Solar Shading Assessment – Maniototo Peppercress

Validation of the 10 m planting buffer · Haldon Station Solar Farm

Date: 16 July 2026

Lodestone

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1. Executive summary

This report assesses whether the proposed protection conditions for the Nationally Threatened Maniototo peppercress (Lepidium solandri) at the Haldon Station solar farm will ensure no meaningful reduction in sunlight reaching the plants. The conditions combine a 10 m panel-free buffer around each plant, a 1–2 m physical cage with flagging, and an ongoing Plant Management Plan (PMP).

The shading question was tested with a purpose-built, minute-by-minute solar-geometry and ray-casting model, run over a full year (525,600 minutes) for the Haldon site using measured 1-minute SolarGIS typical-meteorological-year (TMY) irradiance. Every panel and tracker in a representative 10-column by 3-band array was placed in three dimensions, and for each daylight minute the model tested whether the direct beam from the sun to the plant was physically blocked.

The findings are set out in full in Section 4 and are summarised here:

- **The buffer is appropriate as it retains more than 99.5% of available light.** Depending on exactly where a plant sits within the array, the modelled loss of annual irradiance ranges from 0.39% to 0.81%, with a weighted average of approximately 0.5%. The central (representative) case is 0.42%.
- **This shading loss is smaller than the natural year-to-year variation in sunlight.** Interannual variability of the solar resource at the site is of the order of 3.6% according to SolarGIS, so the entire range of shading outcomes sits well inside the difference between one year and the next.
- **In everyday terms, the 10m buffer results in shading equivalent to roughly one minute of full-strength sunlight per day.**
- **At a 10 m buffer, Lodestone can commit to excluding all infrastructure** – panels, torque tubes and piles – from the buffer, not just the panels. Doing so more than halves the modelled loss (the central case falls from 2.47% to 0.42%).
- **The effective, real-world buffer is larger than 10 m.** Because whole tables are removed as units, the effective minimum clearance is about 10.5 m and the average is nearer 13 m. In every plant position modelled, an 8 m buffer gives similar results to the proposed 10 m buffer.
- **Long shadows only occur when quality or intensity of light is extremely low.** Backtracking flattens the panels at low sun aimed at maximising generation at very low generation periods of the day, cutting the peak shadow reach from about 132 m (without backtracking) to about 38 m (with it). The longest shadows fall in the first and last hour of the day, when direct-beam irradiance is very low and most of the light is diffuse – and diffuse and reflected light are never blocked by the array.

Taken together, the analysis **validates the 10 m buffer** and demonstrates that the panel proposed buffer **will result in no meaningful shading effect** to any Nationally Threatened plants.

2. Introduction and purpose

2.1. Background

The Maniototo peppercress (Lepidium solandri) is classified as Nationally Threatened. Where the species is present within the footprint of the Haldon Station solar farm, ecological advice has been to retain and protect individual plants in place rather than disturb them.

2.2. The protection conditions

The conditions combine three complementary layers of protection:

- **A 10 m panel-free buffer** — a cleared buffer around each plant from which solar infrastructure is excluded. This is the subject of the shading analysis in this report.
- **A 1–2 m physical cage, with flagging** — the cage and flag are the direct physical protection. They prevent accidental disturbance during construction, operation and maintenance, and make each protected plant clearly visible to site personnel.
- **An ongoing Plant Management Plan (PMP)** — to be finalised, the PMP is expected to include measures such as quarterly inspections and weed control to ensure invasive species do not colonise the caged area and outcompete the peppercress.

2.3. Scope of this report

This report is concerned principally with the shading question: does the 10 m buffer, and the associated array geometry and control strategy, preserve the sunlight the plants need? It sets out the summary findings of the shading analysis and their implications for the buffer distance. The physical protection (cage and flag) and the ongoing management (PMP) are described for context in Section 5; the detailed cage specification and the finalised PMP are, or will be, documented separately.

The full technical methodology for the shading model is provided in Appendix A. The worst-day hourly shadow progression is provided in Appendix B. The site solar-resource data is summarised in Appendix C.

3. Methodology in brief

The complete methodology – software architecture, solar geometry, irradiance physics, the ray-casting engine, aggregation and export – is provided in Appendix A. This section summarises the essentials needed to interpret the findings.

3.1. What the model does

For each of the 525,600 minutes in a year, at the Haldon latitude and longitude, the model computes the sun's position, the irradiance and its split into direct-beam and diffuse components, and the tracker tilt for that minute. It then builds a three-dimensional array of single-axis trackers around the plant, clears a circular buffer, and casts a ray from the plant toward the sun to test whether the direct beam is geometrically blocked by any surviving panel or steelwork. The per-minute results are aggregated into the annual metrics reported here.

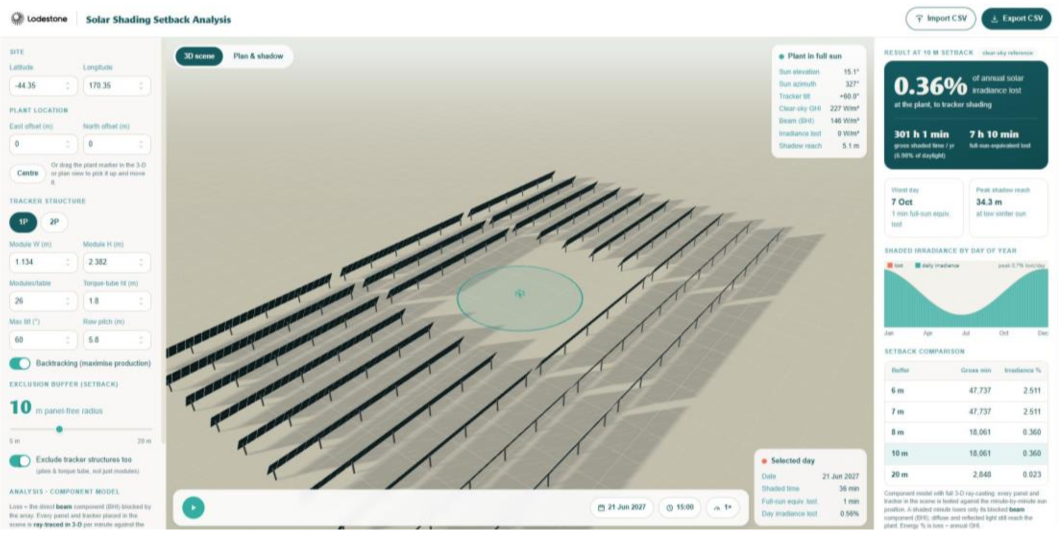

Figure 1 – The Solar Shading Buffer Analysis tool (clear-sky reference mode), plant centred in the array at a 10 m buffer. Headline annual loss 0.36% on the clear-sky reference.

