BCworkshop2025

How critical light-sharing in solar parks affects module design

Kay Cesar, Bas van Aken

December 2025

Start presentation

TNO innovation for life

How critical light-sharing in solar parks affects module design

The business opportunity of transmitted light

Kay Cesar, Bas van Aken

Evaluation method and module design for cost-effective compliance with irradiance guidelines to maintain soil quality in solar parks, Cesar et.al, EPJ Photovoltaics **16**, 13 (2025), https://doi.org/10.1051/epjpv/2025003

zon in landschap

Why solar on land?

- **Autonomous**
- **Renewable**
- **Cost-effective**
- **Speed**
- **Challenges for people and nature**
- **With opportunities for synergy**

Motto: speed without regret

Triple proposition: Autonomous renewable energy +

Nature inclusive solar parks

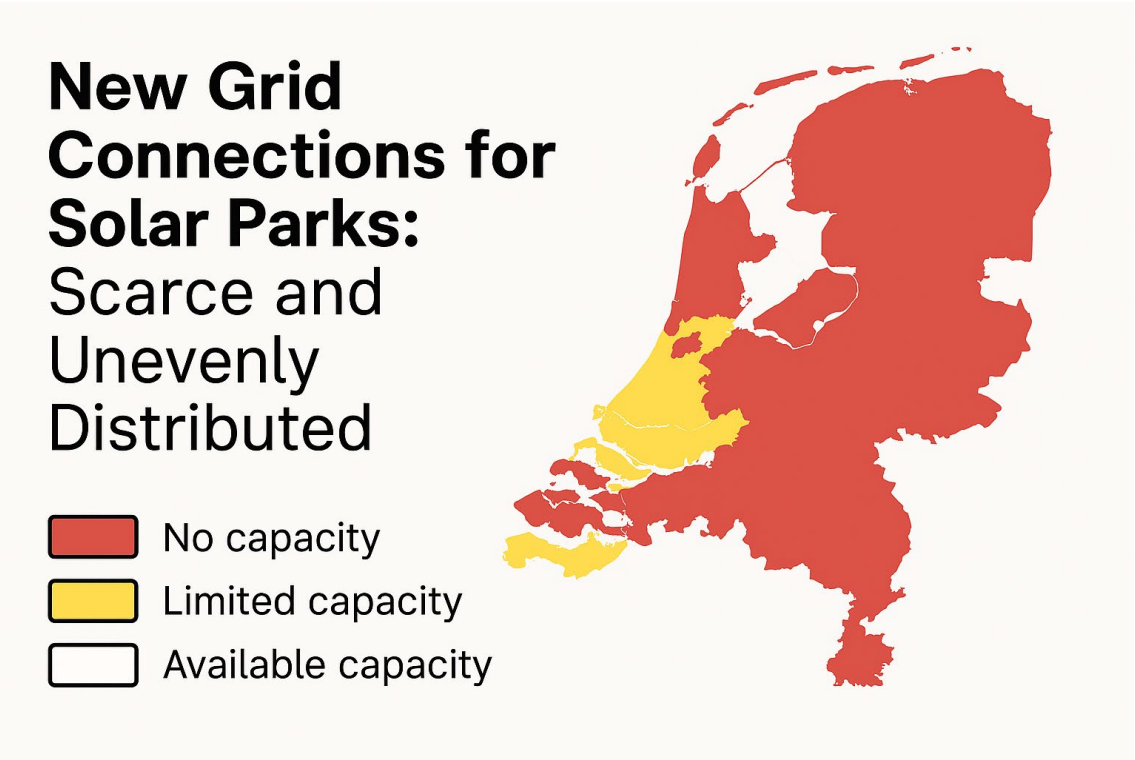
Nature restauration

Agrivoltaics

Food production

Zon-PV ontwikkelingen

- Deployment of solar slows storage accelerates
- Negative capture prices[1] shortage grid connection
- Feed-in restrictions as in Germany [2]
- No feed-in subsidy for battery power



https://data.partnersinenergie.nl/capaciteitskaart/totaal/invoeding

[1] **Marginal Effect of Variation in Photovoltaic System Configuration's Generation Profiles on Price Stabilisation in the Netherlands Compared with Deployment of Flexible Demand and Supply**, B.B. Van Aken et al. Sol. RRL, 6, 2100484 (2022). https://doi.org/10.1002/solr.202100484
[2] [**Feed-in power limitation of grid-connected PV battery systems with autonomous forecast-based operation strategies**, J. Bergner et al. , Proc EU PVSEC (2014).

Developments in utility-scale PV in NL

- Deployment of solar slows storage accelerates
- Negative capture prices[1] shortage grid connection
- Feed-in restrictions as in Germany [2]
- No feed-in subsidy for battery power
- Ground coverage ratios 75 - 98%
- Subsidy scheme demands nature-inclusive solar parks

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Pacht, bodemkwaliteit en eco-label

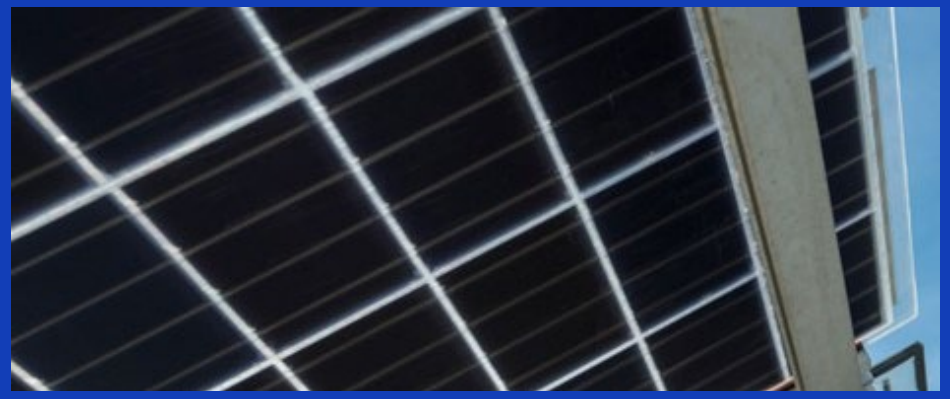
Lease contract: Maintain soil quality!

