INTEGRATED-PV IN BUILDINGS & INFRASTRUCTURES:

.

A CARBON FOOTPRINT PERSPECTIVE

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TABLE OF CONTENTS

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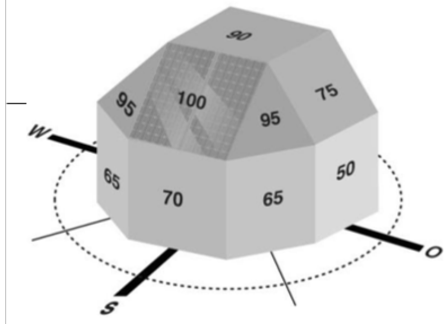

?!?

Do North-facing BIPV facades in Europe make sense?

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MOTIVATION

1. 5 to 10 TW_p of PV to be installed in Europe by 2050 to meet climate targets
2. **Conflicts** of PV with other land uses (agriculture, forestry, etc.) are frequently reported
3. Installation in the **built environment** (***buildings/infrastructures***) to be favoured
4. Previous studies: PV-rooftop potential in EU of ~1 TWp (>2 kWp/p)

   >> **potential of other surfaces** (including non-optimally oriented ones)?

5. **Why PV in facades (90°-tilt) or other sub-optimal orientations?**

   - **S-facing façade**: more stable production throughout the year, maximize production in winter & minimize effects of curtailements in summer

   - **E/W-facing façades**: PV generation peak shaving/shifting

   - the availability of optimal-oriented surfaces may be limited (shading!)

OUTLOOK

a. We are not taking an economical perspective

See e.g. *Gholami & Rostvik, Energy 2020* (in some countries N-facing facades may be "profitable" on a 20-30 yrs horizon;

b. Focus on the **carbon intensity (CI) of PV** (gCO2/kWh) deployed at different orientations/locations;

b. Comparison to the **CI of electricity consumption** in all European countries:

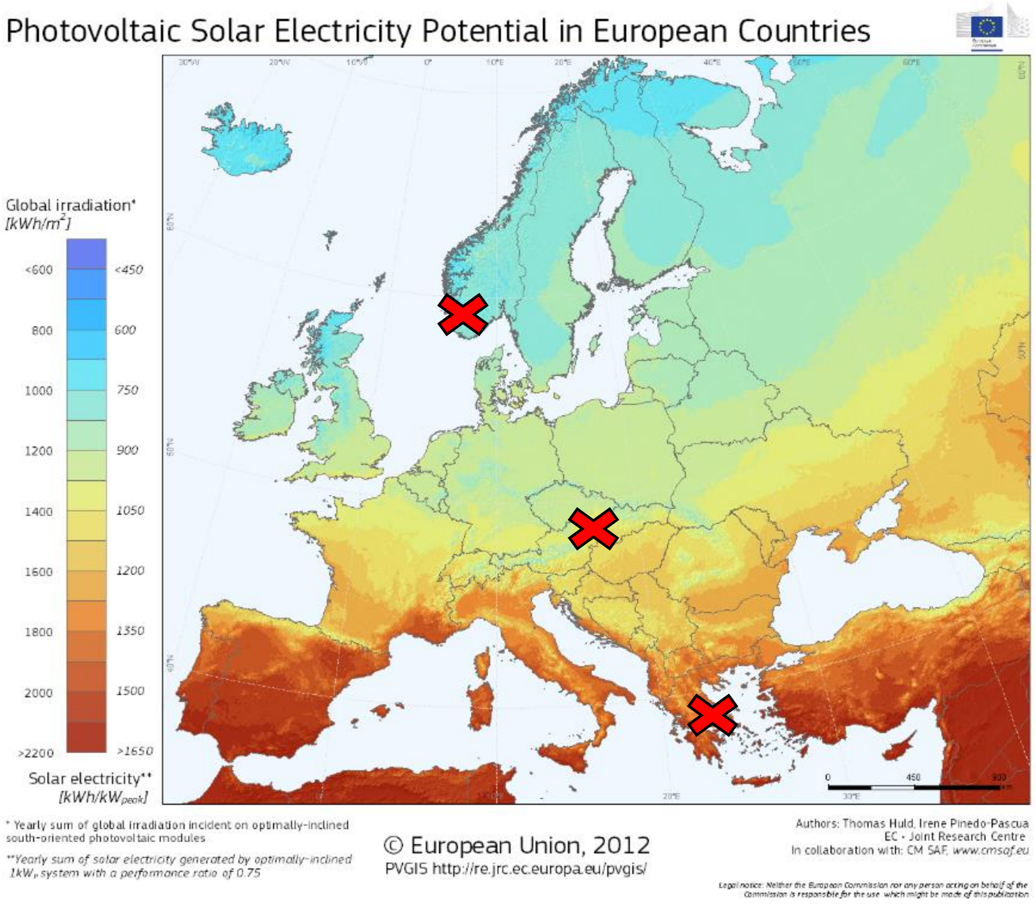
>>asses if **PV is acting as a net *CO_2 sink* or *source*** (compared to local el. mix);