3.2. Beam-only loss – why the numbers are small but real

The array can only block the direct beam travelling along the straight line from the plant to the sun. Diffuse sunlight and ground-reflected light arrive from all directions and therefore are unaffected by the long-shadows cast in mornings and evenings. A shaded minute therefore costs the plant only its beam component (BHI) for that minute, never the full global irradiance (GHI). This is a physically correct treatment, and it is the main reason the losses are a fraction of a percent. The effective shading is the weighted average of just direct beam light in 6.7% of daylight hours where shading occurs.

3.3. Data basis

Two irradiance sources are used. The clear-sky reference is a cloudless model – a deliberately conservative upper bound, because it assumes the sun is never obscured by cloud, so every shaded minute is counted at full beam strength. The measured SolarGIS TMY replaces the clear-sky model with the site's Typical Meteorological Year (TMY), so the headline figures reflect real cloud cover at Haldon. The figures quoted in Section 4 are the measured TMY results unless stated otherwise.

4. Findings

4.1. A 10 m buffer allows exclusion of all infrastructure

The model can clear the buffer in two ways: remove only the panels inside the buffer (leaving torque tubes and piles in place), or remove whole tables – panels, torque tube and piles – wherever any part of a table falls inside the buffer. It is not physically or electrically practicable to use partial tables, smaller than those modelled.

Removing whole tables (excluding all infrastructure) produces markedly less shading, because it leaves no panel surviving right at the buffer edge and to a lesser extent, no steelwork inside the buffer to cast shadows. Moreover, it creates a larger effective buffer in all cases due to the dimensions of the tracker and geometry of the layout. In the central case, excluding all infrastructure reduces the modelled annual loss from 2.47% (panels only removed; Figure 3) to 0.42% (all infrastructure removed; Figure 2).

At a 10 m buffer this whole-table exclusion is practical, and Lodestone can accept it as a commitment.

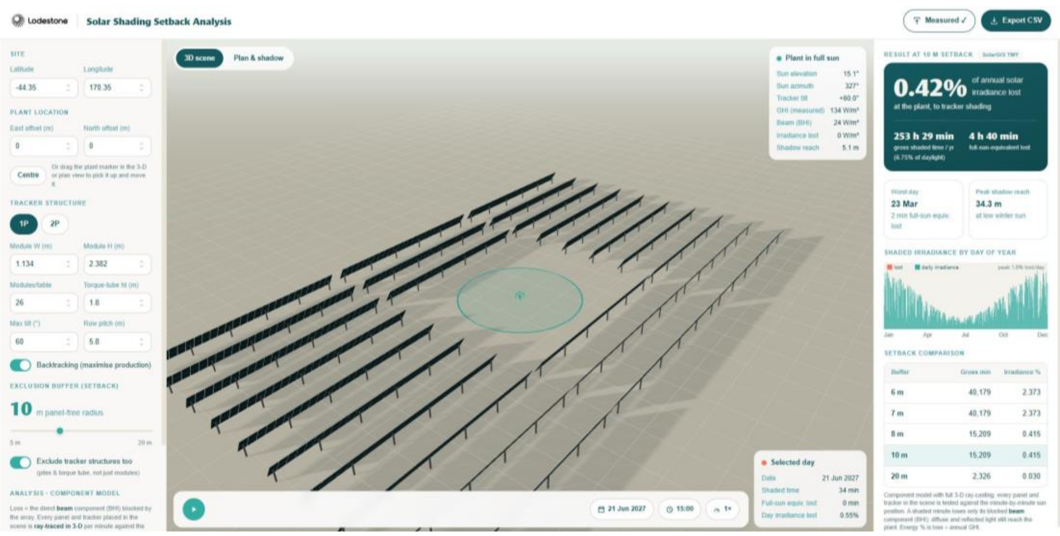

Figure 2 – Measured SolarGIS TMY, plant centred, all infrastructure excluded within the 10 m buffer. Headline annual loss 0.42%.

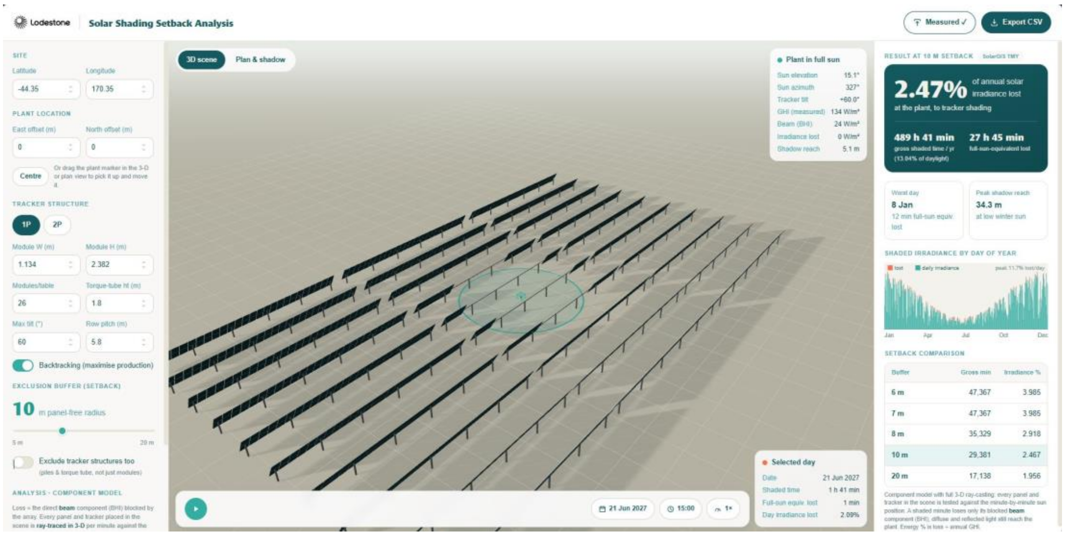

Figure 3 – Same case with tracker structures kept (only panels removed): torque tubes and piles remain in the buffer and a panel survives at the buffer edge, raising the annual loss to 2.47%.

4.2. Effective buffer geometry – the real buffer is larger than 10 m

Because whole tables are removed whenever any part of them intrudes into the 10 m buffer, the cleared area is a rectangle of roughly 27 m by 29.5 m (about 800 m²) around each plant. The 29.5 m dimension corresponds to a full table length (26 modules by 1.134 m, or about 29.5 m).
A consequence of this discrete geometry is that the actual minimum clearance to the nearest surviving panel is about 10.5 m, and the average clearance is nearer 13 m than 10 m. The nominal 10 m buffer therefore delivers a real-world buffer that is consistently larger than 10 m. This functionally means accepting an 800 m^2 buffer or in extreme cases 1600 m^2 buffer – much larger than the 10m buffer (315 m^2) implies. All findings that follow assume this whole-table (all-infrastructure) exclusion.