2022- First irradiance rules published [1]

2025 - Transparent bifacial modules cost-effective [2]

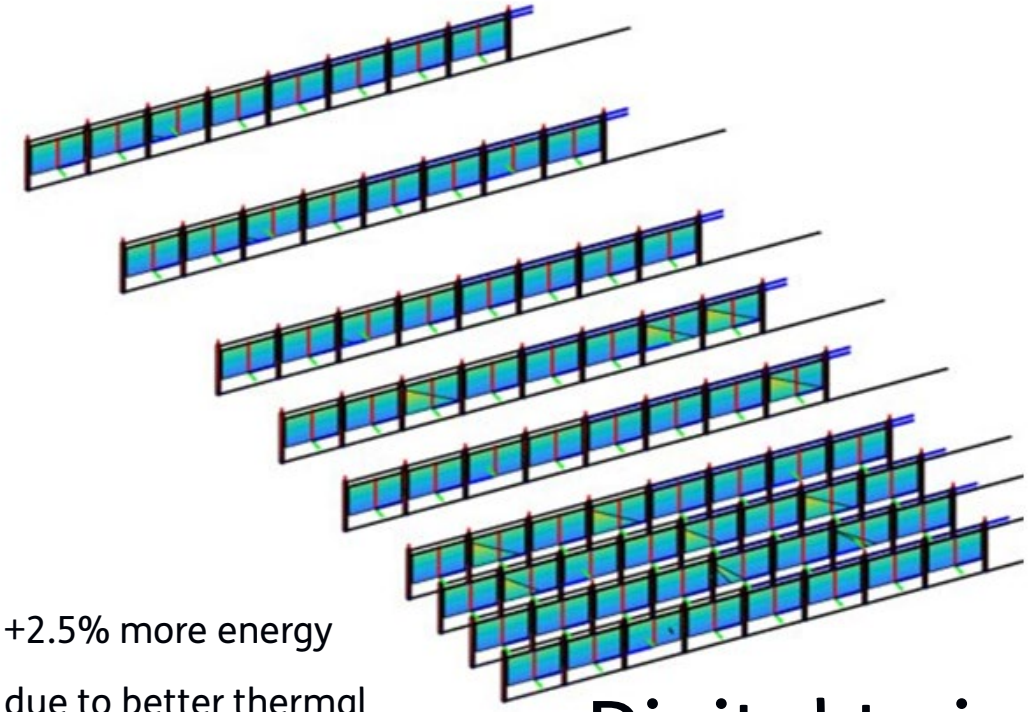
2025 - Ground irradiance rules in Dutch eco-label [3]

2025 – Grid restrictions hapers eco-positive design[4]



[1] **Nieuwe ontwerptoets verankert bodemkwaliteit in zonneparken,** Cesar et al., Bodem (April 2022)
[2] **Evaluation method and module design for cost-effective compliance with irradiance guidelines to maintain soil quality in solar parks,** Cesar et.al, EPJ Photovoltaics **16**, 13 (2025), https://doi.org/10.1051/epjpv/2025003
[3] **EcoCertified Solar Parks. Openbare eindrapportage,** Krijgsveld et al., (September 2025) Doi:10.18174/699847
[4] **The dark side of feed-in restrictions for nature-inclusive solar parks**, Cesar et al, Oral EUPVSEC 2025, paper pending

Validation of digital twin is good for business



+2.5% more energy

due to better thermal

parameterisation

Digital twin

Real twin

Thermal model in digital twin of vertical PV system helps to explain unexpected yield gains
EPJ Photovoltaics **14**, 32 (2023), https://doi.org/10.1051/epjpv/2023027

R&D combo: light sharing for ecology & PV reliability

Clay

Sand

Science-based design rules for economic and nature inclusive solar parks

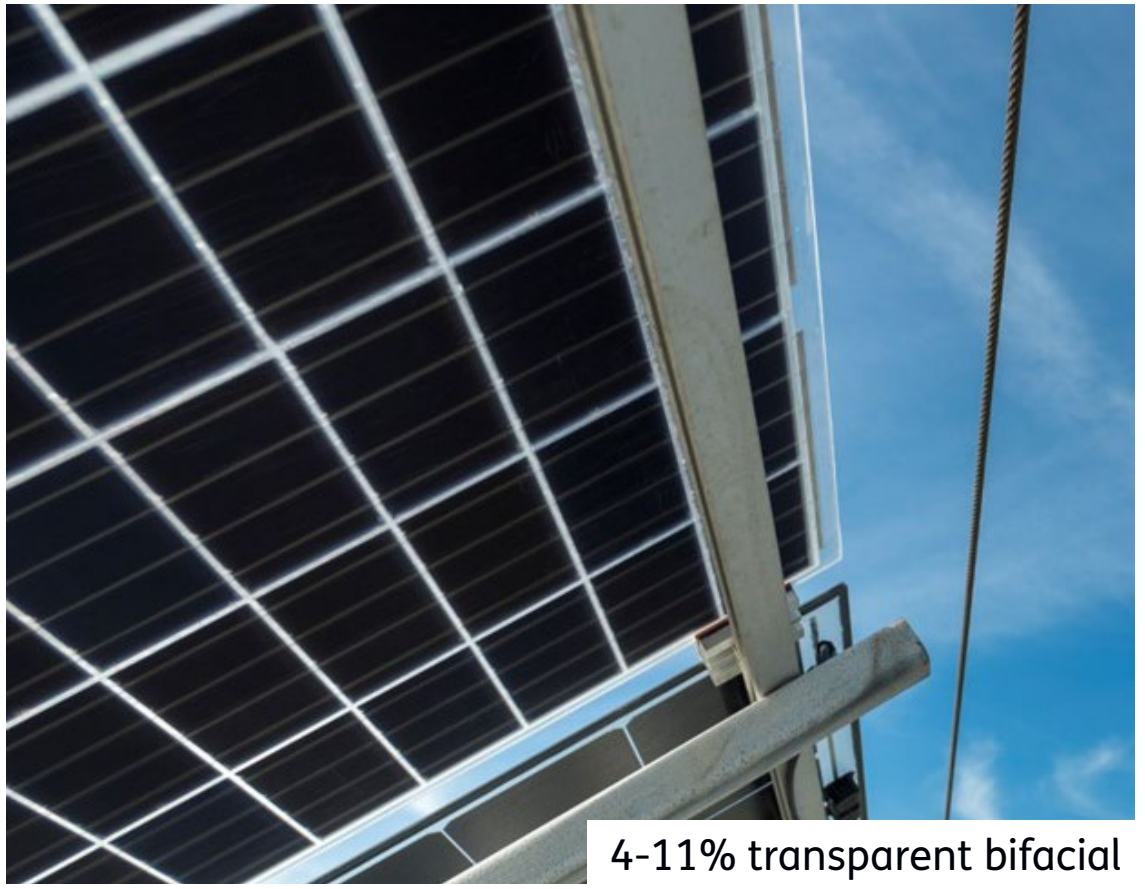
Coming up: 7 more sites, 3.5 MWp - on ecology and agrovoltaics– let's discuss and align test fields!

