DO NORTH-FACING BIPV FACADES IN EUROPE MAKE SENSE?

Alessandro Virtuani[1,2], Andrew Fairbrother[1], Fabiana Lisco[1], Laure-Emmanuelle Perret Aebi[1],
Nicolas Wyrsch1, and Christophe Ballif[1,3]
1 – École Polytechnique Fédérale de Lausanne (EPFL), Institute of Electrical and Micro Engineering (IEM),
Photovoltaics and Thin-Film Electronics Laboratory (PV-Lab), Rue de la Maladière 71b, 2002 Neuchâtel (Switzerland)
2 – Officina del Sole (O'Sole) srl, 20100 Milan (Italy)
3 – CSEM PV-Center, Rue de Jaquet-Droz 1, 2002 Neuchâtel (Switzerland)
Email: alessandro.virtuani@epfl.ch

ABSTRACT: In order to minimize unnecessary land exploitation and to allow PV to play a major role in the decarbonization of Europe, a massive deployment of PV in Europe should occur through the **integration of PV in buildings and infrastructures**, including the integration of PV on surfaces with a sub-optimal orientation. To assess the meaningfulness of installing PV on surfaces with sub-optimal orientations, we consider firstly the **carbon intensity balances** for PV. We show that for several cities (Milan, Frankfurt, La Valletta, …), it becomes obvious that a carbon intensity balance is largely in favor of PV not only for the optimal orientations, but also for less favorable ones: i.e. all the facades, including north-facing ones. For other cities/countries with a very low carbon footprint for the local electricity mixes (e.g. Oslo), the installation of PV may in principle not always be justifiable exclusively from a carbon balance point of view. We should however point out that in countries massively relying on **nuclear power** for their electricity supply – or planning nuclear phase-outs - other elements should be considered simultaneously. We also highlight the fact that installations in surfaces with **less optimal orientations** (e.g. north-facing facades) should possibly not be incentivized in the first place, but not expressly "prohibited" (or abandoned), as we have demonstrated that, in several countries, they are fully justifiable from the point of view of a carbon footprint balance. In addition, this may still help in promoting and creating ***"PV-awareness"*** among citizens and help architects in preserving building harmony/aesthetics.
Keywords: Building Integrated PV (BIPV), Integrated PV (I-PV), Carbon Intensity, Carbon footprint

1 INTRODUCTION

The European Commission is setting very ambitious targets for a net decarbonization of the European economy by 2050, requiring a massive electrification of the mobility and heating sectors, coupled with a major shift towards renewable energies sources, among which solar photovoltaic (PV) electricity is deemed to play a key role. By this horizon European member states may have to install from 5 to 10 GW of PV power around the Old Continent. In some countries with limited availability of land (the Netherland, Malta, Switzerland, etc.) the full deployment of PV on land may conflict with other land uses, such as agriculture, forestry, etc. Also in larger countries (e.g. Italy) the deployment of large PV parks on agricultural land is nowadays sometimes reportedly facing resistances from the local administration because of land use conflicts.

For these reasons, the adoption of PV projects leading to a double land/space use (e.g. so-called agri-PV or floating-PV) is highly welcomed.

Nevertheless, a massive deployment of PV in Europe should primarily occur through the **integration of PV in urbanized settings and into the built environment**. Including residential buildings, commercial and industrial buildings/warehouses, and more in general all the available **infrastructures**. The latter may include: noise barriers along roads and railways, car-ports, water treatment plants, bus and train stations, and many others.

In this work, we are not focusing exclusively on North-facing facades, but more in general on surfaces with sub-optimal orientations (see Fig.1), of which the former constitutes a sort of *extreme case*. To do this, we first asses the generating potential (insolation and PV energy yield) of non-optimally exposed surfaces in buildings (and elsewhere) for different European cities distributed at different latitudes (from 35° to 60°N).

To assess the meaningfulness of installing PV in surfaces with sub-optimal orientations, we do not take an economical perspective, a topic recently reviewed by other authors [1], but that of a **carbon intensity balance**. To do this, we try to assess in the first place whether – on a time horizon of 30 years – installing PV at different orientations acts as a net CO_2 sink or source, when compared to the same amount of electricity that would be generated with local electricity mixes.