This has a direct implication for the buffer distance. Because tables are removed as whole units, the shading outcome does not change in a central plant location between an 8 m and a 10 m nominal buffer. The table below gives the modelled annual loss at each candidate buffer for the three plant positions (measured TMY, all infrastructure excluded):

Nominal buffer	Central case	Worst-case position	Best-case position
6 m	2.37%	2.82 %	0.81%
7 m	2.37%	2.15%	0.80%
8 m	0.42%	1.06%	0.39%
10 m	0.42%	0.81%	0.39%
20 m	0.03%	0.06%	0.03%

In nearly every plant position, the 8 m and 10 m results are identical. It can therefore be argued that an 8 m minimum buffer would be practically equivalent to the proposed 10 m buffer; the proposed 10 m provides additional margin.

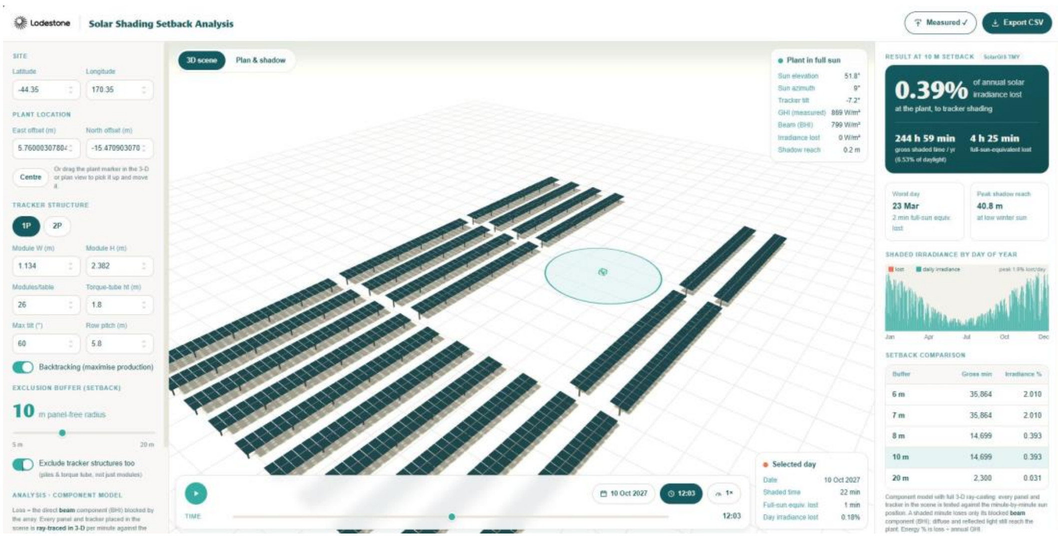

Figure 4 – A favourable plant position at midday, showing the whole-table footprint cleared from the array by the 10 m buffer.

4.3. Annual irradiance loss: 0.39–0.81%, weighted about 0.55%

The exact loss depends on where the plant sits relative to the array. Across the modelled positions the annual loss ranges from 0.39% (most favourable position; Figure 4) to 0.81% (least favourable position; Figures 5 and 6), with a central representative case of 0.42% (Figure 2) and a weighted average of approximately 0.55%.

Case	Annual loss	Annual gross shaded time	Annual full-sun-equiv. lost	Worst day
Best-case position (Fig. 4)	0.39%	244 h 59 min (6.53%)	4 h 25 min	23 Mar
Central / representative (Fig. 2)	0.42%	253 h 29 min (6.75%)	4 h 40 min	23 Mar
Worst-case position (Figs 5–6)	0.81%	361 h 59 min (9.64%)	9 h 6 min	10 Oct
Clear-sky reference (Fig. 1)	0.36%	301 h 1 min (6.90%)	7 h 10 min	7 Oct

Gross shaded time is shown as a percentage of daylight minutes. The clear-sky reference returns a slightly lower percentage than the measured TMY because the annual GHI denominator differs between the two; both are well under 1%.

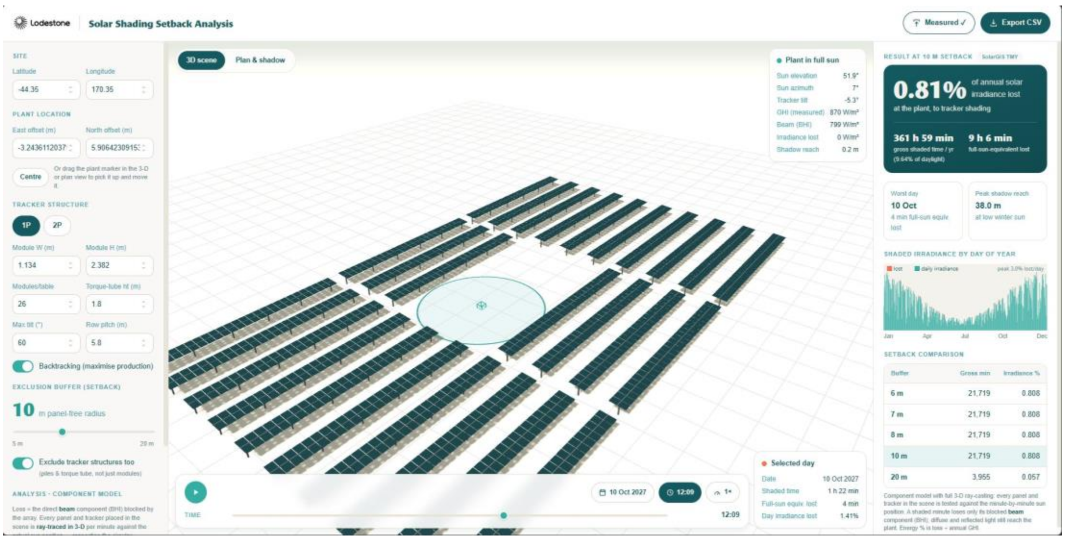

Figure 5 – The least favourable plant position at midday, in full sun. The annual loss for this position is 0.81%.

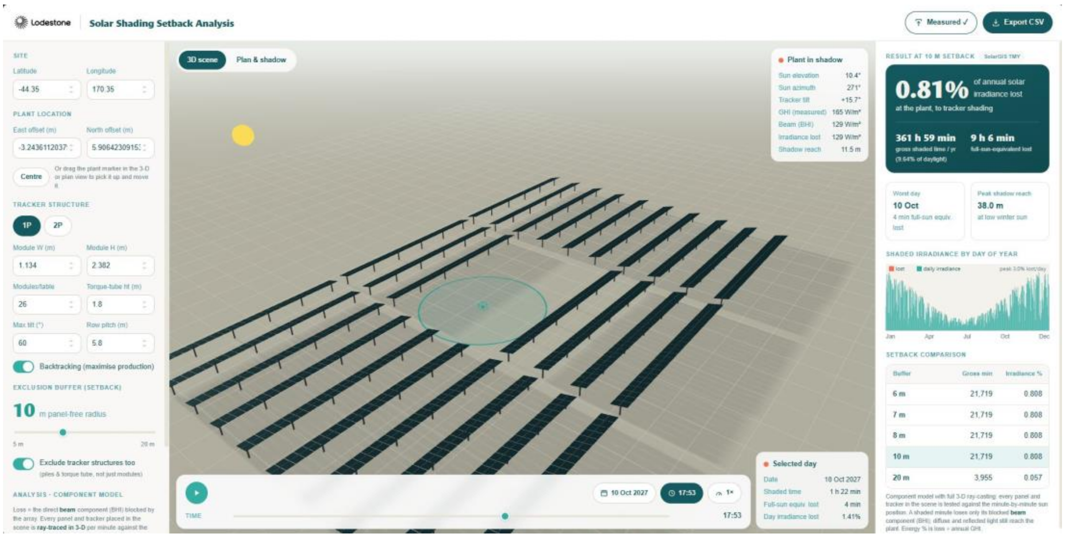

Figure 6 – The same least-favourable position at low evening sun (10 Oct), when the plant is briefly shaded. Peak shadow reach 38.0 m with backtracking.