TNO innovation for life | WAGENINGEN UNIVERSITY & RESEARCH | low carbon powering tomorrow | Eelerwoude | VRIJSTAD ENERGIE | Energiefonds Groningen | Ministry of Economic Affairs, Agriculture and Innovation | zon in landschap

Reflector foil in bifacial modules

trend based on known technology to increase front side efficiency

White bifacial



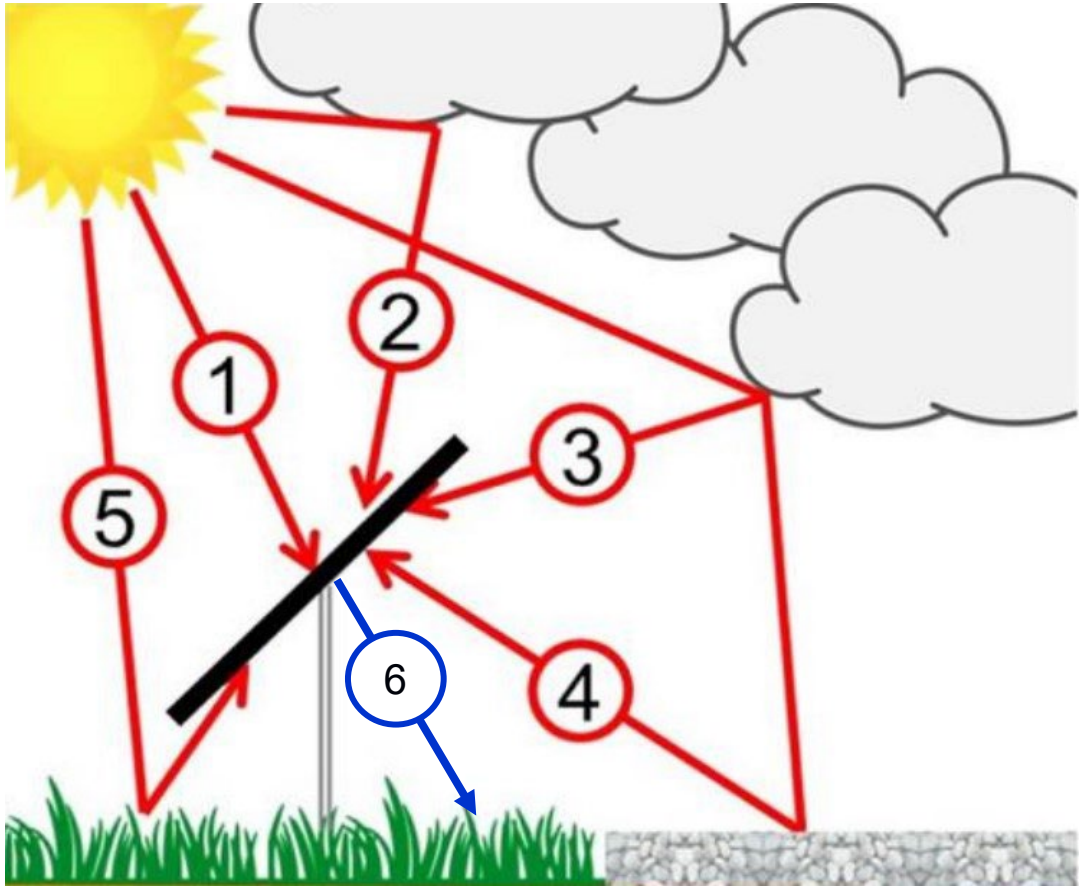
4-11% transparent bifacial

Which design is better for permits and business case?