Fig. 1: South- (left) and north- (right) facing BIPV (Building-Integrated PV) facades of the same building in Milan (Italy). The building has undergone a major renovation process in the years 2019 and 2020.

Thus, for the same cities, by using as a starting point updated (2021) figures for the carbon intensity (CI) of PV, we first correct these values to reflect the different generation potential of surfaces with different exposures and placed at different latitudes, coming out with some CI thresholds that would fully justify the deployment of PV. We then compare these numbers with CI values of the local (country) electricity mixes (focusing on country's electricity *consumption* rather than generation figures), finding out that for several cities/countries in Europe installing PV on north-facing facades (or other sub-optimal orientations) is fully justifiable.

2 APPROACH and METHOD

2.1 Insolation and PV energy yield of surfaces with different exposures

Insolation (H, [kWh/m^{2}y]) and energy yield (EY, [kWh/kWp]) data for PV as a function of different orientations are obtained by JRC's (Joint Research Center – European Commission) free application tool PV-GIS, which uses satellite-derived data to estimate the availability of solar resources [2]. H and EY for South-facing facades at optimal tilt (opta) are shown in Table I for four European cities: La Valletta (Malta, MT, 35°N), Milan (Italy, IT, 45°N), Frankfurt (Germany, DE, 50°N) and Oslo (Norway, NO, 60°N). This is the orientation which maximizes the annual energy yield of a PV plant.

For three different locations (Malta, Milan, Oslo), Figure 2 shows the ratio of H and EY for different orientations, normalized over the same parameters calculated for an optimal orientation (S-opta, i.e. South-facing at optimal tilt). These include values for a flat roof, for an average rooftop PV installation (*Avg roof*), and for installation facing the different cardinal points at 45° and 90° (facades) tilt, respectively. *Avg roof* values represent an average value for PV systems integrated/applied into/onto rooftops applying a constant -17% loss rate, which should account for misalignments with respect to a S-opta orientation.

As opposed to large utility-scale plants, for which it is often possible to have an optimal (or close to optimal) orientation of the PV arrays, this is generally difficult when integrating PV in roofs as the constraints will be set by the physical arrangement of the building roof/skin.

As can be observed in Fig. 2, with respect to an optimal PV energy yield, the potential of facades in Europe varies from **60% to 76%** (Malta and Oslo, respectively) for **S-facing facades**, from **46% to 49%** (*idem*) for facades with a **W and E orientation**, and from **13.1% to 17.6%** (*idem*) for **N-facing facades**. The corresponding values for Milan or Frankfurt lay in between these two extremes. Difference between E/W orientations are generally low and, for a given location, may be due to presence of different horizons or to far-shading.

2.1 Carbon intensity of solar PV electricity

LCA (Life-Cycle Analysis) figures published in literature about the carbon intensity (CI) of PV are often old or outdated, as they do not reflect the large progress made for this technology in recent years all along the value chain. Several technological improvements have in fact allowed to reduce considerably the carbon footprint of crystalline silicon (c-Si) based PV. These include, among several others: the use of thinner wafers, reduced Si losses in ingot wafering thanks to the use of diamond saws, more efficient processes for the manufacturing of mg-Si (metallurgical grade Si) and Si crystallization processes.

Two contributions have appeared in 2021 reporting updated CI figures for PV. One is a contribution from Frischknecht [3] and one from Fthenakis et al. [4]. The numbers reported by Fthenakis (for sites corresponding to three different insolation level) are slightly lower, possibly with an optimal orientation. The ones reported by Frischknecht are relative to a small-scale (3 kWp) residential rooftop PV system (with non-optimal orientation) located in Switzerland. To be a bit more conservative, and since we are focusing on PV installed in buildings rather than utility-scale systems, we have decided to use the numbers presented by Frischknecht in our analysis.