4.4. The loss is within natural year-to-year variability

The interannual variability of solar irradiance at Haldon is of the order of 3.6% as represented by a single standard deviation. Adding a second standard deviation to cover 95% of years would result in a range of +/- 7.2%. The entire 0.39–0.81% range of shading outcomes is therefore well below the difference in sunlight the plants already experience from one year to the next. In other words, the shading attributable to the array is significantly smaller than the natural background variation in the resource.

4.5. Equivalent to about one minute of full-strength sunlight per day

Re-expressed as full-sun-equivalent time, the annual loss is very small: 4 h 25 min to 9 h 6 min per year across the modelled positions. Spread over 365 days, that is of the order of one minute of full-strength sunlight lost per day (about 45 seconds in the central and best cases, and about one and a half minutes in the worst case).

4.6. Backtracking minimises shadow length

The trackers use a backtracking control strategy: at low sun angles, instead of pointing straight at the sun, the tables rotate back toward the horizontal to avoid shading their neighbours. This reduces the tilt at low sun and therefore shortens the shadows cast across the ground – including the shadows that fall within the buffer.

The effect is large. With backtracking, the peak shadow reach is about 38 m (worst-case position). With backtracking switched off, the same scene produces a peak shadow reach of about 132 m and the annual loss rises to 1.00%. By selecting trackers and paying for backtracking capabilities, the effect of shading is reduced 60%.

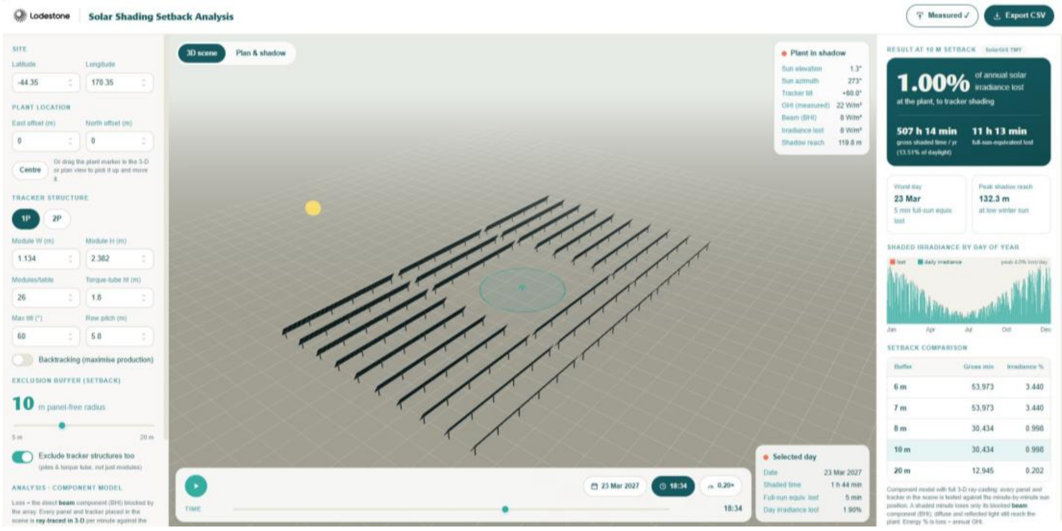

Figure 7 – The same scene with backtracking switched off: peak shadow reach 132.3 m and annual loss 1.00%. Compare with Figure 6 (backtracking on, 38.0 m).

4.7. The peak shadow occurs when there is almost no sunlight

The peak shadow reach of about 38 m (with backtracking) occurs in the very early morning and late evening, when the sun is only a few degrees above the horizon. At these times the direct-beam irradiance is very low. The worst-day hourly progression (Appendix B) shows this clearly: through the middle of the day the plant is in full sun and loses nothing, and the only shaded minutes with any material beam to lose occur late in the day at low sun.

4.8. Timing of the worst case – around the equinox

The worst day of the year falls around the equinox; the exact date depends on the plant's position within the array and on the specific daily conditions in the week or so either side of the equinox. In the modelled cases the worst day is 23 March (central and best-case positions) or 10 October (worst-case position) – both close to an equinox.

4.9. Gross shaded time is large, but the loss is tiny

There are approximately 255 hours of gross shaded time per year in the central case (253 h 29 min, or 6.75% of daylight minutes). Despite this, the irradiance lost is very small, for two reinforcing reasons:

1. **The absolute light level during shaded minutes is low** – typically under about 150 W/m² of GHI, because the shaded minutes are concentrated in the early morning and late evening when the sun is low. This compares to over 1,000 W/m² in clear, midday summer conditions.
2. **A large share of that low-level light is diffuse.** Early and late in the day the ratio of diffuse to direct light is high, and the array's shadow does not affect diffuse or ambient light – only the direct beam. So even a shaded minute still delivers most of its (already low) light to the plant.

This is why 255 hours of shading translates to well under 1% of annual irradiance. The two figures below show the central plant position across a single day: in full sun through the middle of the day (Figure 8) and briefly shaded only at low evening sun (Figure 9), when the light level is low and largely diffuse. Figures 8 and 9 show direct Beam is 1,002 W/m² at midday and 79 W/m² during shaded hours.