CARBON INTENSITY (CI) OF SOLAR PV

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/modules

d. **CI intensity of a PV system** [kgCO_2-eq/kW_p] is fixed
e. **CI intensity of solar electricity** [gCO_2-eq/kWh] largely depends on siting and orientation

(factor of ~2 between Athens & Oslo)



Data:
PV-GIS JRC-EC

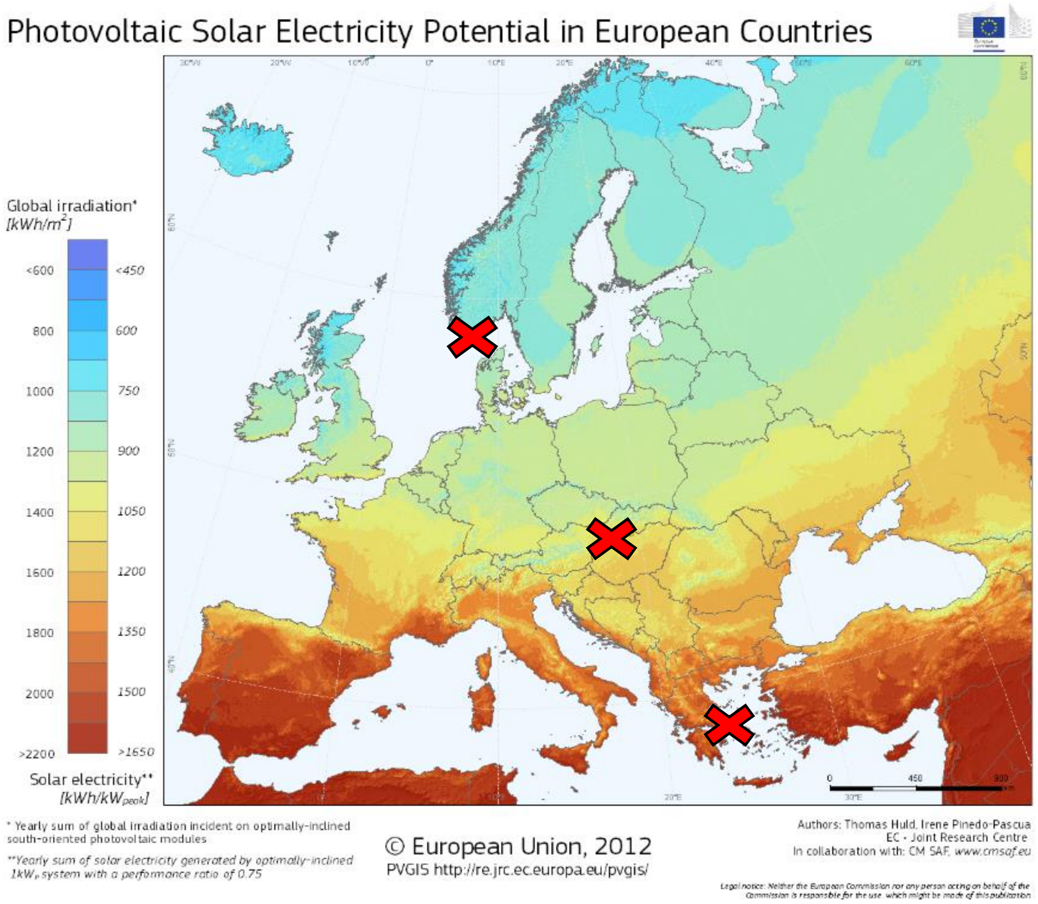
ENERGY YIELD [KWH/KW$_P$] / INSOLATION [KWH/M^2*Y] FOR DIFFERENT ORIENTATIONS/LOCATIONS IN EU

Orientation/tilt

For a given location, the energy yield of a PV systems corresponds:

- **S-facing facade**: ~72% of S-opta
- **E/W-facing facades** ~50% of S-opta
- **N-facing façades**: ~16% of S-opta

S-opta = S-facing at optimal tilt (opta)



Data:
PV-GIS JRC-EC

WHAT IS THE CARBON INTENSITY (CI) OF PV?

- Published figures are often **old/outdated**;
- Majority of **PV module production in China** (high CI of electricity generation -*not consumption*- mix ~1000 gCO_2/kWh in 2019, 65% of electricity comes from coal)
- Few recent works (2021-2022):

  - R. Frischknecht: IEA-PVPS 2022 factsheet

  - V. Fthenakis, *Progress in Photovoltaics* 2021 (lower CI numbers)

  - et al.

- IEA-PVPS 2022 factsheet : **PV 42.5 gCO_2/kWh.**

  Assumptions: **3 kWp rooftop PV**, 975 kWh/kW_p (83% of optimal tilt in Bern, CH 46°N), lifetime 30 yrs, degradation rate -0.7%/y

- In this work:

CI of PV corrected for energy yield (site/orientation) (lifetime 30 yrs, -0.7%/y)

CARBON INTENSITY (CI) OF COUNTRY ELECTRICITY MIXES?

PV electricity in urban environments is generated close to the final user and is mostly injected in low voltage (LV) grids.

