CARBON FOOTPRINT VS RELIABILITY OF SOLAR PHOTOVOLTAIC MODULES: A NEW DILEMMA?

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EU PVSEC

Vienna, EU-PVSEC 2024

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- Carbon intensity of PV systems and of solar electricity
- Results
    - Impact of performance loss rates (PLR) & lifetime on CI of PV
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- Conclusions

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MOTIVATION

….two presentations earlier…..

5CO.6.2 Maximizing Solar Sustainability: Analysis of the Leverages for Low-carbon Impact PV Manufacturing and Electricity Generation
Alexis Barrou et al.

To **reach low-carbon solar electricity**, we need:

- Low carbon **PV modules** robust, with a **long lifetime** and made with **decarbonized electricity mixes**

Here we **focus on**:

1. **Impact of degradation rates and lifetime on CI** (carbon intensity) figures of solar PV electricity.
2. Assessing the impact that some design changes might influence CI of PV.

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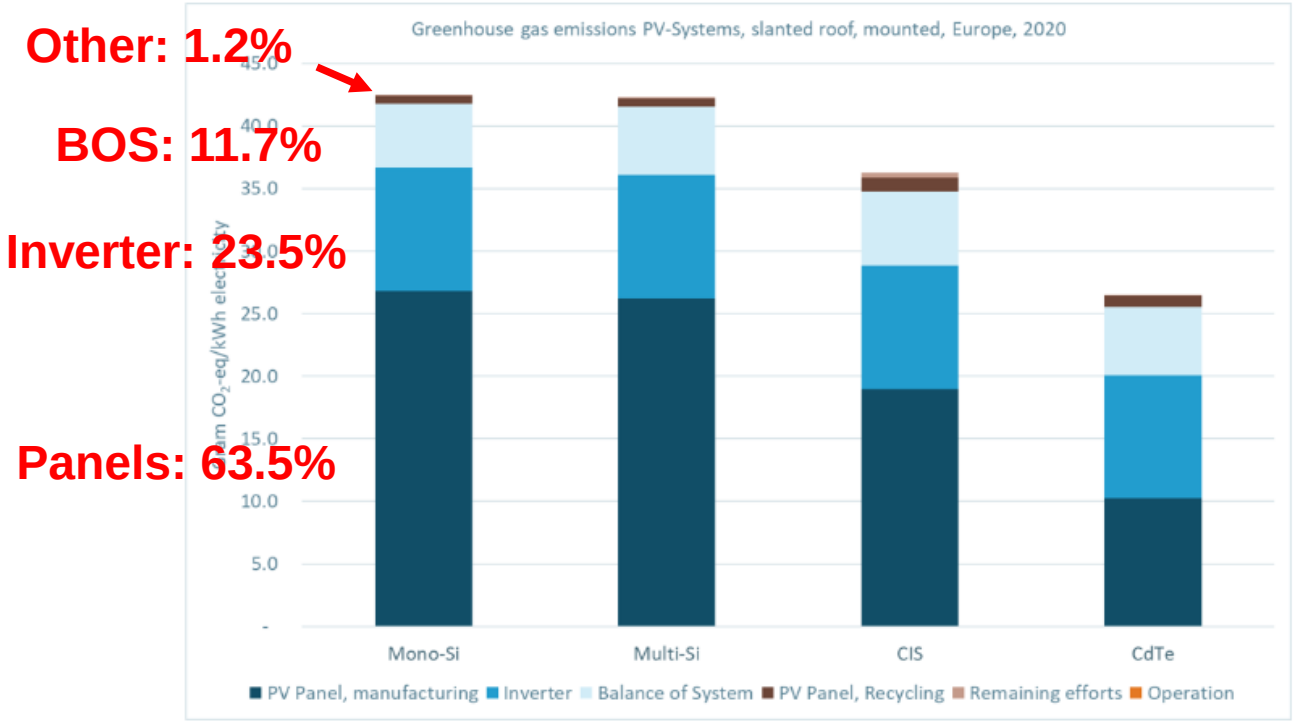
CARBON INTENSITY (CI) OF SOLAR PV SYSTEM (HARDWARE)

a. Most lifecycle CO_2 emission are attributed to HW manufacturing
b. Little to transport, nearly no other emissions over lifetime
c. Breakdown of emissions: largest contributions cells (c-Si) and modules
d. CI intensity of a PV system [$kgCO_2$-eq/kW_p] is fixed



IEA-PVPS Factsheet (2021)

CI of PV: breakdown of system contributions (with mono c-Si panels)

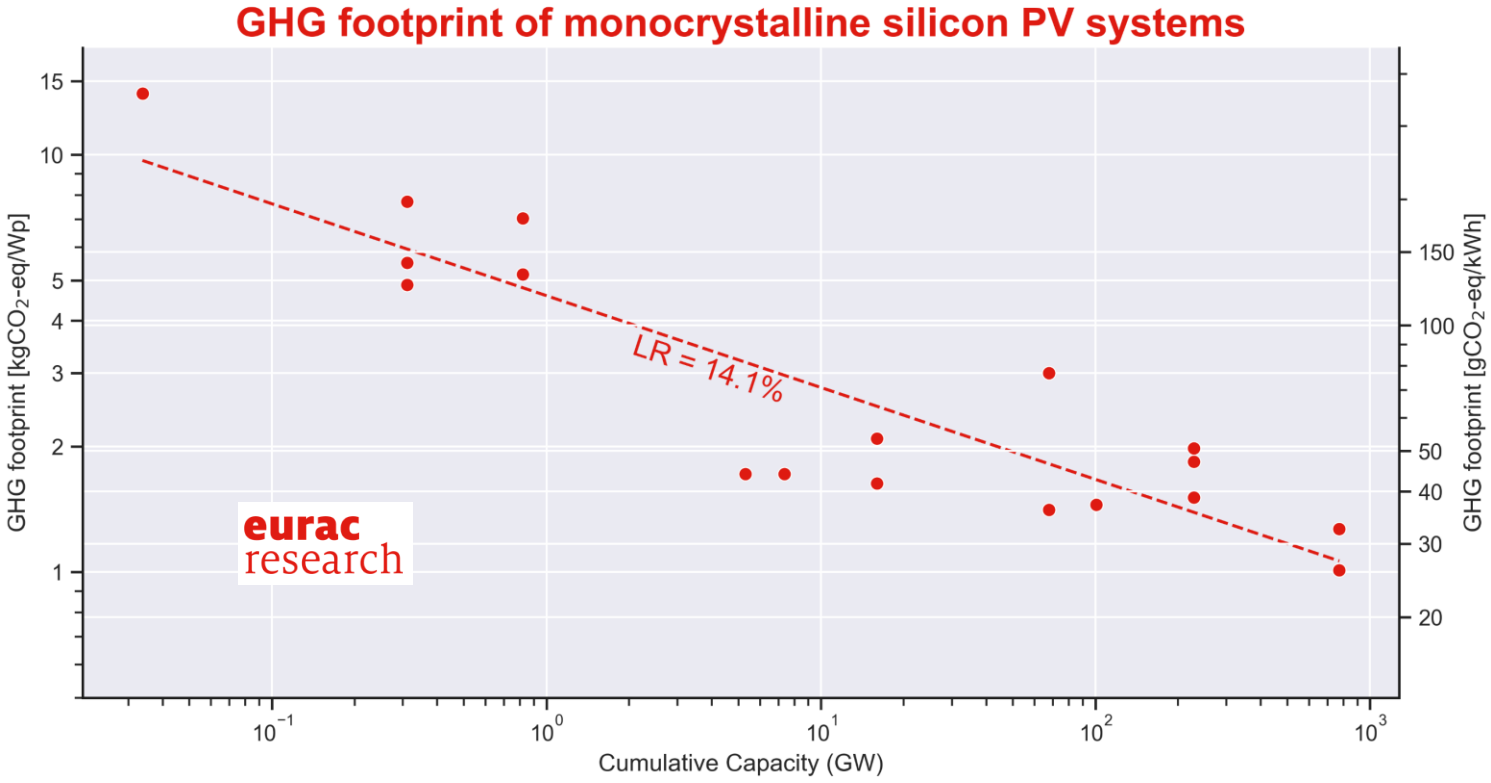
CARBON INTENSITY (CI) OF SOLAR PV SYSTEM