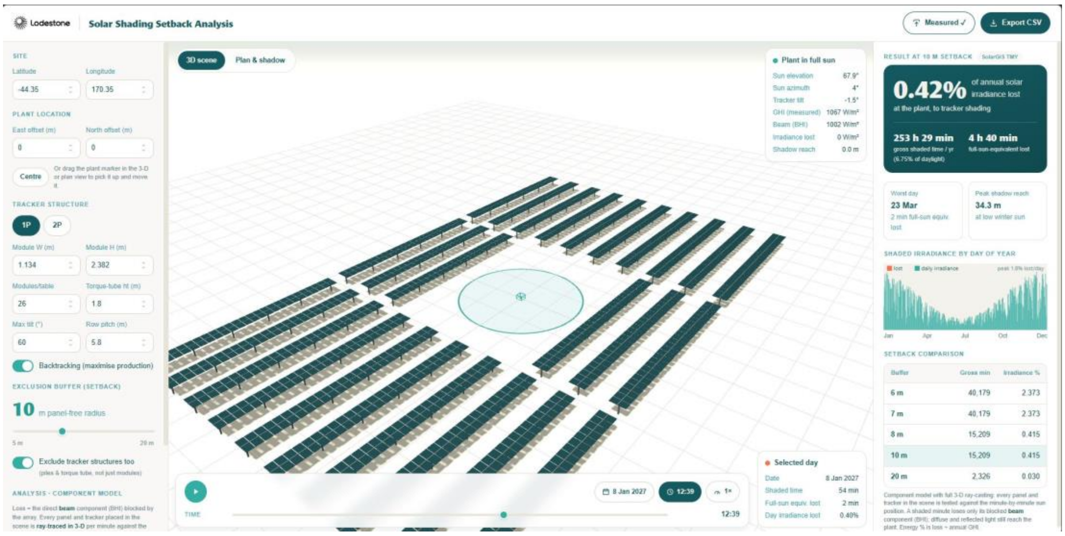

Figure 8 – Central plant position at summer midday: the whole-table exclusion keeps the plant in full sun (sun elevation 67.9°), the scene is bright and the shadow is clearly visible beneath the panels.

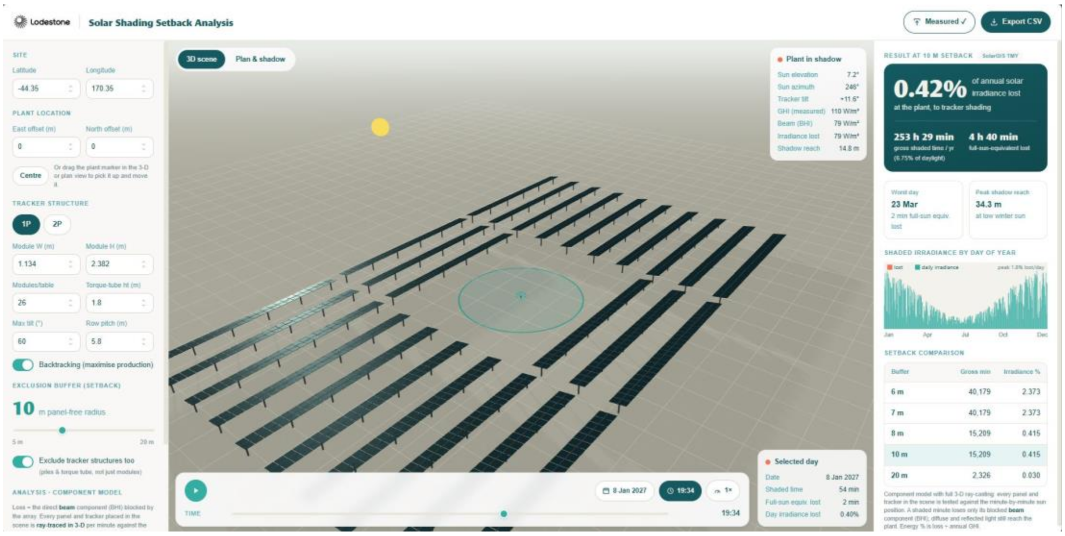

Figure 9 – Central plant position at low evening sun: the plant is briefly shaded, but at this time the light level is low (GHI 110 W/m²) and a large share of it is diffuse and therefore unaffected by the shadow.

5. Physical protection and ongoing management

The shading buffer is one of three complementary protections. The 1–2 m cage and flagging provide the direct physical protection: the cage prevents accidental disturbance of the plant during construction and maintenance, and the flag makes each protected plant clearly visible to site personnel and machinery operators. By removing all infrastructure, not simply panels, there will also be additional buffer area to ensure minimal disturbance to any plants. The Plant Management Plan (PMP), to be finalised, is expected to provide for ongoing care — for example quarterly inspections and weed control — so that invasive species do not establish inside the caged area and outcompete the peppercress.

6. Conclusion

The minute-by-minute, physically-based shading analysis shows that the proposed 10 m buffer — with all infrastructure excluded from the buffer, and with the array's standard backtracking control — reduces the annual sunlight reaching a protected peppercress plant by only 0.39–0.81% (weighted average about 0.55%), equivalent to roughly one minute of full-strength sunlight per day and comfortably within the natural year-to-year variation in the solar resource. The whole-table geometry means the real buffer is effectively larger than 10 m, such that an 8 m buffer would be practically equivalent. On this basis the 10 m buffer, together with the cage, flagging and PMP, is validated as posing no meaningful shading risk to Lepidium solandri.

The proposed 10m buffer proposed by the panel is an appropriate measure to both minimise potential shading effects to the Lepidium solandri without unnecessarily harming the project economics.

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Appendix B – Worst-day hourly shadow progression

The following sequence shows the central plant position on its worst day of the year (23 March), hour by hour. Through the middle of the day the plant is in full sun and loses no irradiance; the only shaded interval with any material beam to lose occurs late in the day at low sun (18:02), confirming that the longest shadows coincide with the lowest light levels.

Time	Sun elev.	Azimuth	Tracker tilt	GHI (W/m²)	Beam BHI (W/m²)	Irr. lost (W/m²)	Shadow reach	Plant status
05:59	below horizon	98°	–	0	–	–	–	below horizon
07:01	2.2°	87°	-3.2°	32	9	0	47.5 m	Full sun
08:02	13.0°	76°	-20.9°	206	169	0	9.3 m	Full sun
09:00	22.7°	64°	-60.0°	386	338	0	5.5 m	Full sun
10:00	31.8°	51°	-51.4°	550	496	0	3.0 m	Full sun
10:59	39.0°	35°	-35.4°	688	631	0	1.6 m	Full sun
11:59	43.6°	16°	-16.2°	752	694	0	0.6 m	Full sun
13:02	44.6°	354°	+5.9°	767	709	0	0.2 m	Full sun
13:59	41.9°	335°	+25.3°	727	669	0	1.0 m	Full sun
14:59	35.9°	317°	+43.2°	620	564	0	2.1 m	Full sun
15:59	27.6°	302°	+58.2°	469	417	0	4.0 m	Full sun
17:00	17.8°	290°	+33.0°	297	254	0	7.0 m	Full sun
18:02	7.0°	278°	+10.4°	103	76	76	16.1 m	In shadow
19:02	below horizon	268°	–	0	–	–	–	below horizon

The figures below show each frame of the sequence.