Annual yield & ground irradiance

- Simulation considers:
  - Direct beam and diffuse components
  - Module transparency
  - Albedo 25%
  - Module 540 Wp, 144 half cells

  Effect reflector
  - **+ 2% Isc**
  - **6.5% module surface – no transparency**
- **Critical soil test norm:**
  - **Ground irradiance > 10%**



TNO BIGEYE PV yield and ground irradiance platform

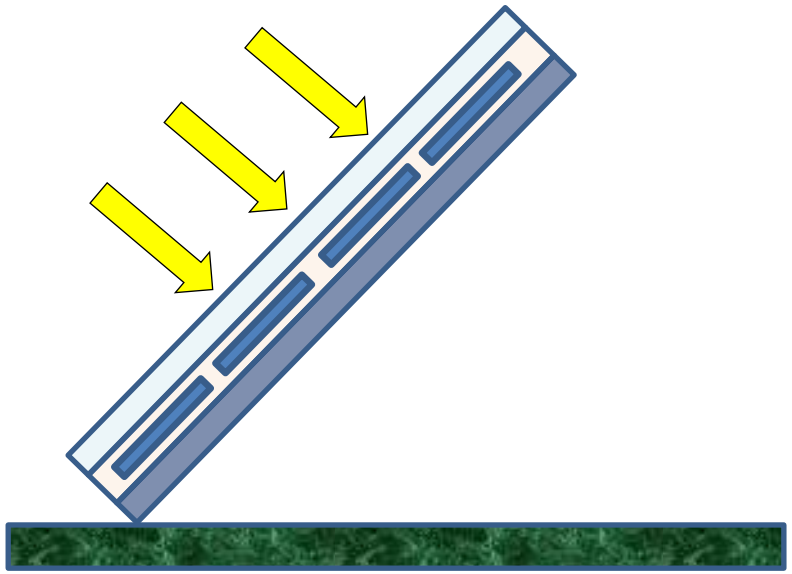
Evaluation method and module design for cost-effective compliance with irradiance guidelines to maintain soil quality in solar parks, Cesar et.al, EPJ Photovoltaics **16**, 13 (2025), https://doi.org/10.1051/epjpv/2025003

Monofacial

Module 144 half-cell - 540Wp

0% Transparency

Reference case



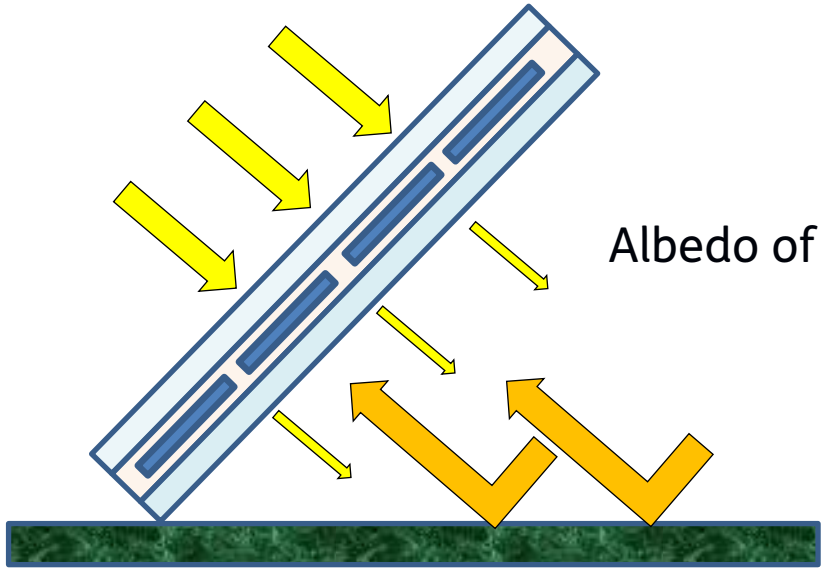
Bifacial

Partially transparent

Has 2% lower WP

6.5% transparency

Annual – yield gain



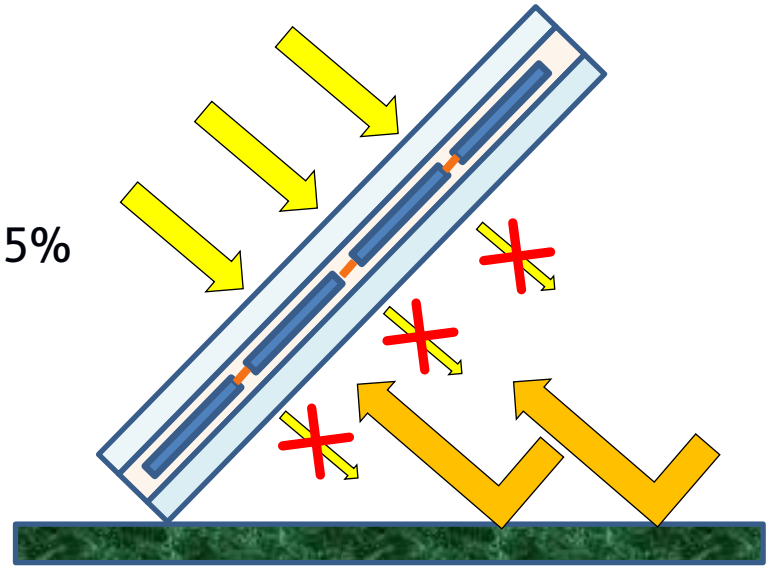
Albedo of 25%

White-bifacial

Has same Wp as monofacial

0% Transparency

Annual – yield gain

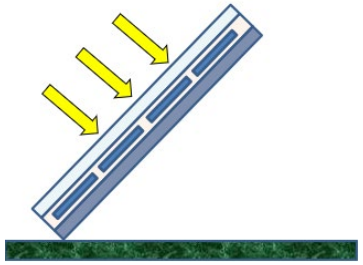


Park design	GCR	BF	Δ	WBF	Gain white foil
NL East-West	0.9	+0.9%		+1.9%	+1.0%
NL South	0.7	+2.0%		+3.4%.	+1.4%
Spain South	0.6	+2.2%		+3.5%	+1.3%