a. Technological evolution brings down CI figures of PV

>> e.g. from 16 to 4 (even 2.5) g-Si/Wp

a. Other leverages: electricity mix in manufacturing, module design,….

PV System



Source:
Eurac
(Atse Louwen,
David Moser)

CARBON INTENSITY (CI) OF SOLAR PV MODULES

Trend in developing **low-C modules**…

a. Consequence of technological progress & design solutions

b. Manufacturing incentives, national call for tenders, Ecodesign directives (EU)…

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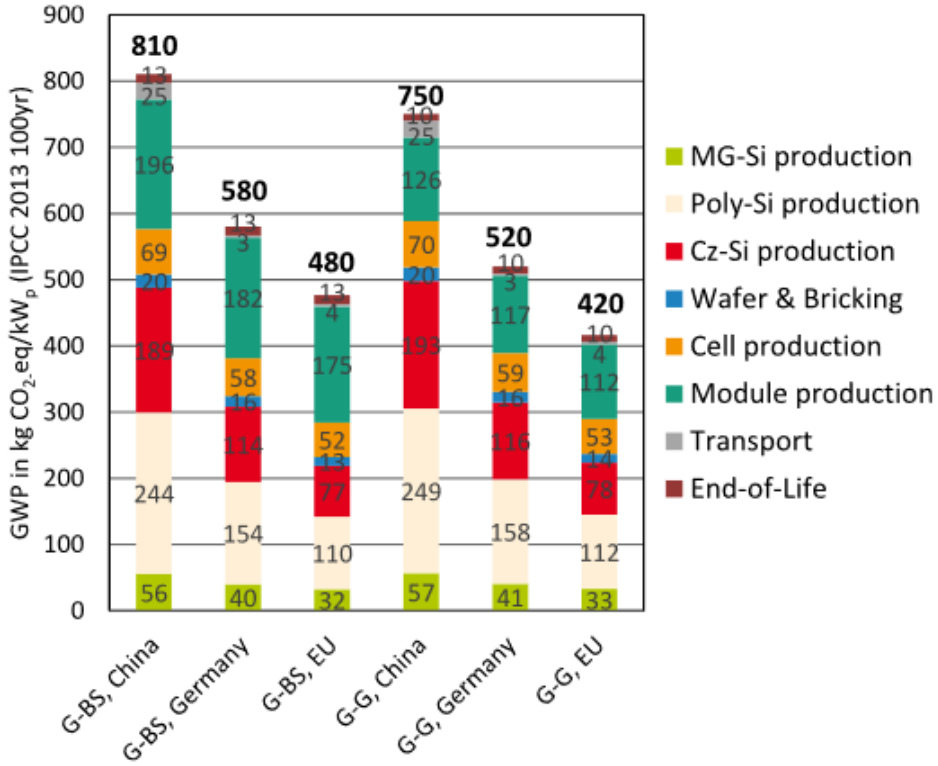
Müller et al. SolEnMatSolCel 2021

PV Modules



Bejat et al. PiP 2023 +EUPVSEC 2023

Received: 29 September 2023 | Revised: 9 February 2024 | Accepted: 19 March 2024
DOI: 10.1002/pip.3803

SPECIAL ISSUE ARTICLE

PROGRESS IN PHOTOVOLTAICS WILEY

Design for the environment: SHJ module with ultra-low carbon footprint

Timea Béjat[1] | Nouha Gazbour[1] | Amandine Boulanger[1] | Rémi Monna[1] | Renaud Varache[1] | Jérôme François[2] | Wilfried Favre[1] | Charles Roux[1] | Aude Derrier[1] | Eszter Voroshazi[1]

CEA announcing 566-Wp module footprint of **313 kgCO2eq/kWp.**

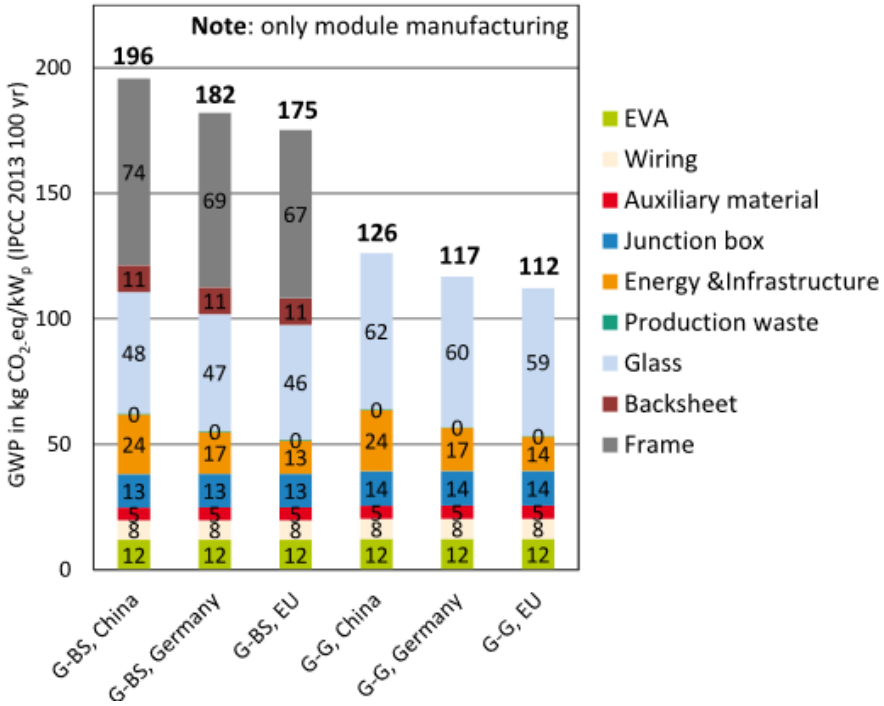
SHJ, made-in EU, wooden frame, thinner glass, ..

CARBON INTENSITY (CI) OF SOLAR PV MODULES

Several **technological trends** are leading to a reduction of the CI of PV modules:

Examples:

- thinner glass > from 3.2 to 2 (or less) mm – thick
- Use of semi-tempered glass
- Frameless design (wooden frames?)
- Thinner cells
- Large cells and modules
- …..



At which expense in terms of reliability?

