection from PV would be thus minimized, a co-existence of PV and farming may certainly still be feasible.

Light transmission is equally critical when designing the structure. Photosynthetically Active Radiation (PAR) must remain sufficient to sustain crop yields. Too much shading introduces significant agronomic risk for many crops unless varieties are specifically shade tolerant. If projected agricultural revenue declines (relative to baseline yields) exceed stakeholder expectations, the dual-use premise is undermined and the project should be reconsidered.

Legal and Regulatory Considerations

Agri-PV regulation is still largely diverse across countries. Spain does not yet operate under a unified national agrivoltaic framework, and regulatory interpretation continues to vary significantly across autonomous communities. Some core principles are nevertheless applied consistently. Agrivoltaic projects must generally remain classified as *suelo rústico* (rural land) and must demonstrate the continuity of agricultural activity throughout their operational life. If authorities perceive a shift from agricultural to industrial land use, reclassification risks may arise, potentially compromising project viability. For this reason, municipalities responsible for permitting may request evidence of ongoing crop production, minimum yield thresholds, or official certification confirming that agriculture remains the primary land use of the site.

Projects exceeding five megawatts typically require an Environmental Impact Assessment (EIA). Assessment criteria include landscape integration, preservation of biodiversity corridors, avoidance of soil sealing, and proper water resource management. Installations located within Natura 2000 protected areas face significantly higher rejection risks. To increase the likelihood of regulatory acceptance, project developers are encouraged to reduce the use of permanent foundations and to minimize practices that may lead to soil impermeabilization.

Compliance with the European Union's Common Agricultural Policy (CAP) must also be considered. Spain currently allows agrivoltaic projects to retain CAP subsidies, provided that agricultural activity remains compatible with CAP eligibility rules. Excessive panel density or the loss of active farmer status may endanger access to funding. Authorities may therefore request technical justification on panel spacing, crop viability, and the adequacy of agricultural management practices. Early consultation with regional agricultural agencies is strongly recommended due to the significant administrative variability across regions.

Regional diversity further contributes to regulatory complexity. Catalonia is progressing toward structured agrivoltaic evaluation pathways following the publication of technical guidelines in 2023, whereas other autonomous communities have not yet developed specific legislation and continue to rely on municipal decision-making. As a result, early engagement with regional legal experts is essential.

Italy, by contrast, has been steadily advancing toward a more comprehensive national framework for agrivoltaics. Recent updates from the Ministry of the Environment and Energy Security (MASE), including the Ministerial Decree of 19 June 2025, refine the implementation of agrivoltaics measures under the National Recovery and Resilience Plan (PNRR). These adjustments introduce clearer procedural timelines, more flexible commissioning periods, and more explicit definitions of installation milestones, thereby facilitating more predictable project development processes.

Italian regulation distinguishes between *standard* and *advanced* agrivoltaics systems, with the latter benefitting from enhanced incentives. National guidelines require that agrivoltaics installations employ elevated and non-intrusive structures, preserve agricultural or pastoral activity, ensure minimal land occupation, and maintain landscape quality. Under the PNRR, agricultural enterprises and consortia may access capital grants and feed-in tariffs, with project selection procedures managed by the national energy agency (GSE).

At the same time, Italy has introduced restrictive measures through a 2024 national law prohibiting new ground-mounted photovoltaic installations on agricultural land, subject to specific exceptions. Crucially, these

restrictions do not apply to agrivoltaic systems installed above active crops, which remain permissible provided that agricultural productivity is preserved and demonstrable. This approach highlights Italy's intention to protect agricultural land while promoting agrivoltaics as an integrated model for sustainable land use and renewable energy generation.

Continuous monitoring of national and regional regulatory developments is therefore essential in both Spain and Italy. Agrivoltaic permitting frameworks can evolve rapidly, and new legislative changes may significantly affect projects that have not yet completed the authorisation process. Following regulatory revisions, administrative procedures often require time to stabilize, and temporary inconsistencies in interpretation are common. A relevant example is the modification of the authorisation law in the Province of Bolzano in May 2024. After the reform enabled experimental ground-mounted agrivoltaic systems, the municipality of Ora (where the Italian Demonstrator is located) initially classified a project under *Edilizia Libera*, later revising its position and imposing a more complex and lengthier permitting pathway. This regulatory uncertainty required the involvement of the Province of Bolzano to clarify the appropriate procedural approach. Such cases demonstrate the importance for project developers of maintaining an active and continuous regulatory monitoring strategy throughout the full development cycle of agrivoltaic projects.

Conclusions

This deliverable has presented the **DualHarvest** (Agri-PV Early Design Tool) together with the **LUSIM demonstrator environment** as complementary modelling solutions developed within the SYMBIOSYST project to support early-stage assessment of agrivoltaic systems. DualHarvest enables rapid and flexible screening of Agri-PV configurations by providing simplified estimates of both photovoltaic energy production and irradiance distribution on crops, while LUSIM allows a more detailed spatial and temporal visualisation of irradiance patterns in representative demonstrator cases. Together, these tools establish a coherent workflow that supports the preliminary exploration of design options and the understanding of key trade-offs between agricultural and energy performance.

The modelling framework described in this report highlights the importance of integrating **radiation modelling with agronomic interpretation**, enabling users to move from physical irradiance outputs to crop-relevant indicators such as PAR, PPFD, and DLI. This connection is essential to ensure that early-stage design choices remain consistent with crop-specific light requirements and agricultural objectives. In this context, the tools contribute to improving the transparency and accessibility of agrivoltaic design processes for a broad range of stakeholders, including farmers, agronomists, project developers, and policymakers.

At the same time, it is important to emphasise that DualHarvest and LUSIM are early-stage support tools, based on simplified modelling approaches and predefined assumptions. Their outputs should not be interpreted as final design solutions, but rather as indicative results to guide further analysis. Co-design must therefore be regarded as a foundational principle of any agrivoltaic project. Engineering choices should be developed in continuous alignment with agronomic needs and constraints, and vice versa, particularly with reference to the operational phase of the installation. Integrated design workflows—supported by appropriate modelling tools—ensure that energy generation, agricultural performance, and long-term land stewardship remain balanced and mutually reinforcing throughout the project lifecycle. The responsible use of these tools requires users to combine model outputs with site-specific data, agronomic expertise, and detailed technical assessments, including aspects such as crop management, local climate conditions, engineering design, grid connection, and regulatory frameworks.

In conclusion, the DualHarvest tool and the LUSIM demonstrator represent a significant step towards the development of accessible and scientifically grounded tools for agrivoltaic system design. By supporting informed decision-making at the early stages of project development, they contribute to reducing uncertainty and risks, improving design coherence, and fostering the adoption of agrivoltaics as a viable and sustainable land-use solution. Future developments may further enhance these tools through the integration of more advanced agronomic models, expanded scenario capabilities, and closer coupling with real-world monitoring data from SYMBIOSYST demonstrators.

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