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Energy and Environment 3.1

What is the contribution of BIPV to the Energy Strategy 2050?

Energy renovation projects with BIPV have the potential to provide a crucial response to the long-term carbon and energy targets of Energy Strategy 2050.

Functioning both as envelope material and electricity generator while providing an aesthetically pleasing, efficient and profitable solution, building-integrated photovoltaics (BIPV) have the potential to reduce the use of fossil fuels and greenhouse gas (GHG) emissions while providing savings in materials and electricity costs.

Keywords: Energy Strategy 2050; Energy efficiency; Renovation with BIPV; Sustainable architectural design.
Target audience: Regulation makers; Owners & other decision makers; Architects & engineers; Suppliers & companies; Broader public.

The Swiss Energy Strategy 2050 [1], related to the 2,000-Watt Society concept [2], provides incentives to limit the consumption of primary energy and reduce greenhouse gas emissions improve energy, notably through direct subsidies and tax deductions for carrying out energy-saving building renovations. Regarding solar installations, these are being promoted in Switzerland at the federal [3], cantonal and communal levels [4] via: simplifications in the administrative process for roof installations, offering direct economic subsidies based on the installed power, encouraging self-consumption of on-site produced energy and sharing through micro-grids at the neighborhood scale, and guaranteeing the possibility of injecting overproduction into the grid in accordance with the local electricity supplier (feed-in-tariff).

Concretely speaking, the Energy Strategy 2050 aims to reach over 10 GW of solar electricity, which corresponds to increasing the contribution of photovoltaics to the national electricity supply by up to 20% by 2050. Studies in Switzerland show that PV systems on roofs and facades could generate over 50% of today's electricity requirements [5]. This will involve the consistent use of existing buildings, especially residential buildings in cities. In this context, renovation projects with BIPV can contribute as follows:

- At a larger scale, working on fostering urban renewal processes (conservation, renovation, transformation or substitution of the existing building stock) in Swiss cities and agglomerations can simultaneously reduce end energy consumption, promote the use of renewable energy and cut CO_2 emissions. BIPV can directly and indirectly stimulate these processes [cf sheets 2.1 and 4.4], in particular thanks to lightweight technologies (disruptive approach) [cf sheet 1.3] and the novel generation of BIPV modules with modified visual appearance (transformative approach) [cf sheet 1.2], likely to increase the appeal of BIPV and its architectural integration in sensitive urban contexts.

- At building scale, the generation of photovoltaic energy represents a significant part of a residential building's electricity needs. Depending on the type of building, installation and potential energy storage system, a self-sufficiency rate between 18% and 87% can be achieved for the newly renovated building (replacing the existing oil/gas-boiler with an electric-based heating, ventilation and air-conditioning (HVAC) system e.g. heat pump) [cf sheet 2.2]. The detailed results can be dynamically explored online [6].

- In terms of energy balance, the assessment conducted within the application case studies [cf sheet 3.2] shows that interventions without BIPV (S0-Baseline scenario) do not reach operational non-renewable primary energy

(CEDnr) and global warming potential (GWP) targets of the Energy Strategy 2050. More specifically, renovated buildings that comply with current standards (e.g. SIA 380/1:2016) emit, during the operating phase, between 2 to 5 times more CO_2 and consume between 1.5 and 2 times more non-renewable primary energy than the objectives of Energy Strategy 2050. Therefore, it is essential to go further: in addition to reducing energy losses through the thermal envelope of the building, on-site electricity generation with a much lower environmental impact than the grid can offer a feasible path. The lower-impacting BIPV scenario S1-Conservation, for instance, provides a CEDnr saving potential during the operational phase between 67% and 110%, according to the building's archetype [cf sheet 2.2]. Greenhouse gas (GHG) emissions savings range between 87% and 110%.

- In terms of life-cycle assessment (LCA) including operation and construction [cf sheet 3.3], the payback period for both non-renewable primary energy and greenhouse gas emissions is significantly shorter than the expected life of a building-integrated PV system. Results in terms of energy and carbon emissions payback times are respectively less than 14 and 21 years. Energy payback time (EPBT) is always shorter than carbon emissions payback time (GPBT), influenced by the energy and carbon content factors of the Swiss grid and the respective savings in energy and carbon emissions. Furthermore, replacing the fossil-fuel based HVAC system by an electric system (more compatible with the PV installation) brings all BIPV scenarios below targets.