E.g. A lot of anecdotal evidence suggests that modules with thinner non-tempered glass are more much more fragile…

Müller et al. SolEnMatSolCel 2021

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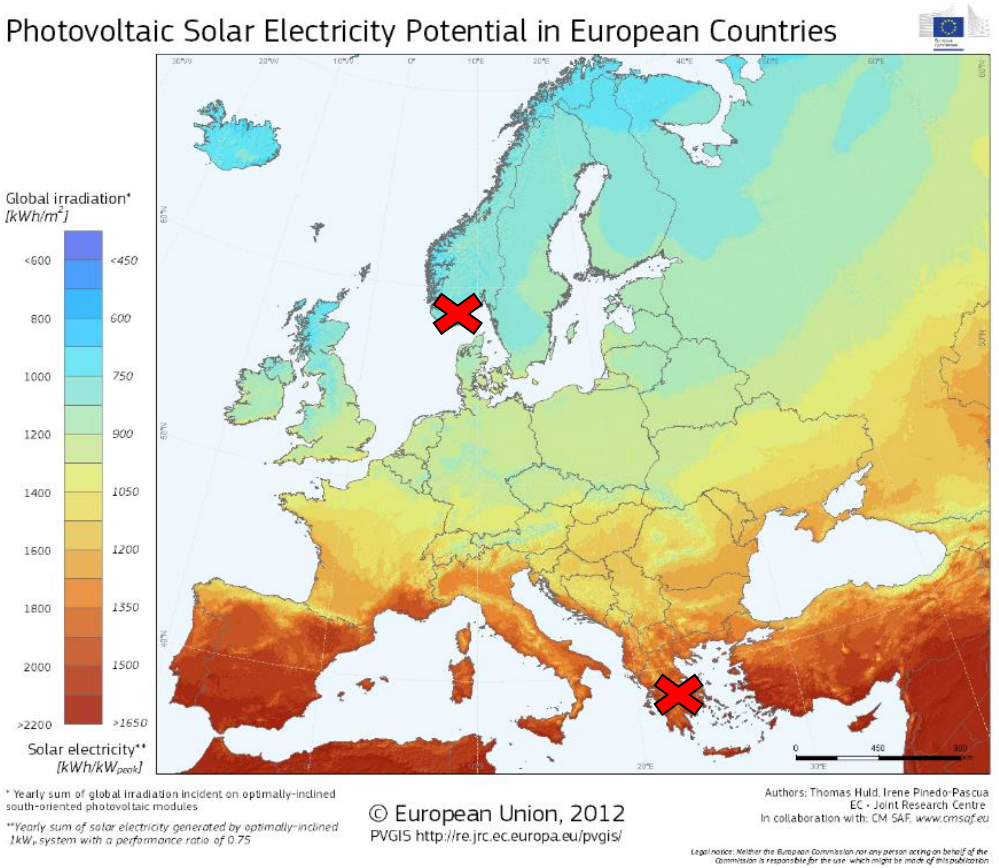
CARBON INTENSITY (CI) OF SOLAR PV ELECTRICITY

a. **CI intensity of a PV system** [$kgCO_2$-eq/kW_p] is fixed

Data:
PV-GIS
JRC-EC

a. **CI intensity of solar electricity** [gCO_2-eq/kWh] depends on **lifetime energy yield E_{lf}**:
   - siting (factor of ~2 between Athens & Oslo)
   - orientation
   - <u>lifetime and long-term performance</u>

$$CI_{PV\_el}\left[\frac{gCo2eq}{kWh}\right] = \frac{CI_{Syst}\left[\frac{gCo2eq}{kWp}\right]}{EY_{lf}(site,\ or,\ PLR)\left[\frac{kWh}{kWp}\right]}$$



Joule

Virtuani et al. Joule 2023 + EUPVSEC-2023

CellPress

Article

The carbon intensity of integrated photovoltaics

Alessandro Virtuani,[1,2,3,4,*] Alejandro Borja Block,[3] Nicolas Wyrsch,[3] and Christophe Ballif[1,3]

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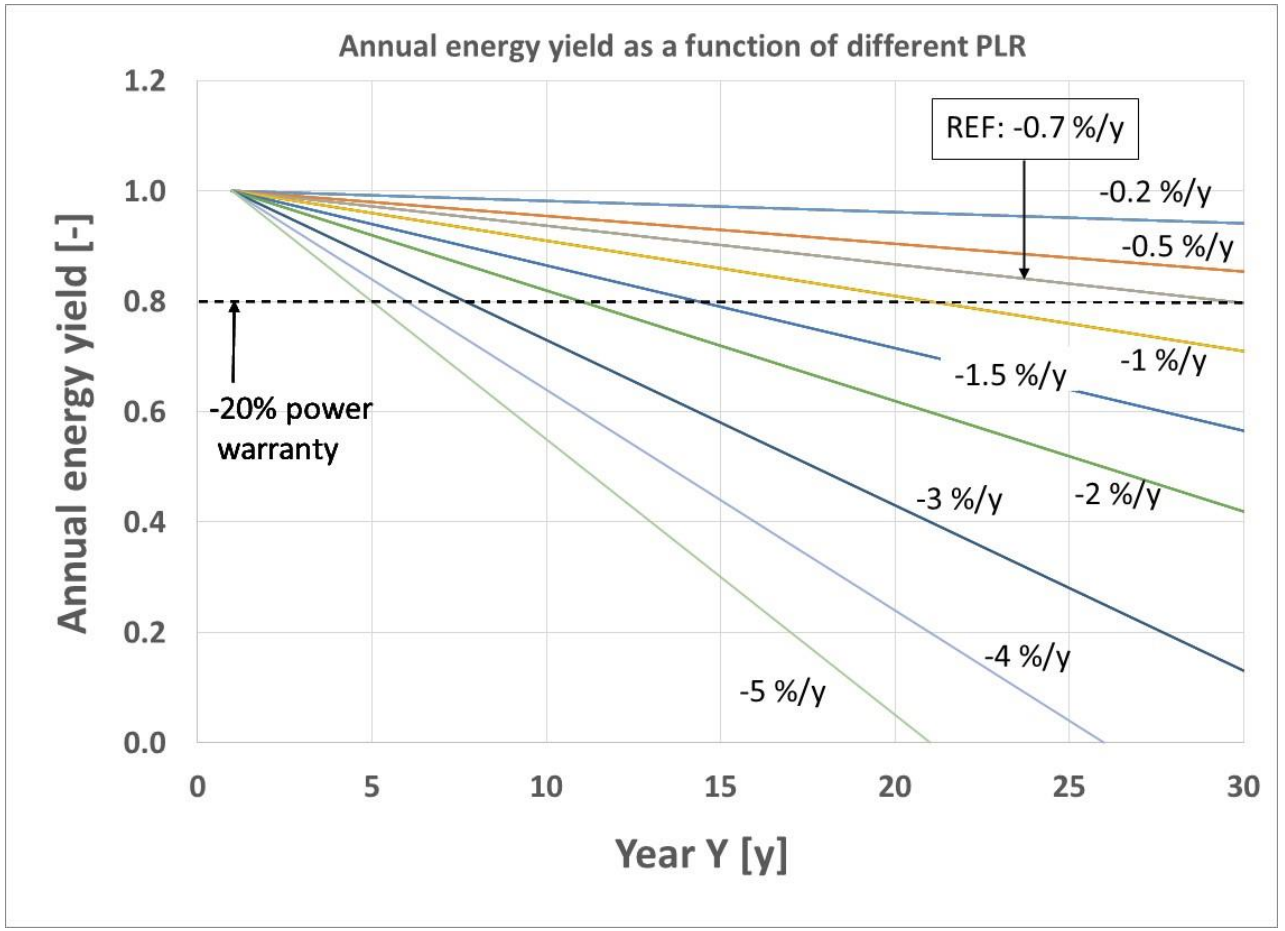
ANNUAL ENERGY YIELD VS PLR (PERFORMANCE LOSS RATES)



Non-linear degradation trends, see:

Jordan et. Al
PIP 2016
Virtuani et al.
Solar RRL 2022

Assumptions: linear degradation rates.