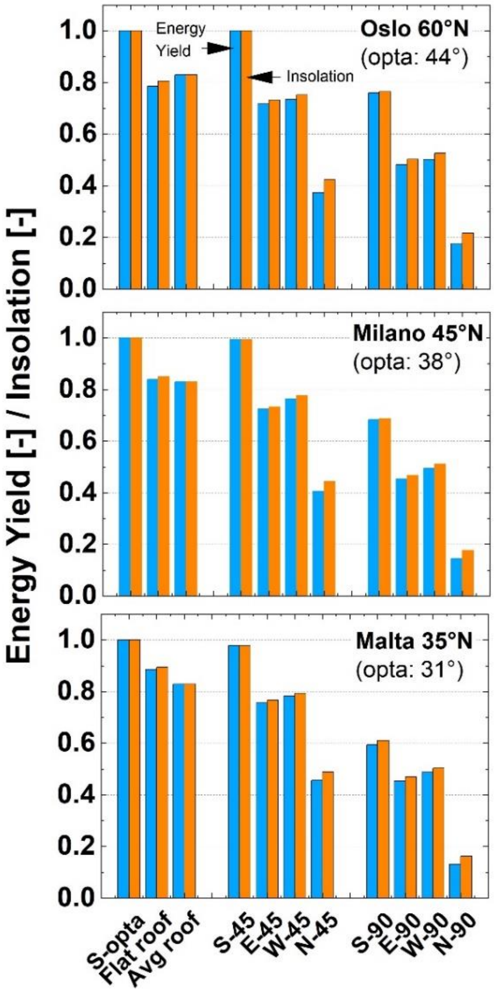

Figure 2. Ratio of the insolation H and energy yield EY for different orientations normalized over the same parameters calculated for an optimal orientation (S-opta) for three cities in Europe. *Avg roof* corresponds to an average value for PV systems integrated/applied into/onto rooftops applying a constant -17% loss rate accounting for misalignments with respect to a S-opta orientation. S-45 and S-90 correspond to a S-facing azimuth with a 45° and 90° tilt, respectively (E=East, W=West, N=North).

The assumptions (for the PV plant and energy yield) used by the author are briefly summarized in Table I (bottom). Under these assumptions, PV has a CI of **42.5 gCO_2/kWh**, assuming a 30-year-long lifetime for the PV plant and an average annual degradation rate of - 0.7%/y.

Since the energy yield (kWh/kWp) of a PV plant over its lifetime is strongly site-dependent and, for a given site, will largely be affected by the plant's orientation, we correct this number for the CI of PV (i.e. 42.5 gCO_2/kWh) to reflect the energy yield of PV plants (over their service lifetime) installed in different locations in Europe and for different orientations (see Table I). This is done by using the same assumptions for the plant service lifetime and annual degradation rates.

Table I. Yearly cumulative insolation of a south-facing surface exposed at an optimal angle (opta), corresponding yearly PV energy yield, and carbon intensity (CI) of the electricity generated by an optimally *oriented* PV system for four cities in Europe.

Location	**Yearly Insolation at opta H_{opta} [kWh/m²y]**	**Yearly PV energy yield at opta EY_{opta} [kWh/kWpy]**	**PV carbon intensity at opta [gCO₂/kWh]**
La Valetta MT 35° N	2’092	1’660	25
Milan, IT45°N	1’687	1’312	31.6
Frankfurt aM., DE 50°N	1’304	1’042	39.8
Oslo, NO 60°N	1’130.5	915.2	45.3

***Starting assumptions for the CI of PV (see [3]): 42.5 gCO_2/kWh** for residential rooftop PV system (3 kWp) installed Switzerland (46°N), yearly PV energy yield of 975 $kWh/kW_p \cdot y$, corresponding to 83% of the energy yield of a S-facing system installed at the optimal angle in Bern (i.e. 1175 $kWh/kW_p \cdot y$); lifetime of PV system 30 years with an annual degradation rate of -0.7%/y. The 42.5 gCO_2/kWh would correspond for an optimal orientation (S, 38°-tilt) in the same location to **35.2 gCO_2/kWh**, reflecting the higher energy yield. Source of the PV cell/modules: China.