New technologies for BIPV therefore provide builders and architects with a wide range of opportunities to refurbish existing buildings and generate sustainable energy. Instead of considering BIPV as a technical constraint, designershave the possibility to integrate BIPV solutions as a new "raw material" for architectural renewal projects [7,8]. While enhancing the overall urban and architectural quality of the existing building stock, renovation projects with BIPV represent a convincing solution to reach the targets of the Energy Strategy 2050.

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Energy and Environment 3.2

What is the energy performance of BIPV at component level?

In order to untangle some misconceptions about the environmental impact of BIPV, here we illustrate how energy and carbon payback times are well below the module's expected lifetime.

This sheet proposes an in-depth study ofn efficiency, taking into account the whole life-cycle analysis (LCA) of a BIPV installation on a building from the 70s (Archetype 4) [cf sheet 2.2]. The results can help overcome certain preconceptions that represent barriers to the large-scale deployment of BIPV.

Keywords: BIPV architectural integration; Renovation project; Energy performance; LCA.
Target audience: Regulation makers; Architects & engineers; Suppliers & companies.

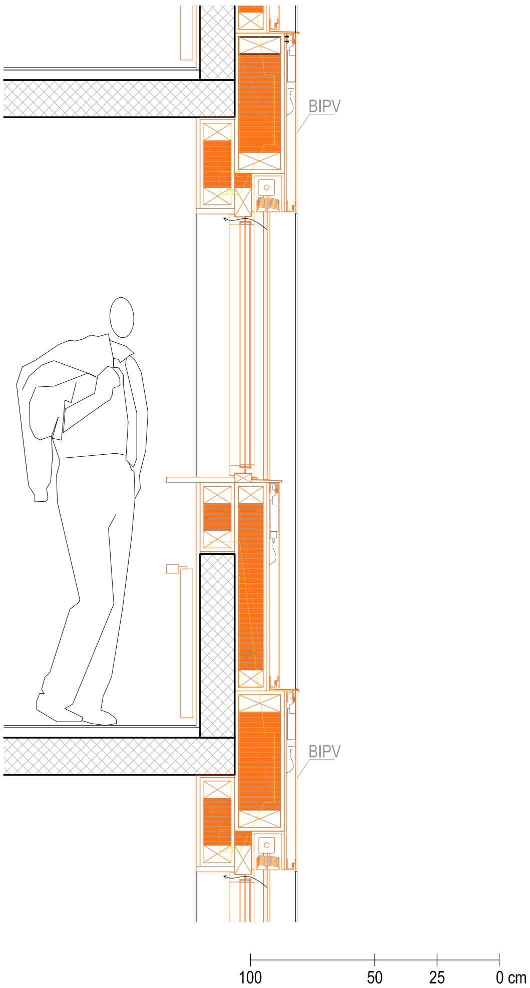

Fig. 1 Facade construction detail, S3-Transformation, Archetype 4 [1].

In choosing to implement scenario S3–Transformation [cf sheet 2.3], our objective and strategy were:

- To obtain highest energy performance and electricity production possible;
- To assess the building's potential; and
- To ensure aesthetic and formal coherence of the building as a whole (reference target performance: 2,000-Watt Society concept according to SIA 2040:2018 for operational energy consumption and construction materials).

Fig. 1 shows the layers and materials composing the prefabricated, ventilated, timber frame facade system proposed for the active renovation of Archetype 4, a building from the 70s [cf. sheet 2.2]. It includes all envelope components, modulated according to the standard size of BIPV elements and prioritizing low-carbon materials. Part of the existing window railing is demolished to enlarge the opening and provide the apartments with improved daylight and outdoor views.

BIPV elements on facade:

- Frameless PV panels with mono-Si cell technology (with an efficiency of 18% in STC);
- Size customization respecting manufacturers' recommendations for glass/glass modules (length 50-3800 mm, width 50-2400 mm) using 6" standard size solar cells [2];
- Visual customization (dark gray colored film)
- Final performance estimation about 14.5% in STC.