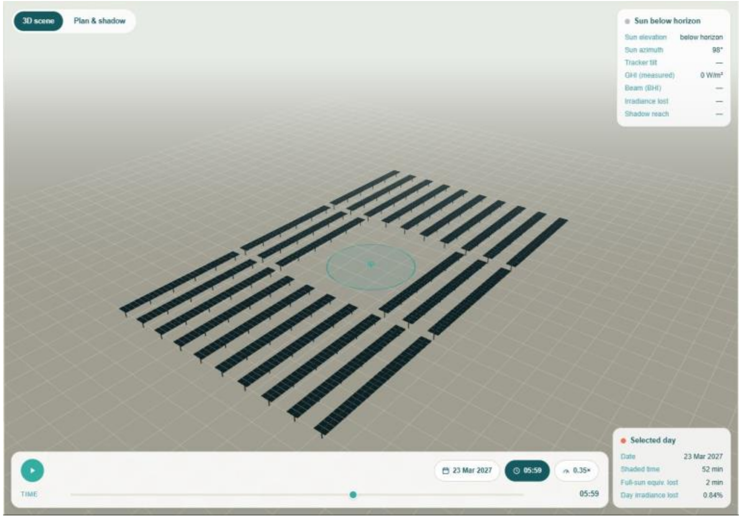

Figure A1 – 05:59 – sun below horizon.

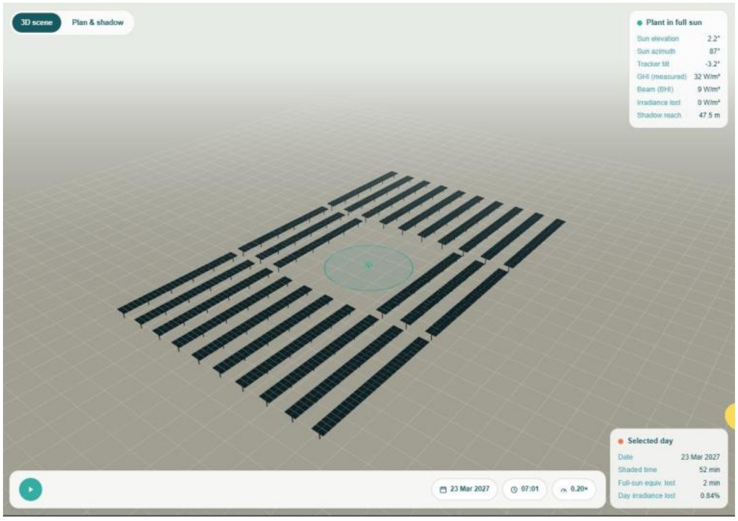

Figure A2 – 07:01 – sun 2.2°; plant in full sun; GHI only 32 W/m²; instantaneous shadow reach 47.5 m.

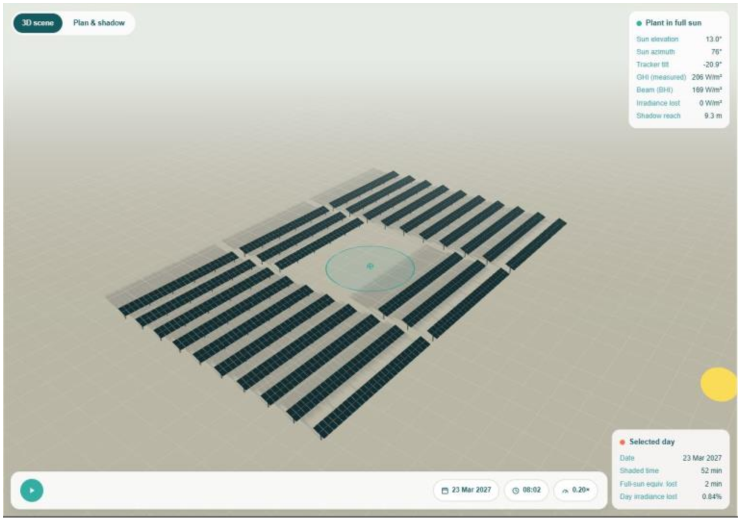

Figure A3 – 08:02 – sun 13.0°; full sun; reach 9.3 m.

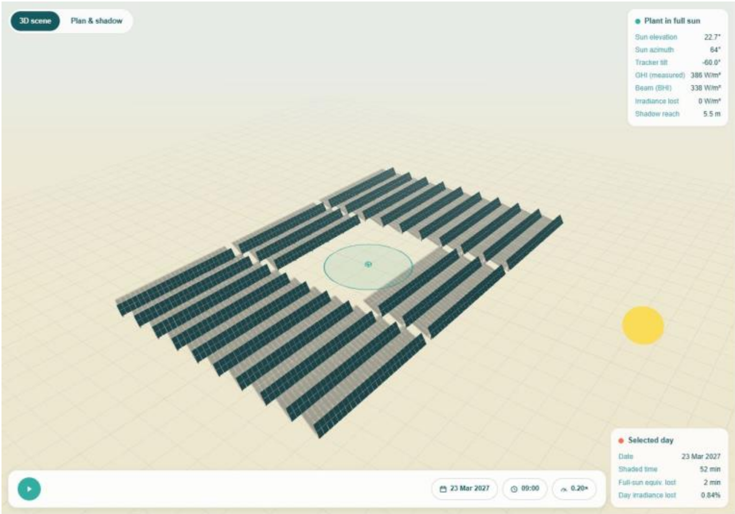

Figure A4 – 09:00 – sun 22.7°; full sun; reach 5.5 m.

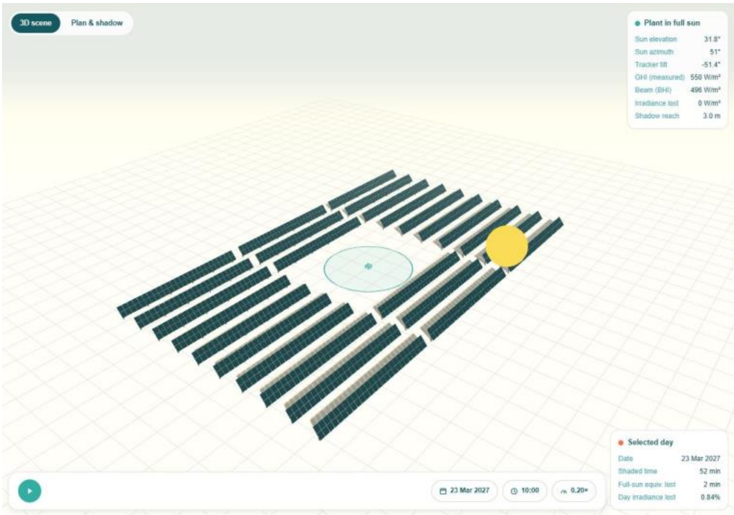

Figure A5 – 10:00 – sun 31.8°; full sun; reach 3.0 m.