2.2 Carbon intensity of European countries energy mixes

As the electricity generated by PV in buildings is generally consumed by or close to the end-user and it is injected into the low voltage (LV) or the medium voltage (MV) grid - depending on the size of the plant - to have a fairer comparison we try to make use - for CI figures of the local electricity mix – of consumption figures rather than generation ones, which are easier to retrieve and can be generally accessed through European statistical databases. In this work we used consumptions figures as published by Moro and Lonza [5], which are compensated for upstream emissions, electricity trading between countries, and for transmission and distribution losses. Other authors have recently published generation/consumption figures for the members states of the European Union and for some neighboring countries using a methodology to compensate for electricity intra-country electricity imports/exports developed by the authors [6]. These numbers are shown in Figure 4 for some representative European countries.

3 RESULTS

3.1 Carbon intensity of PV (at different orientations) vs local electricity mixes

For a PV plant located in Milan (45°N) and different orientations, Figure 3 shows the cumulative energy yield (MWh/kW_p) generated a PV plant under the assumption of a 30-year-long service lifetime (and an annual degradation rate of -0.7%/y); additionally the same Figure (b) shows the amount of CO2 that would be emitted by the same plant over the same temporal horizon using current PV CI figures (*PV-2021*) and under a scenario with a reduced CI (*greener-PV*). The amount of CO2 that would be emitted to generate the same amount of electricity using the CI of the local electricity mix is shown as well for a comparison, and is used to normalized the corresponding values in Figure 3 (c).

By having a closer look at Figure 3 (c), it become obvious that a carbon intensity balance in Milan is largely in favor of PV not only for the optimal orientations (opta, flat roof, avg roof and 45°-tilt), but also for the less favorable orientations: all the facades, including the N-facing one. Using 2021 values for the CI of PV a N-facing faced over 30 years is generating 50% of the CO_2 emissions that would be generated to produce the same amount of electricity using the local electricity mix. Understandably, this balance is by far more in favor of PV for all the other orientations.

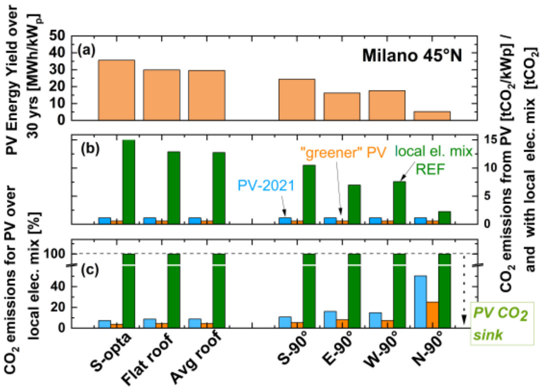

Figure 3: (a) Cumulative energy yield (kWh/kW_p) over 30 years – as a function of different orientations - for a PV system located in Milan (45°N); (b) shows the amount of CO_2 that would be emitted by the same plant over its service lifetime using current PV CI figures (*PV-2021)* and under a scenario with a reduced (i.e. 50%) CI (*greener-PV*). The amount of CO_2 that would be emitted to generate the same amount of electricity using the CI of the local electricity mix is shown as well for a comparison (green bars), and is used to normalized the corresponding values in Figure 3 (c).

We have performed the same analysis (not shown here) for several other cities in Europe (La Valletta, Frankfurt, etc.), for which we could drive the same conclusions as for Milan. Most notably, two extreme cases exist in Europe (see Fig. 4): (1) Malta with a very high availability of solar resources and very large CI of the local electricity mix (>1000 gCO_2eq/kWh); and (2) Norway with a low insolation (see Table I) and very low CI for its local electricity mix (~16 gCO_2eq/kWh).

Understandably, as can be inferred by Figure 4, which presents CI thresholds for PV calculated for the four cities of Table I (and for different orientations), the installation of PV in Malta (and other countries with a large carbon footprint for the local electricity mixes) makes largely sense irrespective of the orientation, including N-Facing facades. Whereas, with the current CI of PV, the installation of PV in Norway is in principle not justifiable exclusively from a carbon balance point of view (not even with an optimal orientation).