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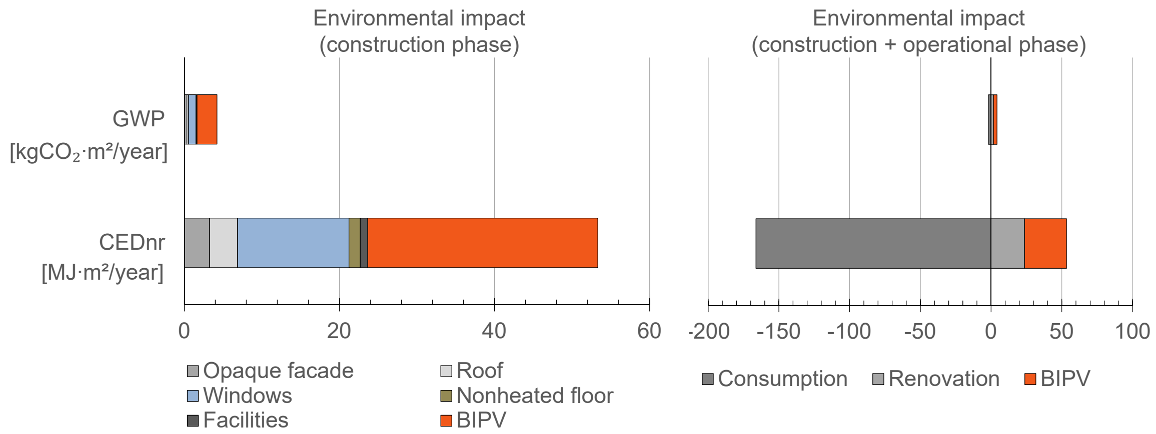

Fig. 2 Environmental impact of the different construction components (construction phase) and global results (construction + operational phase) [1] (©EPFL-LAST).

In the chart on the left in Fig. 2, we show the environmental impact during construction of the different components of the whole renovation project in scenario S3, Archetype 4, based on data from KBOB 2016 [3]. In the chart on the right, we show the global environmental impact considering both construction (materials) and operation (energy consumption) phases.

In terms of photovoltaic performance, the price of the electricity produced is 6.2 to 8.6 cts/kWh, much lower compared to the standard price of electricity from the grid, about 20-25 cts/kWh.

The environmental impact of each kWh produced by this installation corresponds to 0.153-0.222 kWh_{NRE}/kWh_{pv} in terms of non-renewable primary energy (CEDnr) and 0.04-0.058 $kgCO_2/kWh_{pv}$ in terms of carbon emissions. We can thus observe that the impact of the electricity produced by the BIPV installation is much "cleaner" than that obtained using electricity from the Swiss grid [3]: 2.52 kWh_{NRE}/kWh_{grid} and 0.102 $kgCO_2/kWh_{grid}$.

In terms of energy payback time (EPBT) and carbon emissions payback time (GPBT) of these BIPV installations, we obtain 3.4 (S1), 3.6 (S2), and 3.3 (S3) years of EPBT and 15 (S1), 15.3 (S2), and 13.9 (S3) years of GPBT. These values are well below the expected lifetime of the PV installation (25 years and beyond).

These results help to clear up some misconceptions related to the environmental impact of BIPV installations and their feasibility on facades without optimal orientation / inclination.

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Energy and Environment 3.3

What is the energy performance of BIPV at building level?

After the life-cycle analysis (LCA) at component level [cf. sheet 3.2], we now focus on the environmental impact of an active renovation project at building scale.

This sheet proposes an in-depth study of the whole LCA of a renovation project with BIPV installation on a building from the 70s (Archetype 4) [cf. sheet 2.2]. By illustrating the energy performance of BIPV, these results can help overcome certain misconceptions that prevent the large-scale deployment of BIPV.

Keywords: BIPV architectural integration; Renovation project; Energy performance; LCA.
Target audience: Regulation makers; Architects & engineers; Suppliers & companies.