REF scenario: 30 yrs lifetime, PLR 0.7%/y (0.5% generally used in business plans)

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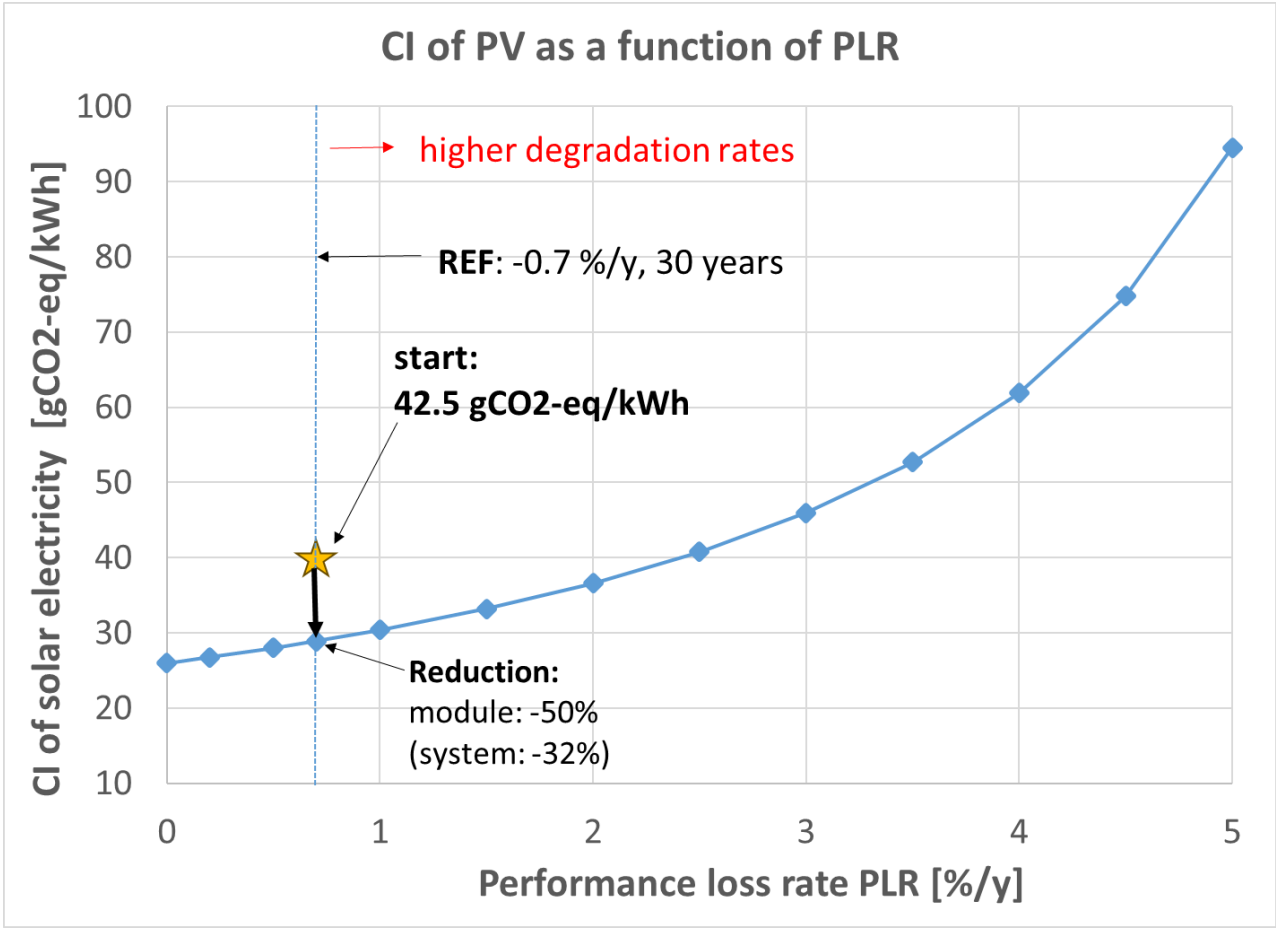
CI OF SOLAR ELECTRICITY VS PLR (1)

CI *PV-2022*:
42.5 gCO2eq/kWh
(rooftop PV
in Central Europe)

Source:
IEA-PVPS Factsheet (2021)



REF: 30 years lifetime, PLR 0.7 %/y
Model: 50% reduction of GHG in module manufacturing (>> -32% of system GHG).
>> CI of solar electricity vs PLR

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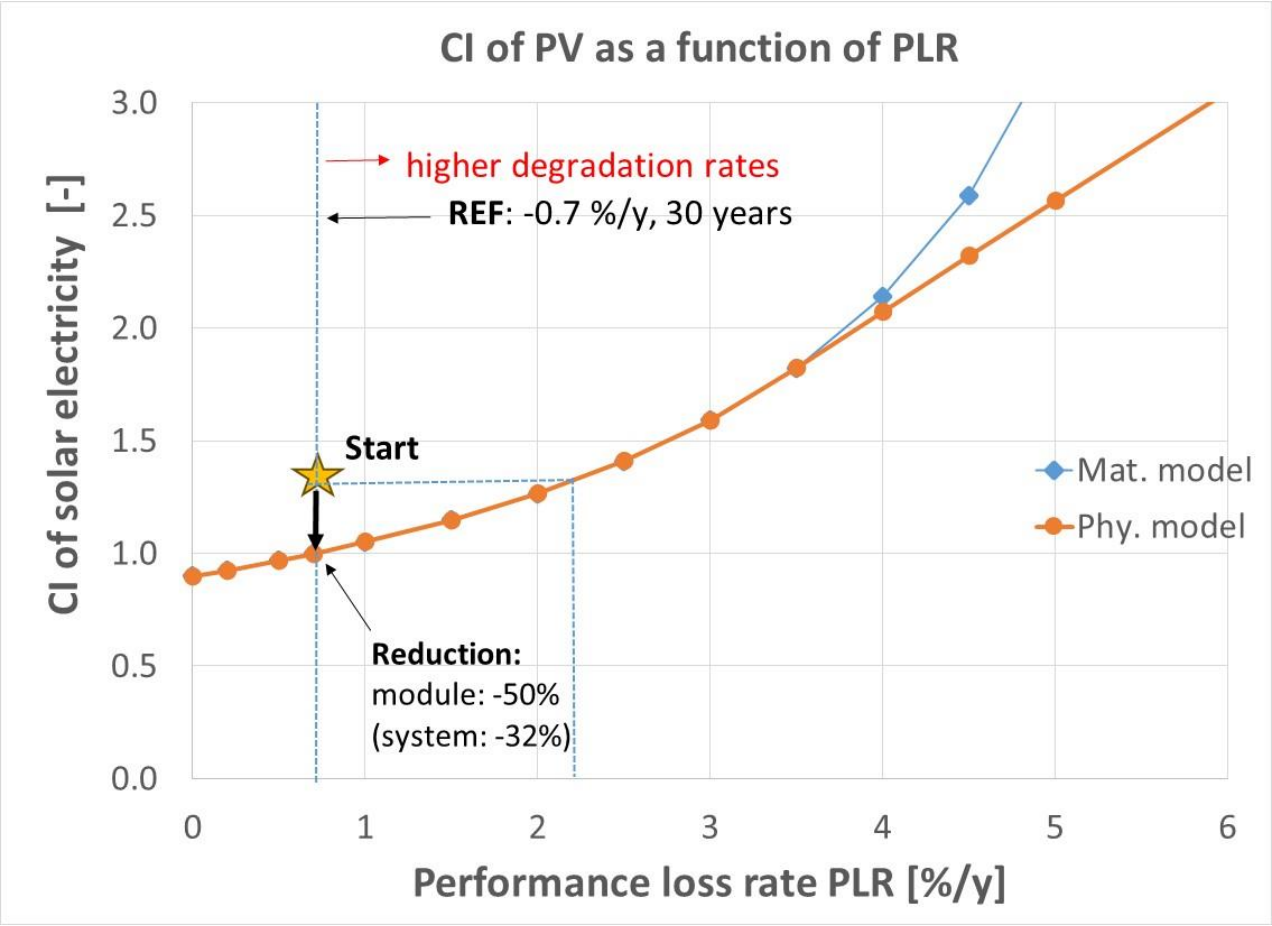
CI OF SOLAR ELECTRICITY VS PLR (3)