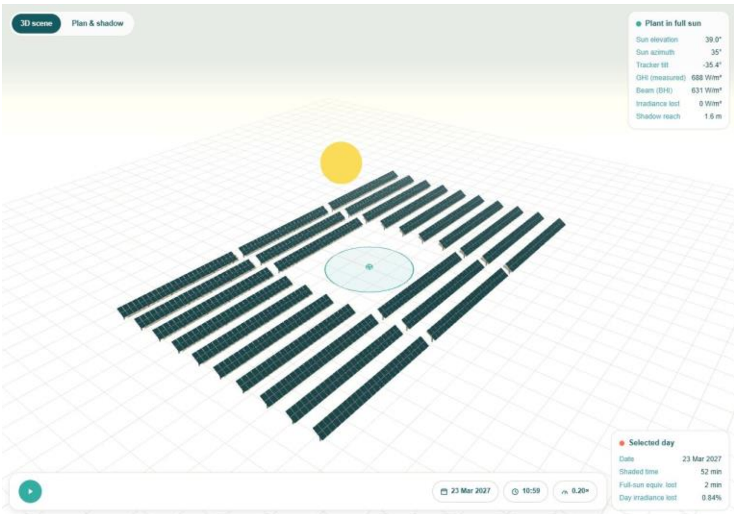

Figure A6 – 10:59 – sun 39.0°; full sun; reach 1.6 m.

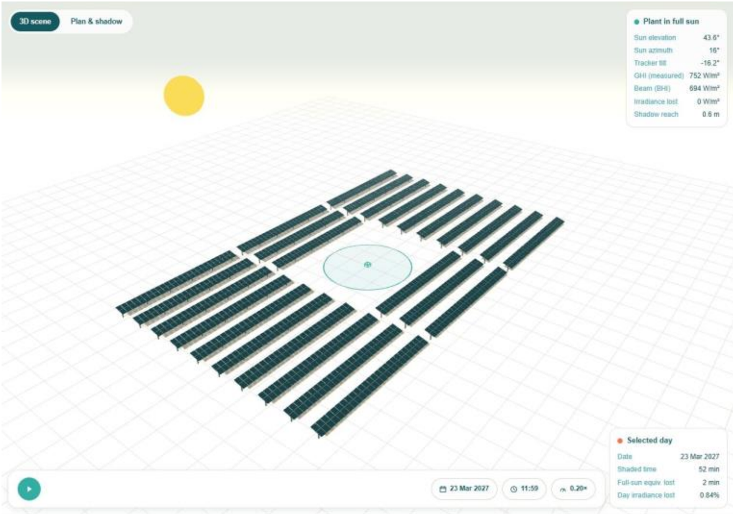

Figure A7 – 11:59 – sun 43.6°; full sun; reach 0.6 m.

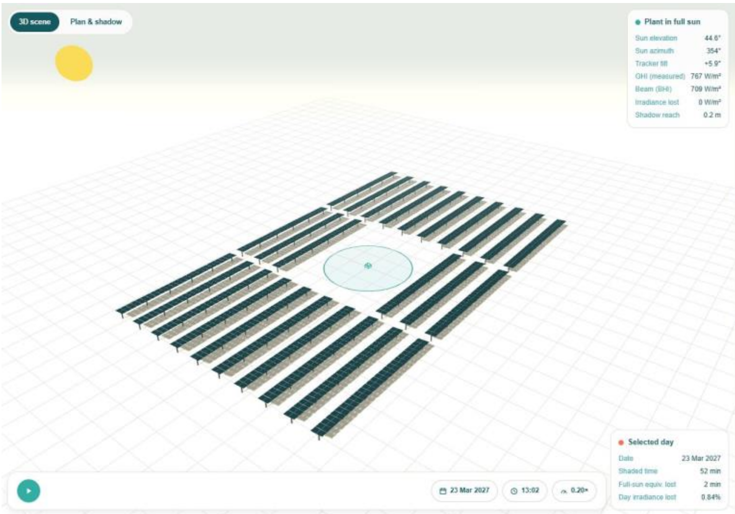

Figure A8 – 13:02 – solar noon; sun 44.6°; full sun; reach 0.2 m.

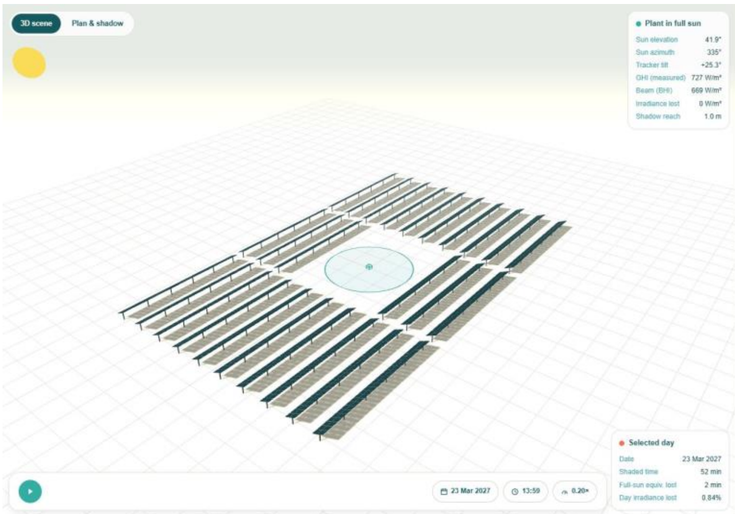

Figure A9 – 13:59 – sun 41.9°; full sun; reach 1.0 m.

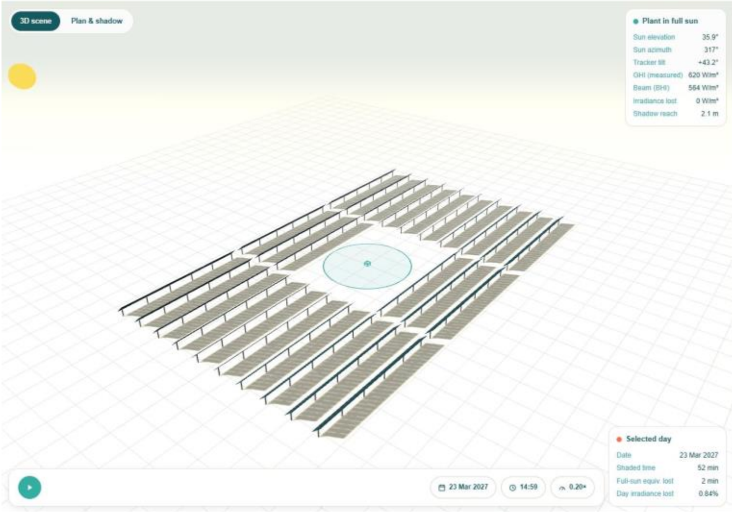

Figure A10 – 14:59 – sun 35.9°; full sun; reach 2.1 m.