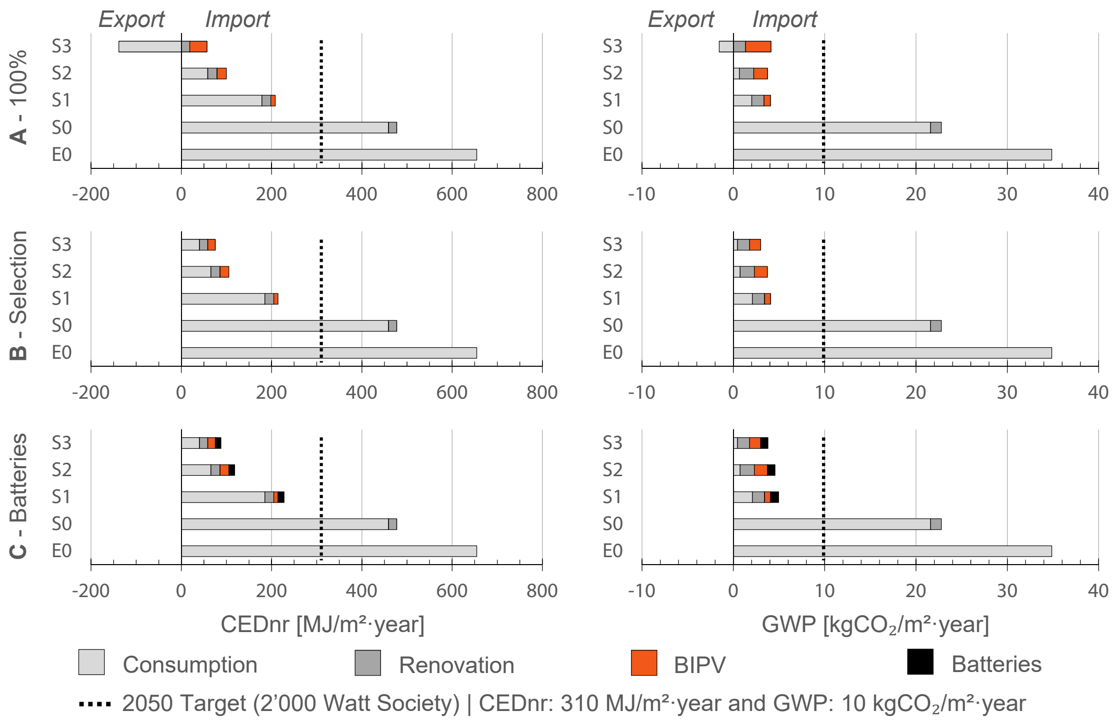

Fig. 1 LCA results (feed-in tariff approach injecting overproduction into the grid) in terms of non-renewable cumulative energy demand (CEDnr) and global warming potential (GWP), considering construction phase (materials) and operational phase (consumption), taking into account the different energy-use variants A) 100% of potentially active surfaces, B) selected surfaces, and C) batteries [1] (©EPFL-LAST).

Life cycle analysis (LCA) is a well-known method to evaluate the potential environmental impacts of products and services and their resource consumption. This method is used in particular in the building sector, where it is a crucial part of the assessment of sustainable buildings, considering the energy consumption and emissions due to the use of the building (e.g. heating) but also the due to the construction material fabrication (e.g. concrete, wood, BIPV element) [1].

This sheet presents an in-depth LCA study of a renovation project with BIPV installation on Archetype 4, a building from the 70s. Fig. 1 presents the results of the LCA regarding the whole renovation project including BIPV strategies and the replacement of the exiting oil-boiler by an electric heat pump. In addition, we propose three comparative energy-use scenarios related to the sizing of the BIPV installation and the implementation of storage systems. Results are presented as follows:

- **A-100%** takes into account the activation of 100% of the possible surfaces detected during the implementation of each renovation scenario [cf sheet 2.3].
- **B-Selection** takes into account a selection of active surfaces that allow an equilibrium between self-consumption and self-sufficiency, resulting in a better adapted installation according to the demand of the building. The rest of the possible active surface will present the same visually but without PV cells.
- **C-Batteries** takes into account the selection criteria from B-Selection and adds a battery system in order to increase self-consumption and self-sufficiency potential.