CI *PV-2022*:
42.5 gCO2eq/kWh
(rooftop PV
in Central Europe)

Source:
IEA-PVPS Factsheet (2021)



Normalized values

Increasing PLR may erode (and highly penalize) CI reduction efforts

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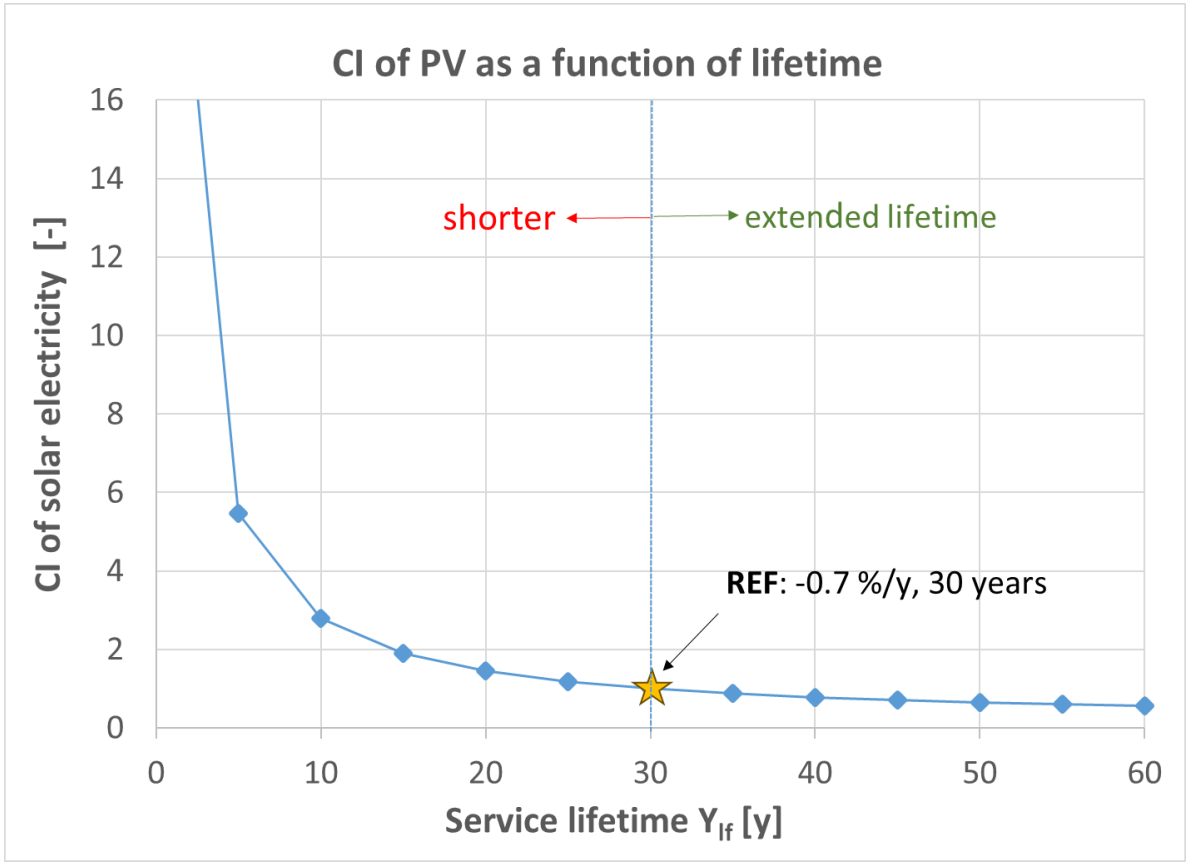
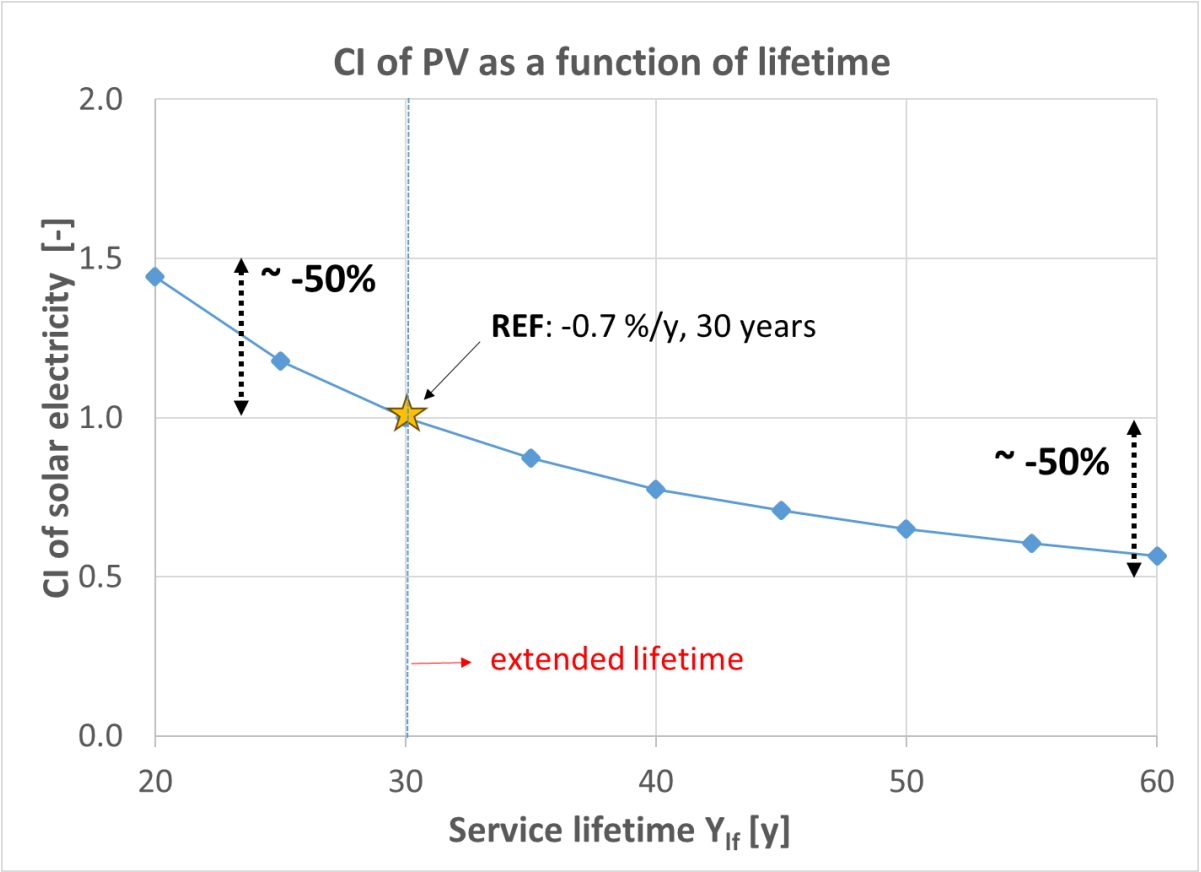
EXTENDING LIFETIME