We should however point out that in countries massively relying on **nuclear power** for their electricity supply (e.g. France, Switzerland, Sweden, …) other elements should be weighted simultaneously. Citizens or politicians in these countries may in fact oppose the use of a technology (nuclear fission), which will leave a huge burden and dangerous legacy to the coming generations in terms of disposal of nuclear fuels/infrastructures and of the costs needed for the decommissioning of the nuclear power plants (NPP). In addition, in countries planning nuclear phase-outs (Germany, Switzerland, …) PV could be a valid alternative to other energy sources to lower or preserve a low CI budget of the local electricity mix.

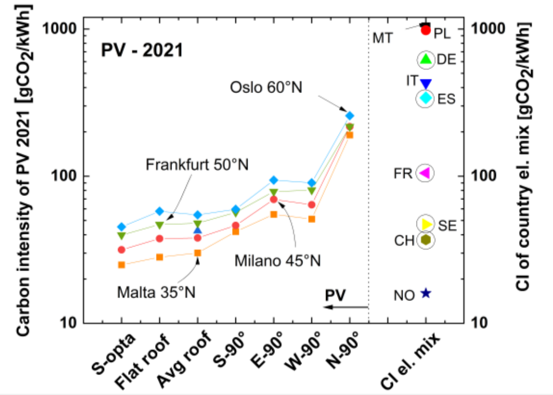

Figure 4: Carbon intensity (CI) thresholds for PV (based on 2021 figures, see Table I) corrected to compensate for different latitudes and orientations. On the right end-side, the CI of the electricity consumption mixes of several European countries are shown for a comparison (from [5]). Circles highlight countries that use nuclear as part of their national electricity mixes.

Installations in surfaces with **less optimal orientations** (e.g. N-facing facades) should possibly not be incentivized in the first place, but not expressly "prohibited" (or abandoned), as we have demonstrated that, in several countries, they are fully justifiable from the point of view of a carbon intensity balance. In addition, this may still help in promoting and creating ***"PV-awareness"*** among citizens, help architects in preserving building harmony/aesthetics, and push market deployment for BIPV and integrated PV (I-PV). Furthermore, they could still make sense from an economical point of view as – for example in the case of a new building or major renovation - they may avoid the adoption of different mounting structures and cladding elements for the different building's facades.

5 CONCLUSIONS

In order to minimize unnecessary land exploitation and to allow PV to play a major role in the decarbonization of European economies, a massive deployment of PV in Europe should primarily pass through the **integration of PV in buildings and infrastructures**, including the integration of PV in surfaces with a sub-optimal orientation.

To assess the meaningfulness of installing PV in surfaces with sub-optimal orientations, we focused on a **carbon footprint analysis**; trying to assess in the first place whether – on a temporal horizon of 30 years – installing PV at different orientations acts as a net CO_2 sink or source, when compared to the same amount of electricity that would be generated with local electricity mixes in different European countries.

For several cities (Milan, Frankfurt, La Valletta, …) it becomes obvious that a carbon intensity balance is largely in favor of PV not only for the optimal, but also for the less favorable orientations: all the facades, including North-facing ones. For other cities/countries with a very low carbon footprint for the local electricity mixes (e.g. Norway, Switzerland, Sweden, etc.), the installation of PV may in principle not be always fully justifiable exclusively from a carbon balance point of view (not even for optimal orientations in Norway).

We should however point out that in countries massively relying on **nuclear power** for their electricity supply other elements should be weighted simultaneously. Citizens or politicians in these countries may in fact oppose the use of a technology, which will leave a huge burden and dangerous legacy to the coming generations.

We also highlight the fact that installations in surfaces with **less optimal orientations** (e.g. N-facing facades) should possibly not be incentivized in the first place, but not even abandoned, as we have demonstrated that, in several countries, they are fully justifiable from the point of view of a carbon intensity balance. In addition, this may still help in promoting and creating ***"PV-awareness"*** among citizens and help architects in preserving building harmony/aesthetics.

A follow-up of this work, we'll be that of drafting a list of recommendations that should help local authorities adopting favorable building codes and the right policies (including proper incentive schemes) to foster and maximize the diffusion of PV in buildings and infrastructures.

To summarize in brief this contribution, we make use and rephrase an older **slogan**: we should move from the approach of "*Solar PV everywhere*" to that of "**Solar PV wherever it makes sense first, and sometimes where it creates awareness**"!

6 ACKNOWLEDGEMENTS

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