To allow a more fair comparison, we use **CI (gCO_2eq/kWh) of electricity consumed** at LV grid with upstream compensation (Well-to Wheel approach **W2W**).

Corrected for:

- electricity imports/exports between countries;
- transmission and distribution losses;
- upstream emissions caused by the extraction, refining and transport of the fuels to the power plants

Source: *Scarlet et al. Applied Energy 305 (2022)*

See as well: *Tranberg et al., En. Strategy Review 2019 & Gholami et al. Energy, 2020*

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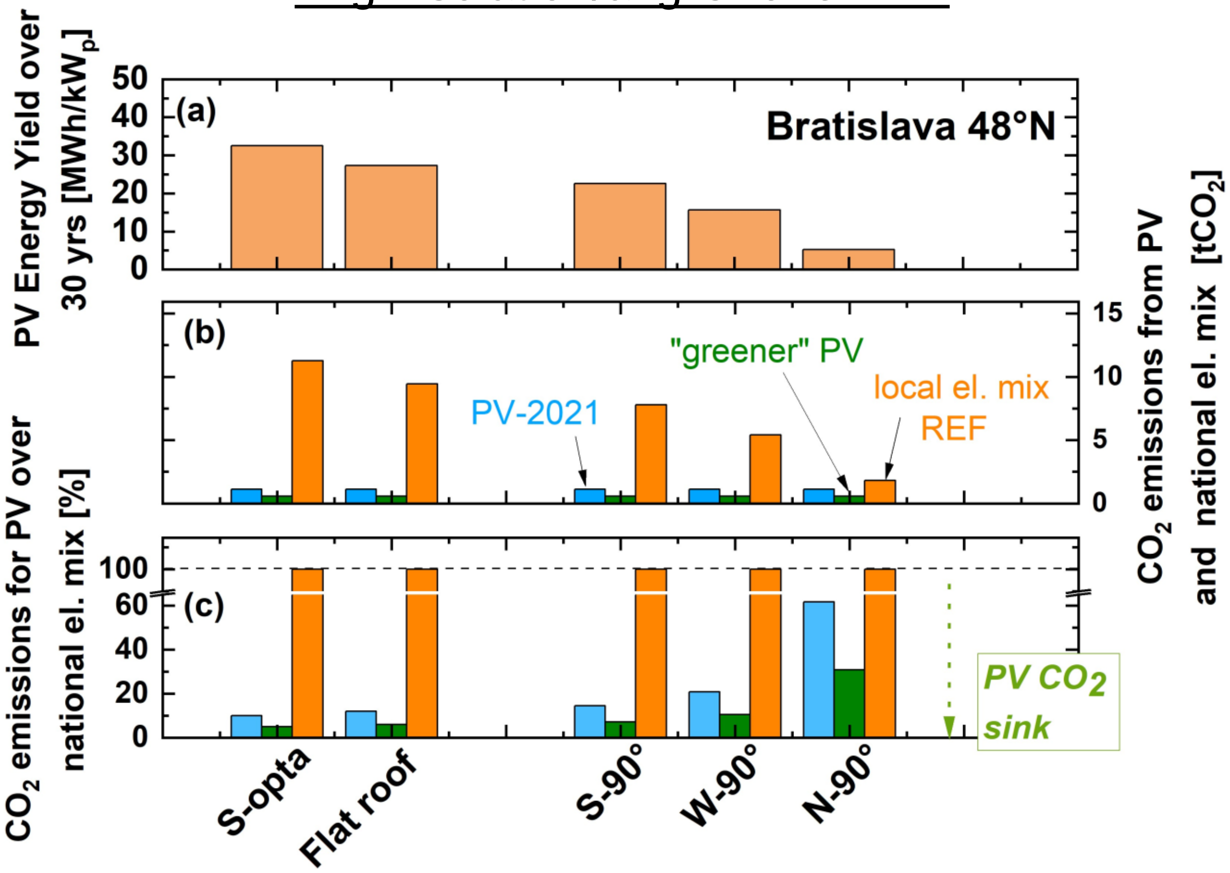
CI OF PV (OVER 30 YRS) VS CI OF COUNTRY CONSUMPTION ELECTRICITY MIX (1)

CI el. mix (SK): 346 gCO2eq/kWh (EU avg is 375 gCO2eq/kWh)