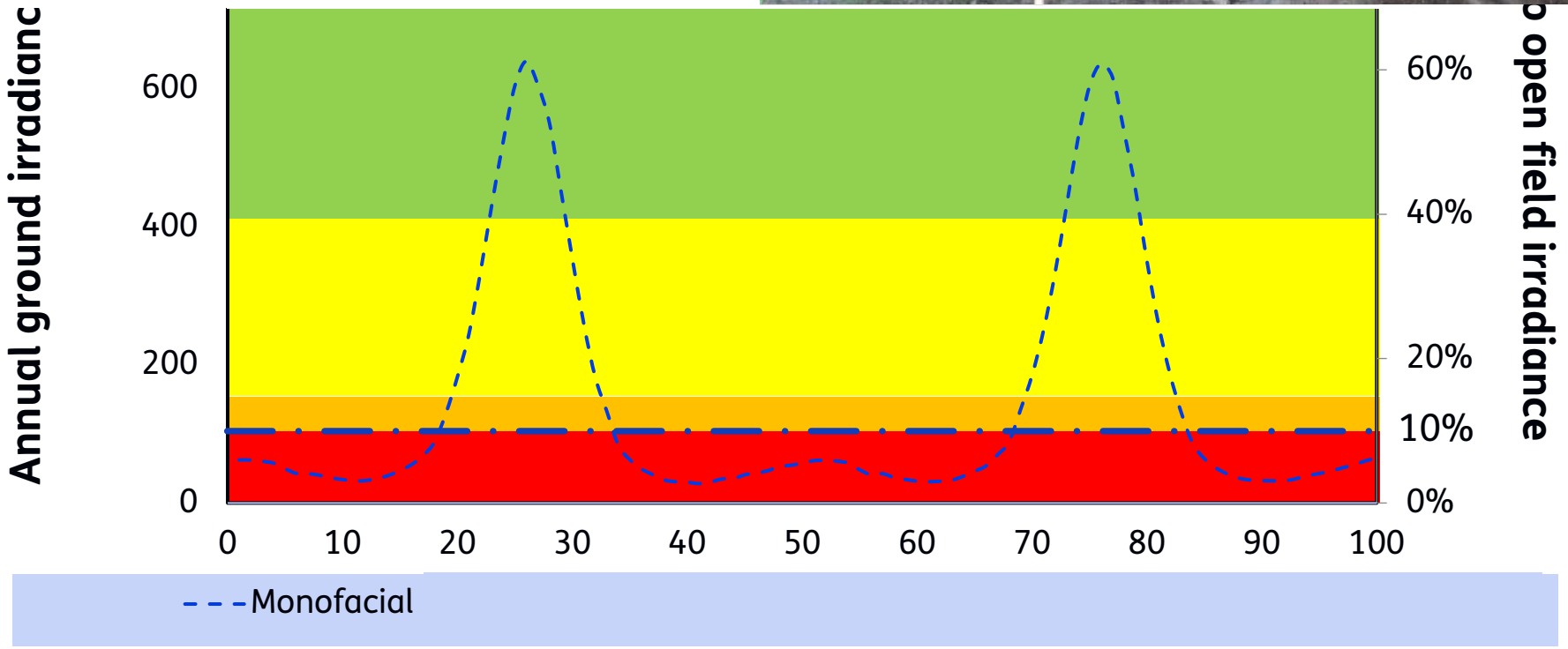
STC Power gain white bifacial = 2%

Gain annual yield white foil =1.0- 1.4%

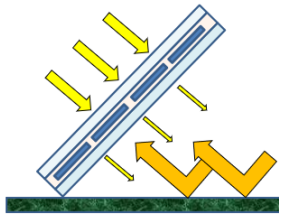
Soil test evaluation – East-West NL – GCR 0.9