Lifetime directly impacts energy yield

>> hyperbolic behaviour of CI of solar electricity vs energy yield.

EXTENDING LIFETIME (2)



Extending lifetime from 20 to 30 years reduces CI of solar electricity by ~50%.

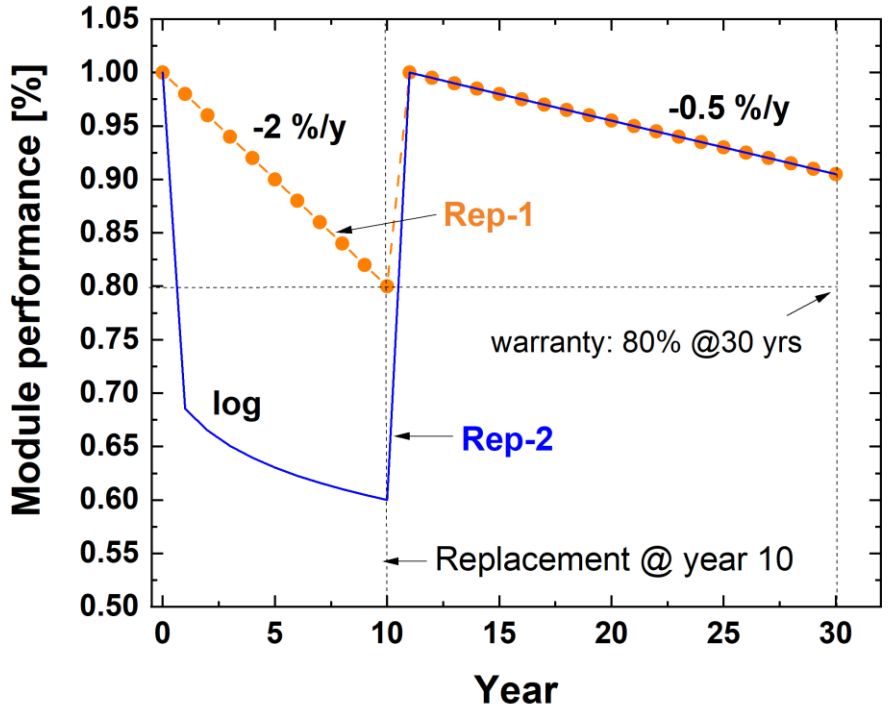
An additional 50% reduction will take ~30 years (30 to 60 years lifetime).

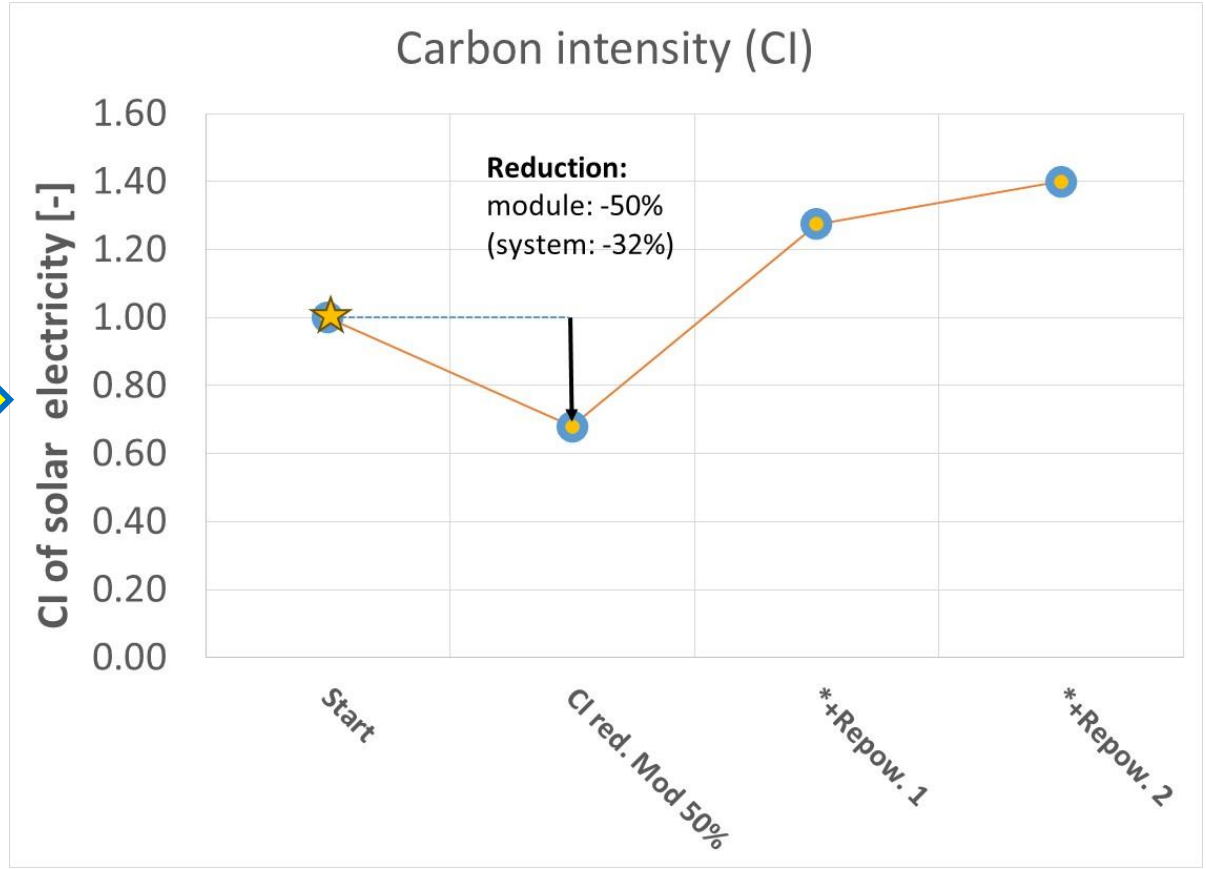
To keep in mind when planning what comes next at the **end of feed-in-tariffs (FiT) era** (20 years).