Avg insolation/avg CI of el.mix

CI *PV-2022*:
42.5 gCO2eq/kWh



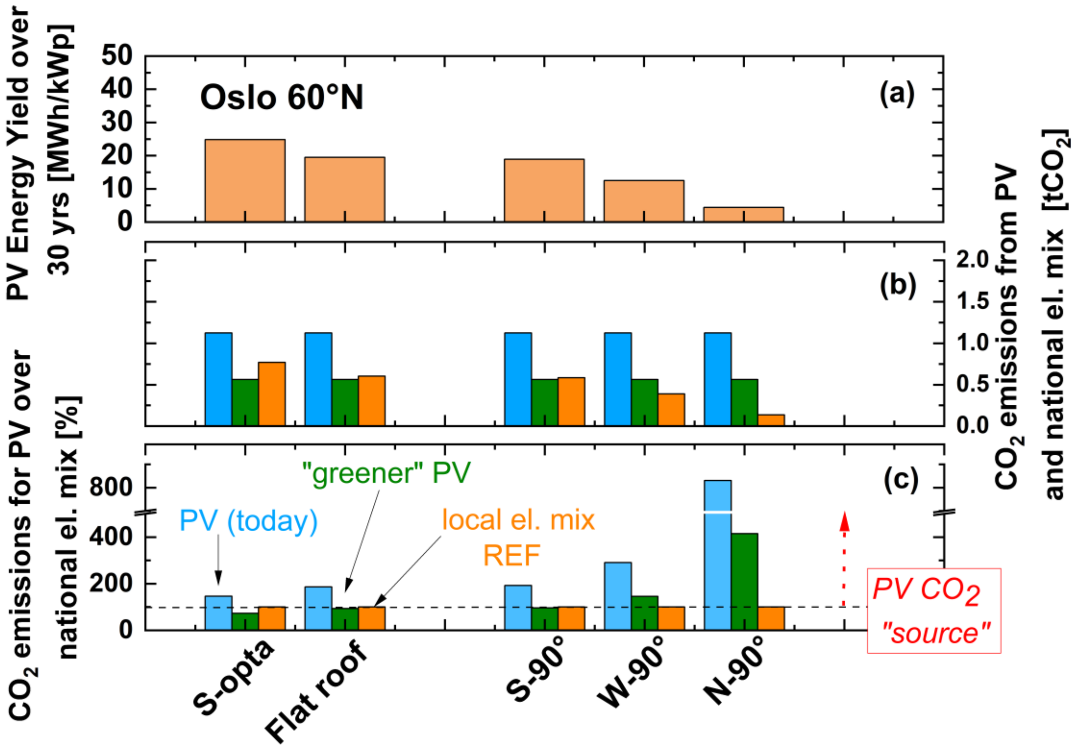
CI «greener PV» (2030-3035):
21.2 gCO2eq/kWh

Technological progress + production in countries with lower CI of el. mix (Europe?)

CO_2 emissions of PV vs local electricity mix:
S- facing facade: 18% , W/E- facing: 23%, N-facing: 71%
>> PV is acting as a net CO_2 sink even in N-facing facades!

CI OF PV VS CI OF COUNTRY ELECTRICITY MIX (2)

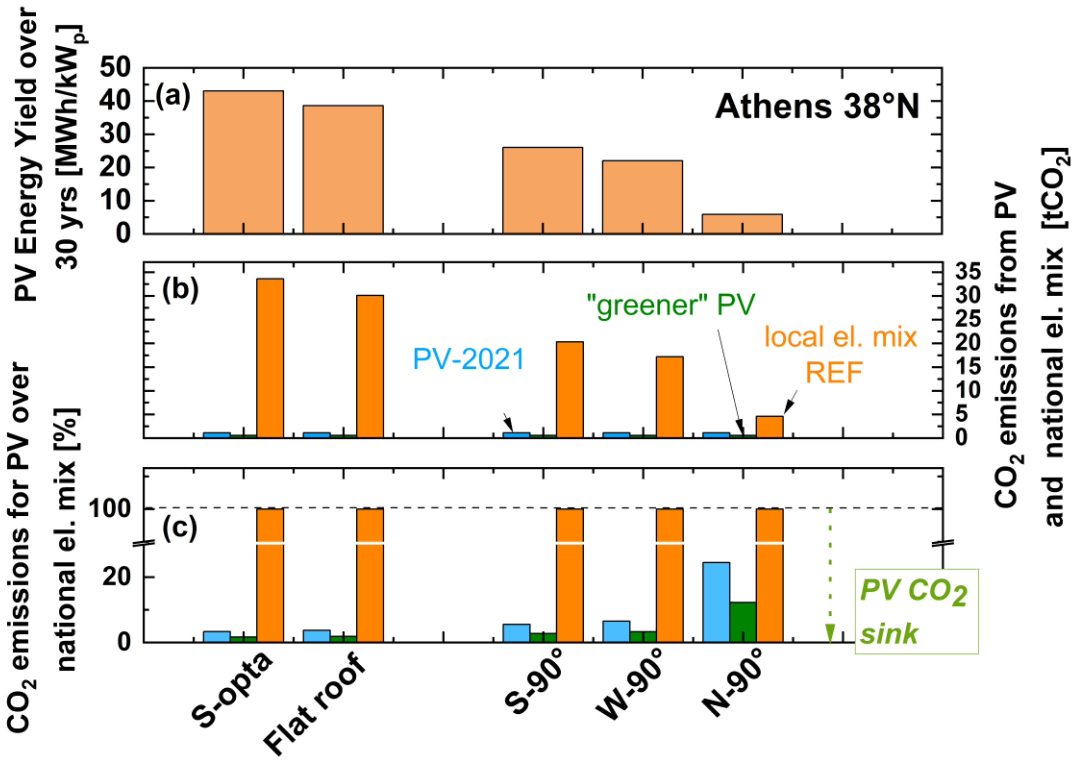
CI el. mix (NO): 31 gCO2eq/kWh
<u>low insolation / low CI-el. mix</u>



NO: today PV, not at the first place!