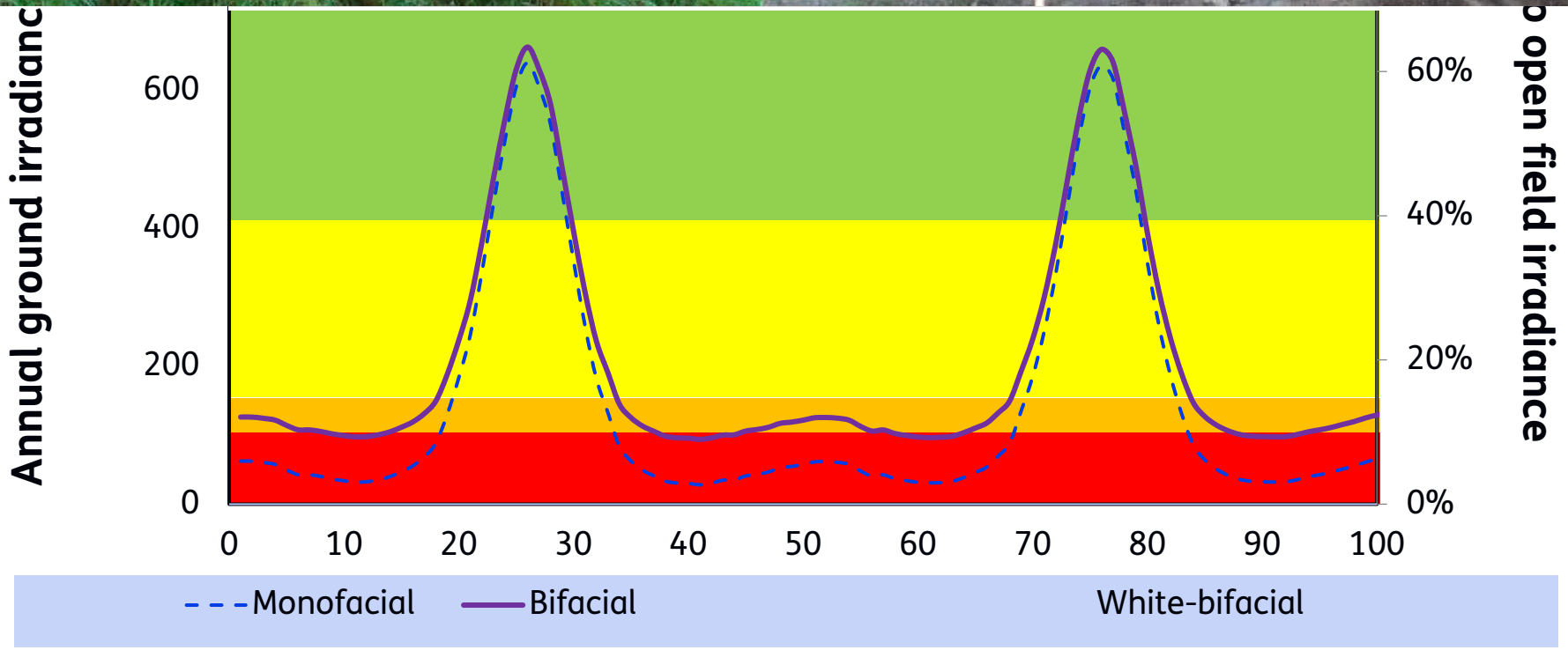
Monofacial


Annual ground irradianc
600
400
200
0
0
10
20
30
40
50
60
70
80
90
100
60%
40%
20%
10%
0%
o open field irradiance
Monofacial

Transparency of (bifacial) modules enables sustainable East-West designs in Netherlands



Bifacial



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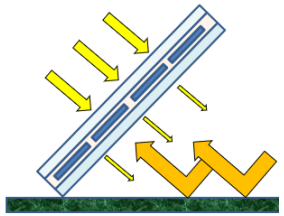
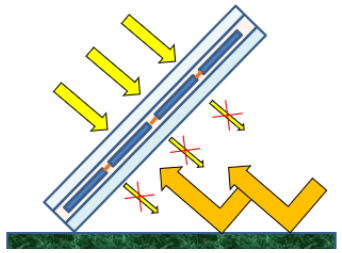
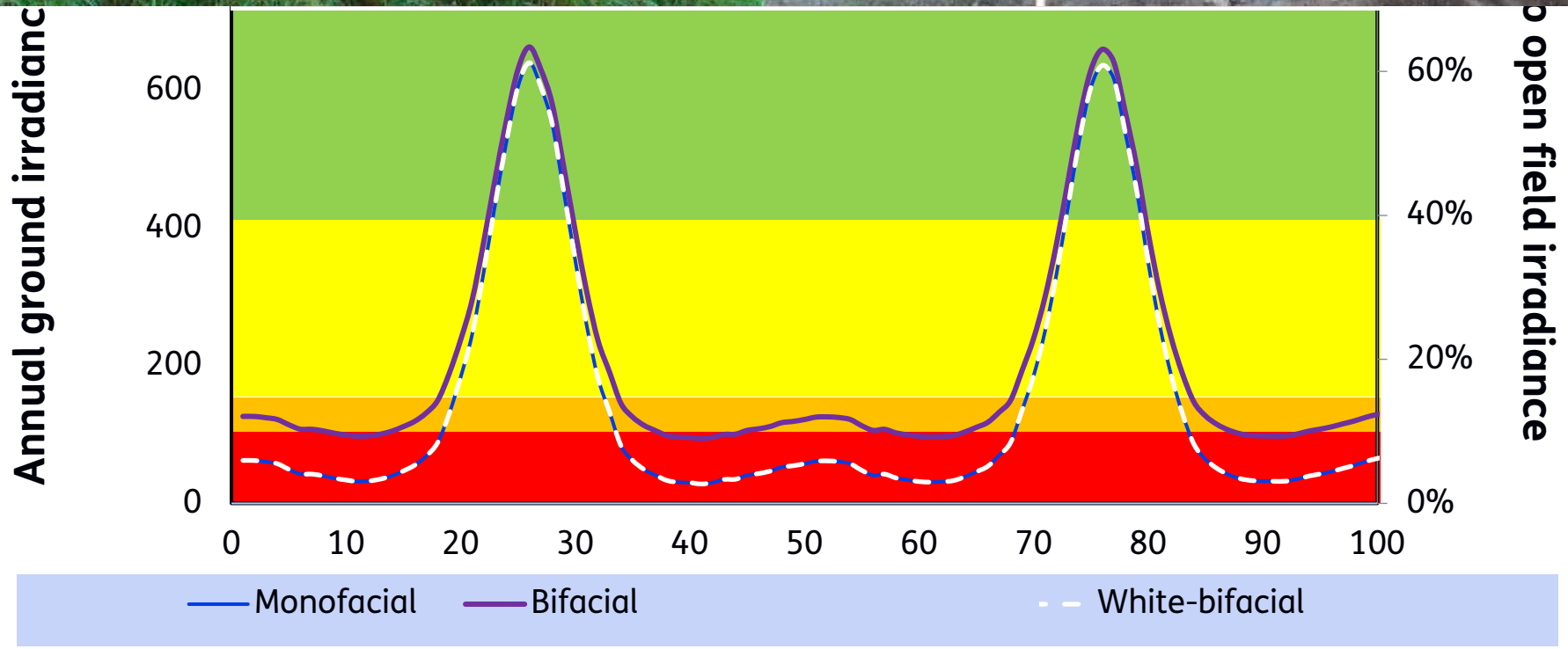