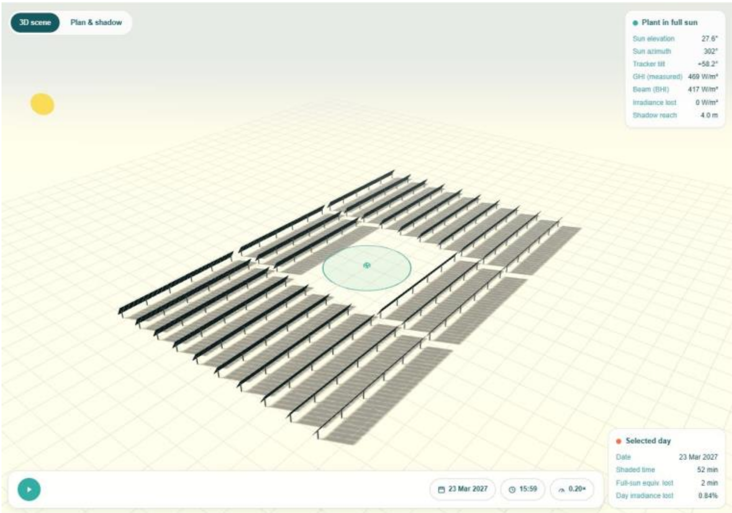

Figure A11 – 15:59 – sun 27.6°; full sun; reach 4.0 m.

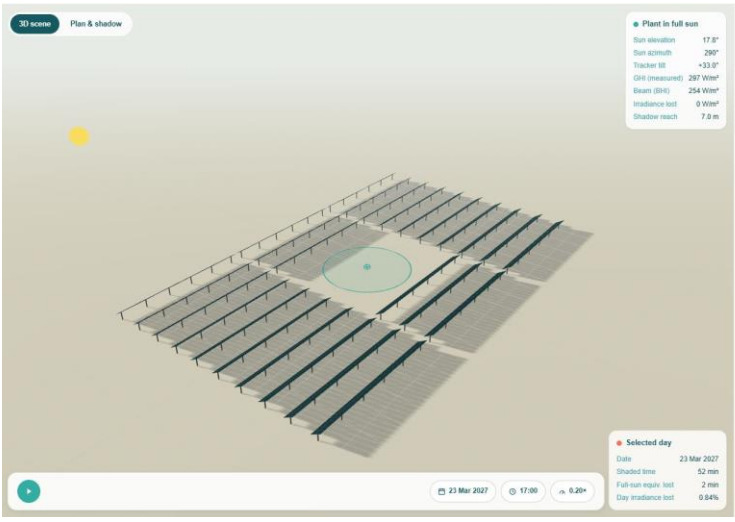

Figure A12 – 17:00 – sun 17.8°; full sun; reach 7.0 m.

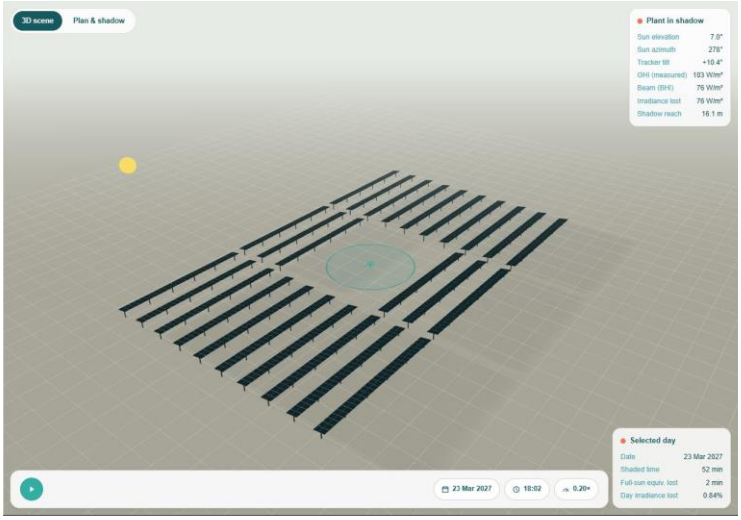

Figure A13 – 18:02 – sun 7.0°; plant briefly in shadow; irradiance lost 76 W/m²; reach 16.1 m.

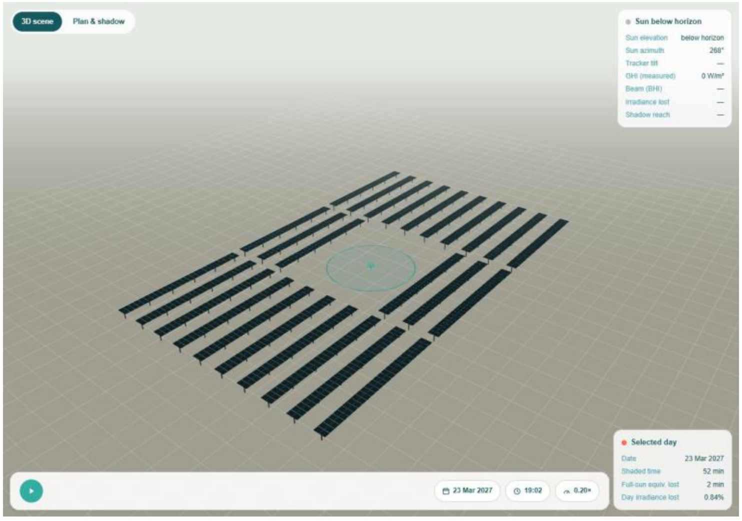

Figure A14 – 19:02 – sun below horizon.

Appendix C – Site solar-resource data (SolarGIS)

The measured typical-meteorological-year (TMY) irradiance used in the shading model is derived from SolarGIS data for the Haldon site. The table below summarises the long-term monthly and annual solar resource from the SolarGIS Prospect report (report SG-P-s20801-260714-231418, Lodestone Energy Limited; site coordinates −44.3533°, 170.2357°; elevation 374 m; data period 2007–2025). GHI is global horizontal irradiation; DNI is direct normal irradiation; DIF is diffuse horizontal irradiation; D2G is the diffuse-to-global ratio.

Month	GHI (kWh/m²)	DNI (kWh/m²)	DIF (kWh/m²)	D2G	Air temp (°C)
Jan	206.4	216.8	60.6	0.294	15.3
Feb	162.5	181.6	46.2	0.284	15.4
Mar	135.3	169.9	40.8	0.301	13.2
Apr	88.3	137.8	28.0	0.317	10.4
May	58.1	114.6	19.8	0.340	7.2
Jun	42.0	92.2	16.2	0.385	3.7
Jul	50.7	105.1	18.3	0.361	2.6
Aug	79.3	137.6	25.2	0.317	4.2
Sep	116.3	160.0	36.0	0.309	6.8
Oct	158.6	176.5	52.3	0.330	9.0
Nov	187.6	192.9	59.9	0.319	11.4
Dec	203.1	195.1	69.4	0.341	13.8
Yearly	1488.3	1880.0	472.5	0.317	9.4

Note that the D2G (diffuse-to-global) ratio rises through the low-sun months and in the shoulders of each day, consistent with the finding (Section 4.9) that a large share of the light available during shaded minutes is diffuse and therefore unaffected by the array's shadow. The full SolarGIS Prospect report is held on file as a supporting reference.