NO: with «greener»-PV, possibly «somewhere».

CI el. mix (NO): 780 gCO2eq/kWh
<u>High insolation /high CI-el- mix</u>



GR: today PV makes sense everywhere!

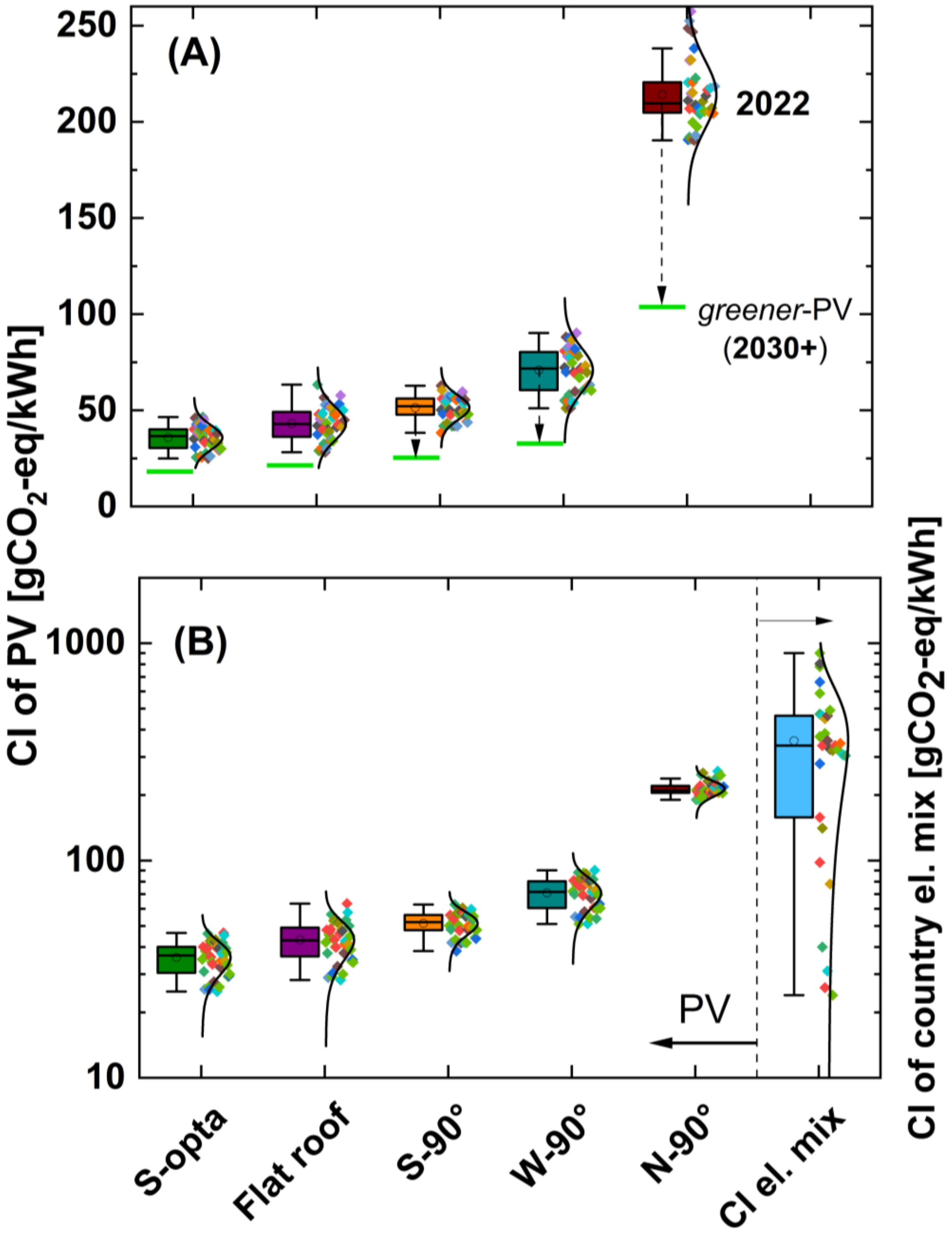
CI OF PV VS CI OF COUNTRY ELECTRICITY MIXES (3) – ALL EUROPE

- Results for capital cities
- Probability distribution of the CI of PV (all European countries, top &bottom)

    - CI of PV 2022

    - CI of PV 2030+ (*greener PV scenario*)

- Probability distribution of the CI electricity mix (all European countries, bottom)