Bifacial



White Bifacial



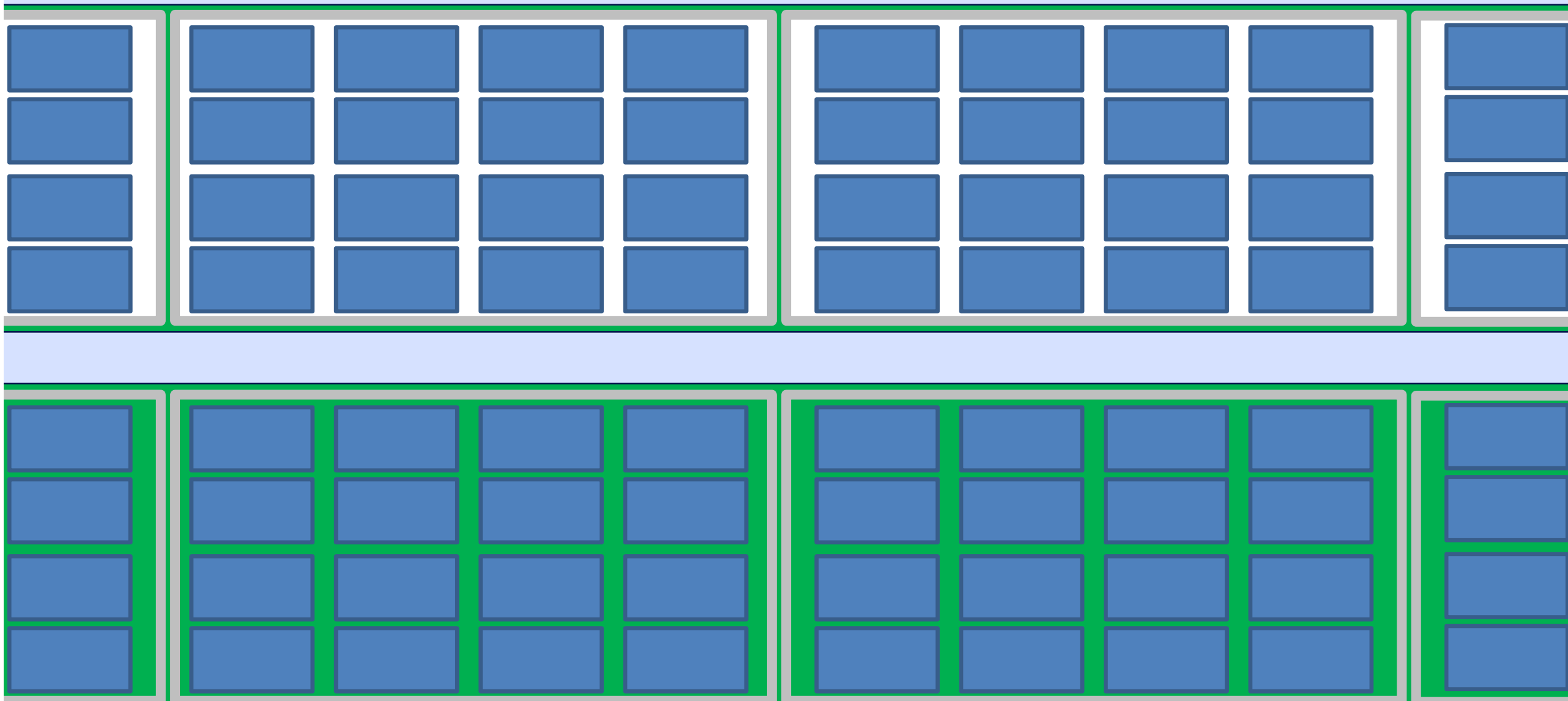
Legend

White bifi: η = 22.4 % (IV Flash)

Transparent bifi: η = 22.0 % (IV Flash)

White intercell area: η = 6 % (IV Flash)

Transparent area: η = 3 % (rear absorption!)



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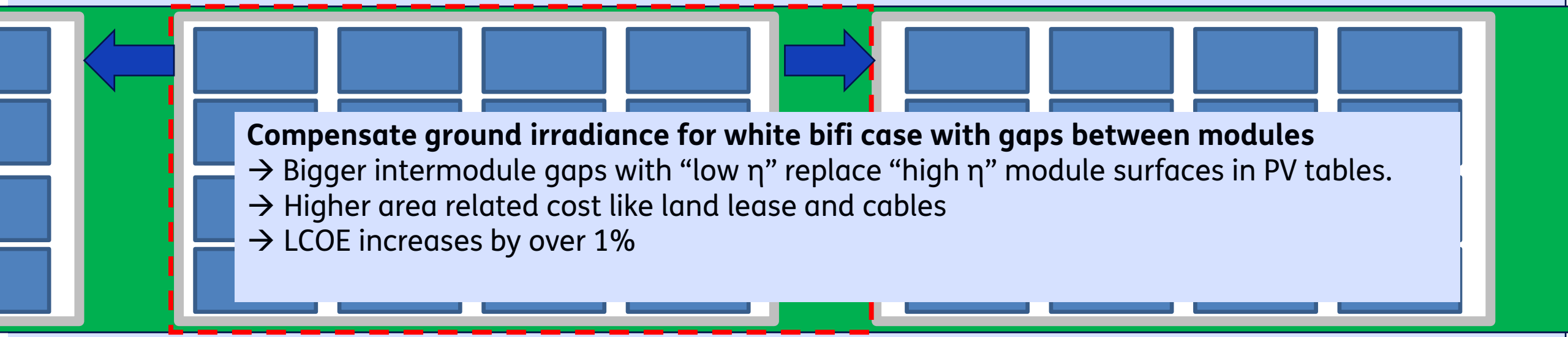

Compensate ground irradiance for white bifi case with gaps between modules

→ Bigger intermodule gaps with “low η” replace “high η” module surfaces in PV tables.

→ Higher area related cost like land lease and cables

→ LCOE increases by over 1%

For nature-inclusive park design use transparent bifacial panels:

→ Lower LCOE

→ More modules per project

→ Lower cost module

→ Easier module recycling

→ Compact & aesthetic park design

Please improve availability of transparent bifacial modules!