EFFECT OF REPOWERING SCENARIOS ON THE CI OF SOLAR PV ELECTRICITY

2 accelerated degrad. scenarios (mild/severe) followed by module repowering @ year 10:

>> add to model CI of new set of modules





CONCLUSIONS

Key take-away message:

we should not reduce the CI of modules (other components or full systems) at the expense of reliability and long-term performance.

Focus should be on:

1. *risk-neutral* technological progress.

2. not on design solutions that endanger reliability and durability.
   (BOM & design changes need to be carefully assessed)

Extending lifetime of **PV plants in FiT regime** (20 to 30 years) – if still working well - might be meaningful from a C footprint perspective.

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ON THE TOPIC FROM OUR GROUP….

TUE
4BO.6.2 **30+ Years of Operation** – A Comprehensive Review of the Long-Term Performance of the Mont-Soleil PV System and its Peers
Hugo Quest et al.

WED (this session)
CO.6.2 Maximizing Solar Sustainability: Analysis of the Leverages for Low-carbon Impact PV Manufacturing and Electricity Generation
Alexis Barrou et al.
(this session)

THU
5DV.2.28 Are **Bio-Based Materials Suitable for PV**?
Lison Marthey et al.

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Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

www.seamlesspv.eu

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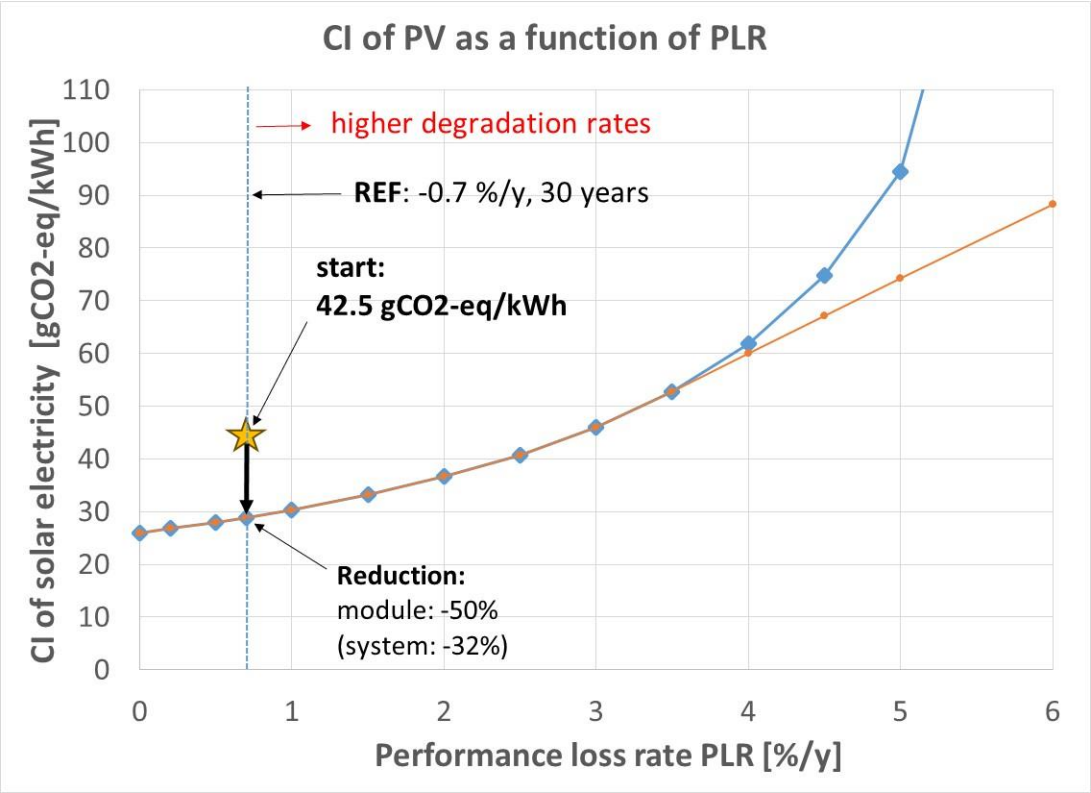
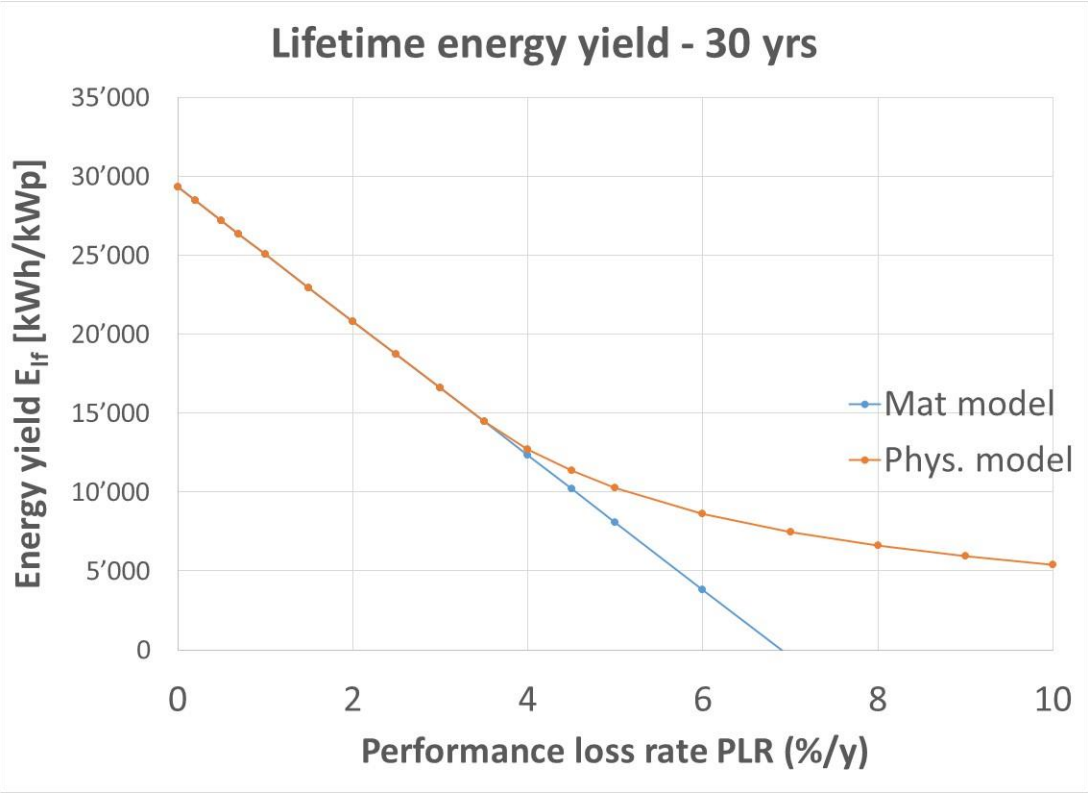
CI OF SOLAR ELECTRICITY VS PLR (2)