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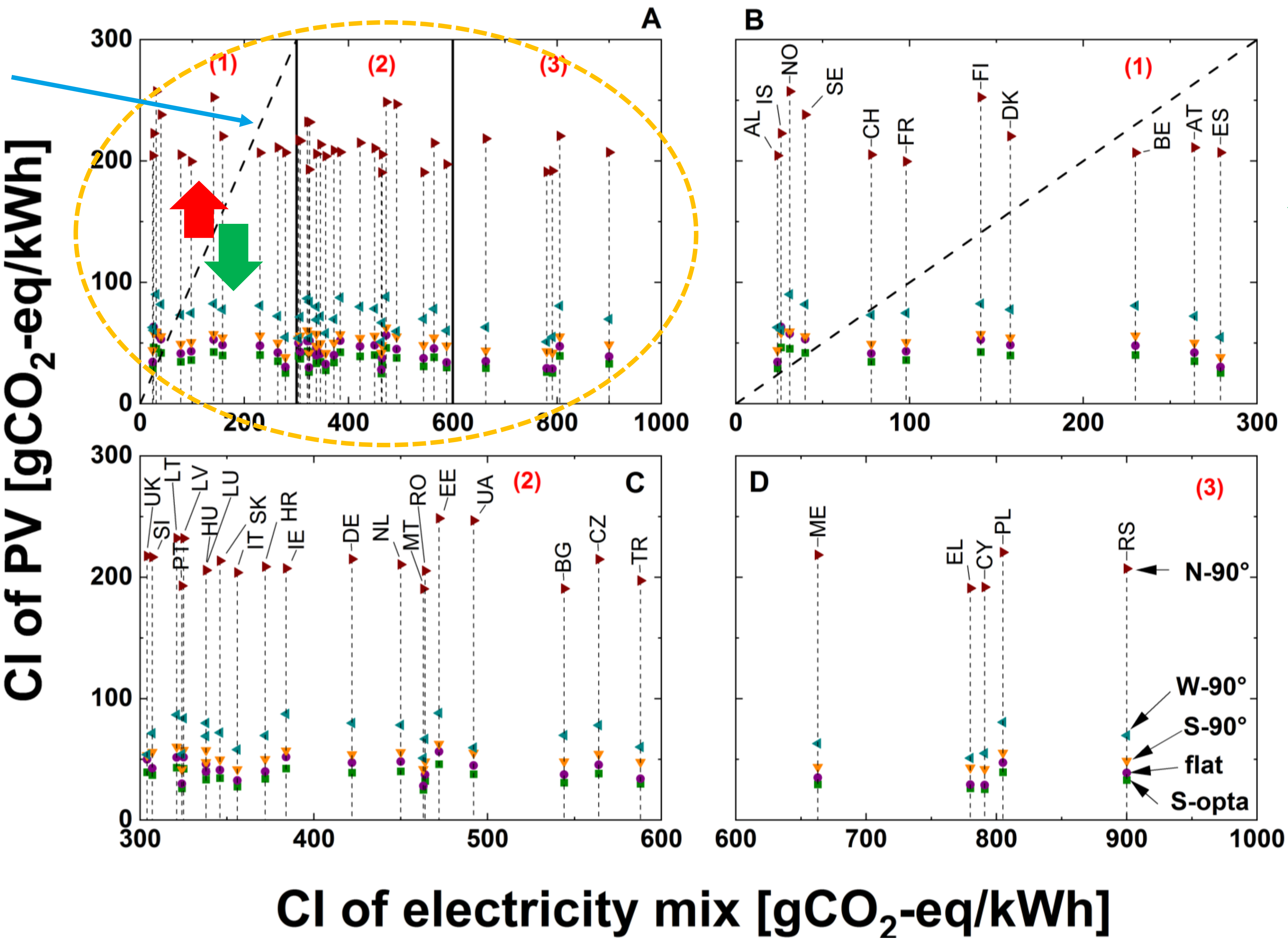
CI OF PV VS CI OF COUNTRY ELECTRICITY MIXES (4)

Y(x) = x



PV C-sink

PV C-source

CAVEATS

1. Both CI of PV and of national electricity mixes are «**moving targets**»

>> **the sooner PV is installed, the greater the value (decarbonization potential)**!!!

2. We do not differentitate between BAPV (building-added) vs BIPV (building-integrated)

3. We do not offset the CO_2 footprint of BIPV/I-PV modules when they are replacing other construction elements;

4. We do not take into account lower pv generation due to:

- Full integration (BIPV), i.e. higher operating temperatures
- Use of Colored-PV or more-transparent PV (lower efficiency)

CONCLUSIONS

1. PV in urban/built environments - even at sub-optimal orientations – is a key-enabling decarbonization technology

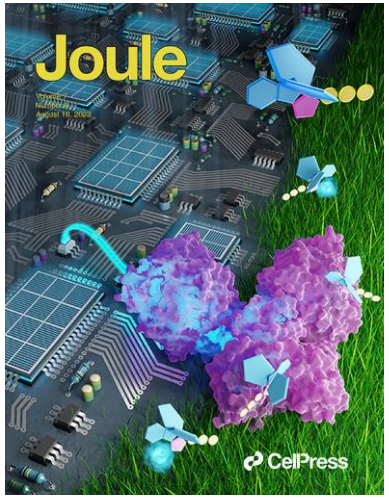
2. Carbon intensity considerations tell us that today PV is justifible in most European countries and for most orientations (including – in several cases – N-facing facades);