Conclusion

- TNO test field expansion to 5 MWp : fixed tilt, HSAT, vertical
  - 7 locations for nature-inclusive solar parks & agrivoltaics
- Ground irradiance rule part of solar park Eco-label
- Transparent bifacial most cost-effective module design
  - 1% lower LCOE & more modules per project
- Recommendation:
  - Establish soil irradiance tests in other climate regions
  - **Please improve availability of transparent bifacial modules!**

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Questions?

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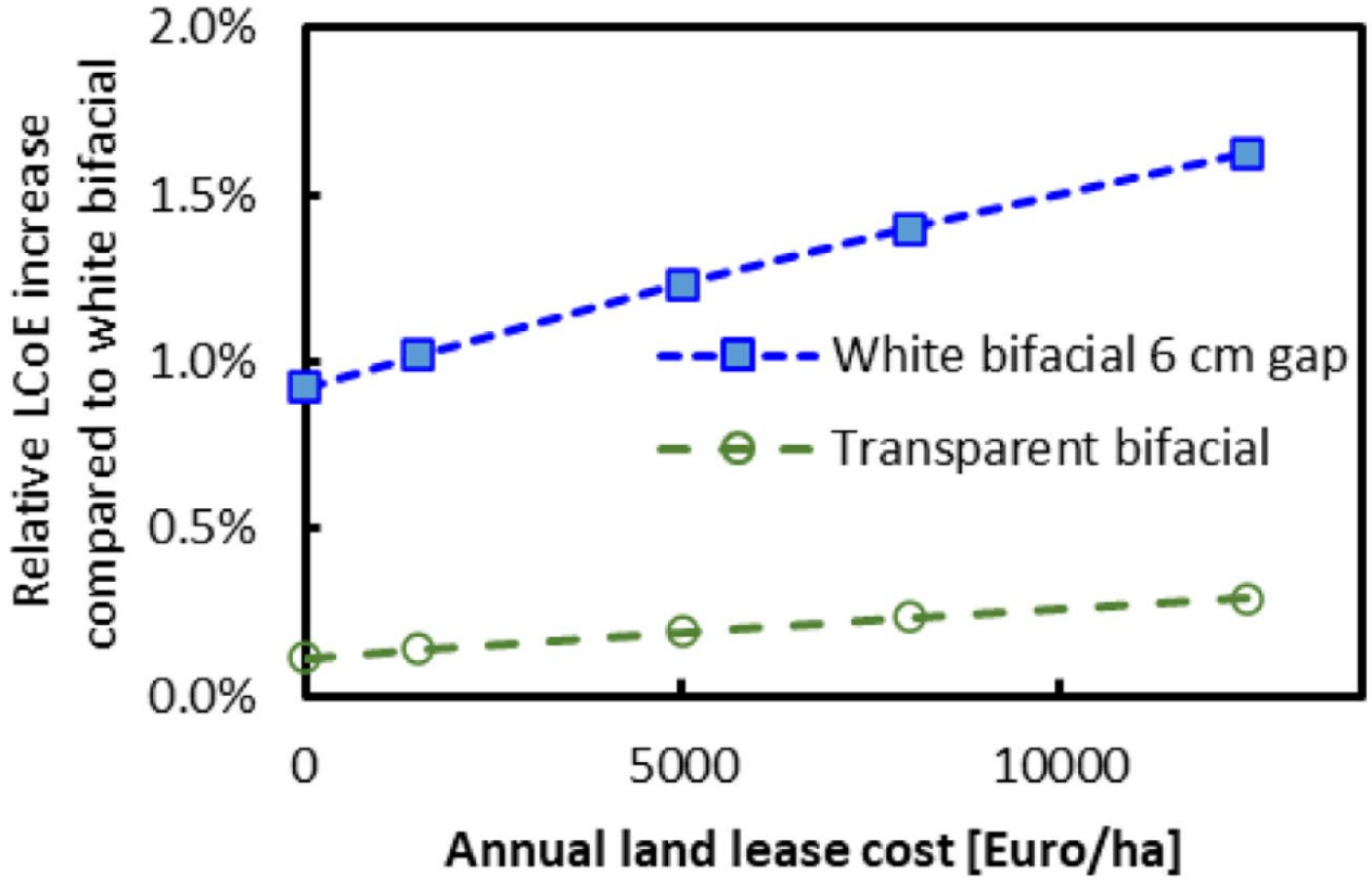
Partners national project SolarEcoPlus:

LC Energy, Energiefonds Groningen, Eelerwoude, Vrijstad Energie, WUR, TNO

DEI+ Grant from the Ministry of Economic Affairs and Climate

Dependency on landlease



Cost difference increases with land-lease White bifacial with gap

LCOE calculation parameters and results

Capex: 535 €/kWP

Opex: 15.4 €/kWp/yr

Land lease cost 5k€/yr

Wacc_real = 6%

Equal module prices/Wp & degradation assumed

Area 22 hectare

GCR 70% (*WBF+gap=66%)

3P south in the Netherlands

Table 4. Overview of minimum irradiance, module and system power, specific yield and levelised cost of electricity for a 22-hectare solar park in the Netherlands for different module and table designs.

	Module spacing [cm]	min G	Module power [W]	Installed power [MW]	Specific yield [kWh/kWp]	LCoE [€/MWh]
Monofacial	0	2.6%	540	31.4	985	58.9
White bifacial	0	2.6%	540	31.4	1019	56.9
Transparent bifacial	0	8.9%	529	**30.8**	1026	**57.0**
White bifacial	6.0*	8.9%	540	**29.5**	1025	**57.6**

"min G" is the lowest irradiance in the park below the PV table

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Discussed availability of transparent bifacial panel with manufacturers

White border: Manufacturer with
Partial transparent bifacial panel in production

Black border: Manufacturer can produce depending on demand

Zon in Landschap living lab alliance


Almere


Havebos


Wadenooijen


Vlissingen


Culemborg


Wijkerbroek


Petten


Kootwijkerbroek