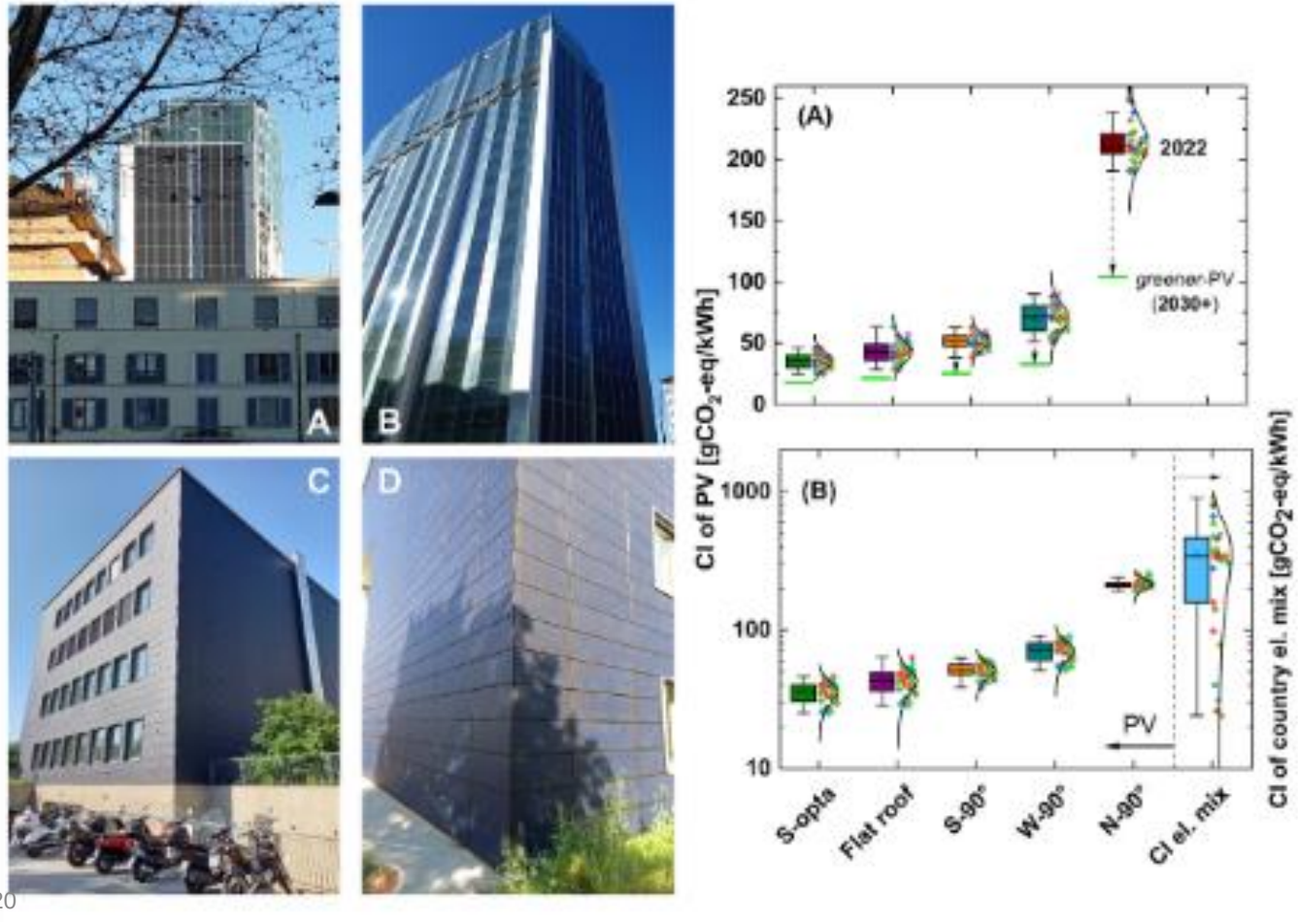
For PLR > 4 %/y, a correction is needed to the model, reflecting the fact that the energy yield cannot be negative (<0).

Joule

CellPress

Virtuani et al. JOULE 2023
+ EUPVSEC 2023

The carbon intensity of integrated photovoltaics



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Highlights

Deployment of solar PVs should primarily occur in buildings and infrastructures

The C footprint of PV facades is lower than electricity mixes for most EU countries

Most of the time, this is true for north-facing PV facades too

PV in facades clearly supports a transition toward a C-neutral electricity mix

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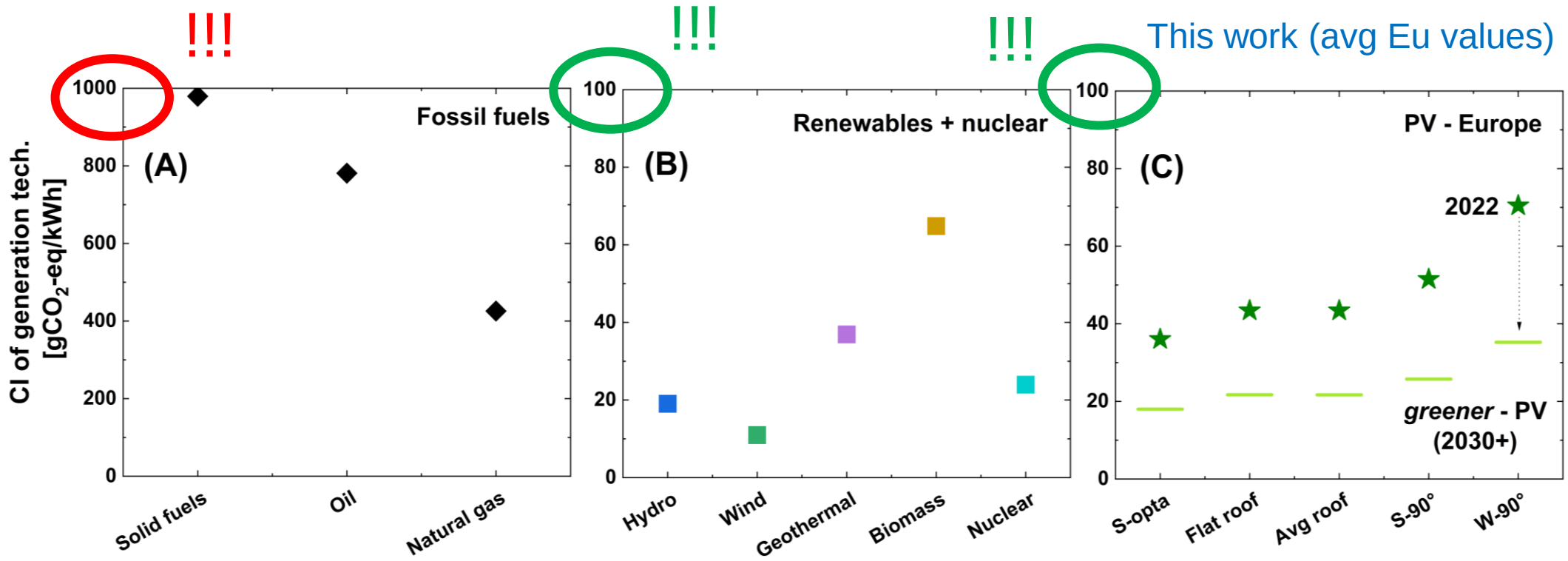
HOW DOES PV COMPARE TO OTHER GENERATION TECHNOLOGIES?



- Fossil & other renewables
- PV: this work (mean European value)
- Both case: large varaibility

Virtuani et al. JOULE 2023

FACING THE CHALLENGES OF OUR TIME