3. In a «greener-PV» scenario (42.5 >> 21.2 gCO2eq/kWh) this threshold is further reduced;

4. CI of PV vs CI of local elect. mix may serve as a first (but not unique) discriminant to incentivize PV in buildings/infrastructures (e.g. countries phasing out **nuclear power)**

5. Recommendations for adopting favourable building codes for PV in buildings/infrastructures.

JOULE 2023 (accepted for pub.)
Virtuani et al., Solar Everywhere - the Carbon Intensity of PV



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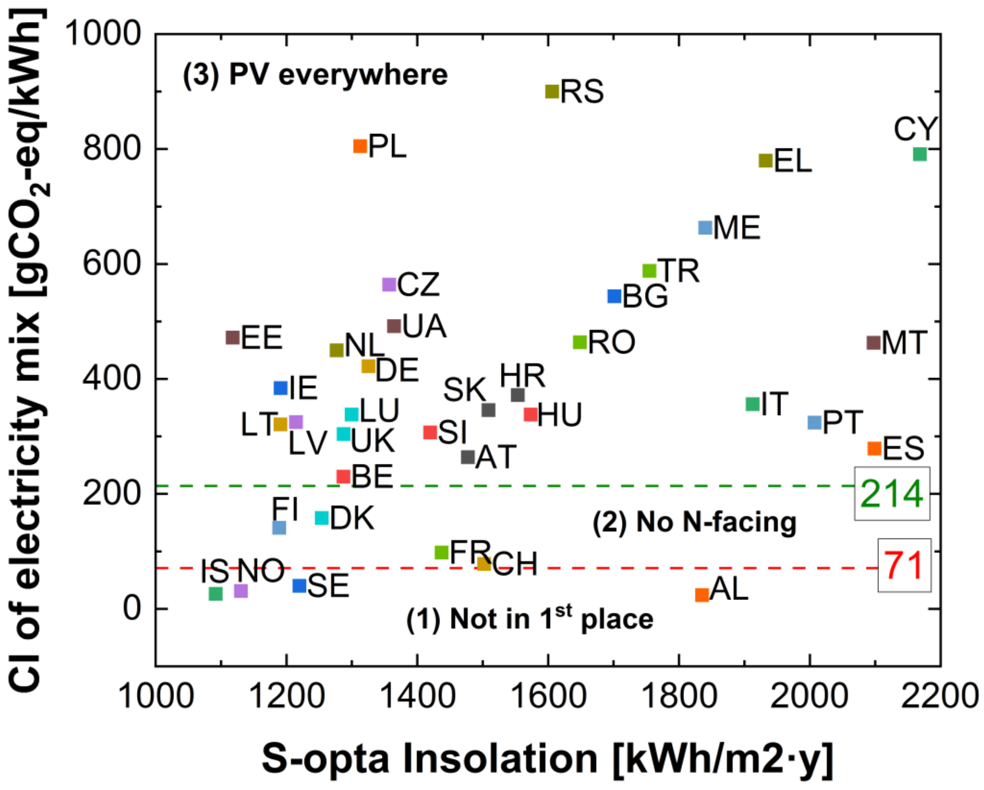
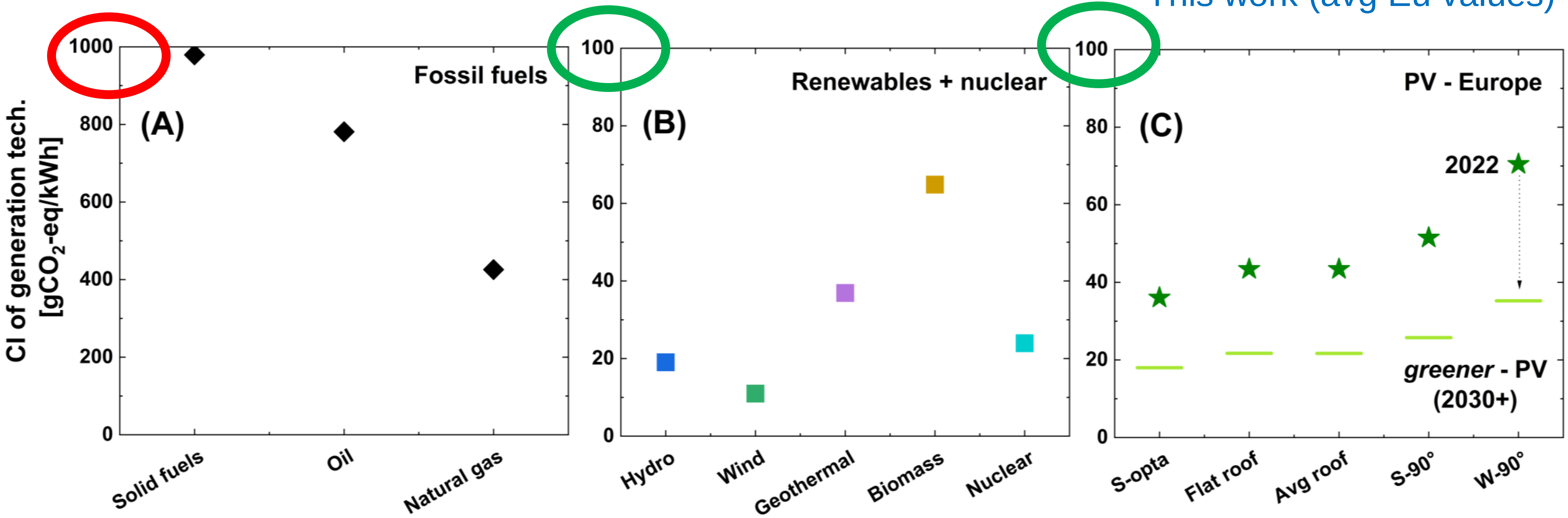
WHERE DOES PV GO FIRST?



CI of national electriciy mix vs S-opta Insolation (capital city)

HOW DOES PV COMPARE TO OTHER GENERATION TECHNOLOGIES?

This work (avg Eu values)



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

Source: *Scarlet et al. Applied Energy 305 (2022),* NREL factsheet Report 2021

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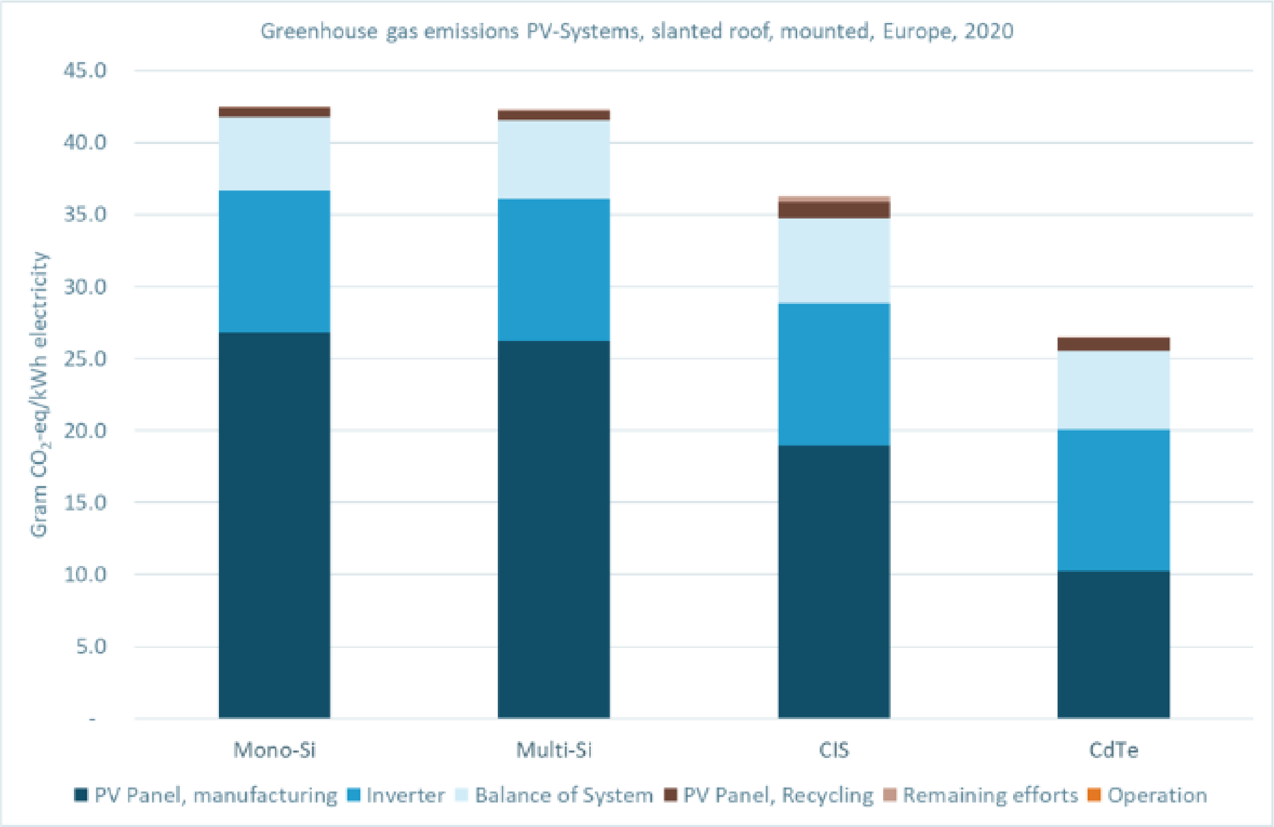
CI OF PV: BREAKDOWN OF SYSTEM CONTRIBUTIONS



IEA-PVPS Factsheet (2021)

AGAINST …MINIMAL PV REQUIREMENTS (AS THEY ARE SET)

Source: Thomas Södestrom (csem)

Legislations demanding minimal PV requirements lead sometimes to the **«absurd» situations** where only 10 m^2 of PV is installed on single family houses, when 100+ m^2 (of well oriented PV) could be installed.

The situation of such roofs will likely be locked-up for the next 30 years.

E.g. new residential project in Switzerland

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FACING THE CHALLENGES OF OUR TIME