Regarding batteries, we consider a variable lifetime in function of the expected number of charging-discharging cycles each year. We use Lithium-ion batteries - a mature technology - with about 5,000 cycles of lifespan, corresponding to about 10 years, depending on the sizing and the energy-use scenario.

The environmental impact values for construction materials, PV elements, and HVAC systems are obtained with ECO-BAT software [2], using the KBOB database [3] and considering lifespans of 60, 30, and 20 years respectively. A global (building) lifespan of 60 years is considered for the results. The values of non-renewable cumulative energy demand (CEDnr) and global warming potential (GWP) used in this project correspond to the BAU (business-as-usual) scenario published in [4]. To take into account the photovoltaic industry trend of reducing environmental impact mainly through increasing manufacturing efficiency, we implement a reduction of these impacts following a real scenario, with -19% from current values from the ECO-BAT software [2], to conduct calculations oriented for a horizon between 2020-2050. The final values used for each m² of monocrystalline BIPV panel are 104 MJ/m²·y for CEDnr and 6.70 kgCO_2/m²·y for GWP; the values per each kWh of storage capacity are 189 MJ/m²·y for CEDnr and 11 kgCO_2/m²·y for GWP.

As Fig. 1 shows, only the renovation scenarios integrating BIPV strategies achieve the 2050 targets defined by SIA 2040:2017 “The SIA pathway to energy efficiency” [5] (CEDnr: 310 MJ/m^2.year and GWP: 10 kgCO_2/m^2.year). Batteries could play a key role if the injection of overproduced PV electricity were to become impossible. In conclusion, our project demonstrates that the integration of BIPV elements during the energy renovation projects can contribute to the 2,000-Watt Society targets for 2050 [5].

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Energy and Environment 3.4

What is the solar potential of buildings at city-scale?

City-scale evaluation of buildings' PV potential is essential to target efforts. Here, we show how accounting for vegetation and weather variability highly affects the results of the evaluation.

This sheet presents a tool for mapping the energy potential of existing buildings in urban areas under uncertain environmental conditions. Indicators are based on the simulated hourly energy production of PV modules and energy demand of buildings. Multiple modeling scenarios give the confidence bounds of the simulated energy potential, and different spatial aggregation scales convey relevant information to decision-makers. The results are expressed in a solar score giving a robust ranking of the performance of each spatial location.

Keywords: Simulation-based urban energy planning; Decision support; 3D city models.
Target audience: Regulation makers; Owners & other decision makers.

Fig. 1 Visualization of the 3D city model (City of Neuchâtel) [2].

Solar cadastres, or solar maps, are tools to provide decision-makers with information about the suit-ability of a given building surface for the installation of solar power systems, such as photovoltaic or solar thermal. There is currently a gap between detailed simulation tools for single solar installations and those used in large-scale analyses, such as solar cadastres. The latter are usually based on sim-plified solar radiation tools and provide time-cumulated results and up to the building surface.

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This work aimed at pushing the boundaries of the analysis in terms of granularity, using state-of-the-art solar radiation and PV performance models, advanced 3D geo-data and weather measurements recorded over lengthy periods of time. In particular, the developed simulation workflow took ad-vantage of the high-resolution 3D point clouds from airborne laser scanning and 3D city models that are widely available in Switzerland, through the Confederation and many cantons.

This proposed workflow also integrates climate-based dynamic simulation of building energy demand showing the potential for energy retrofit of the building thermal envelope. We argue that, in fact, BIPV installations complement building energy retrofit interventions ideally. Moreover, simulation of the hourly energy demand allows for sizing the solar installation based on building self-consumption, as encouraged by the new Federal Energy Act.

In existing urban-scale solar assessment methods, the decision support is usually neglected or is associated to simplified modeling tools or input data. This work instead couples the advanced simulation method presented above in an innovative planning-support system [1,2,3], aimed at comparing the building's energy potential under uncertain environmental conditions through risk-averse scenarios. The method also accounts for some crucial uncertainty factors (vegetation and weather), so as to provide robust decisions based on multiple modeled scenarios.

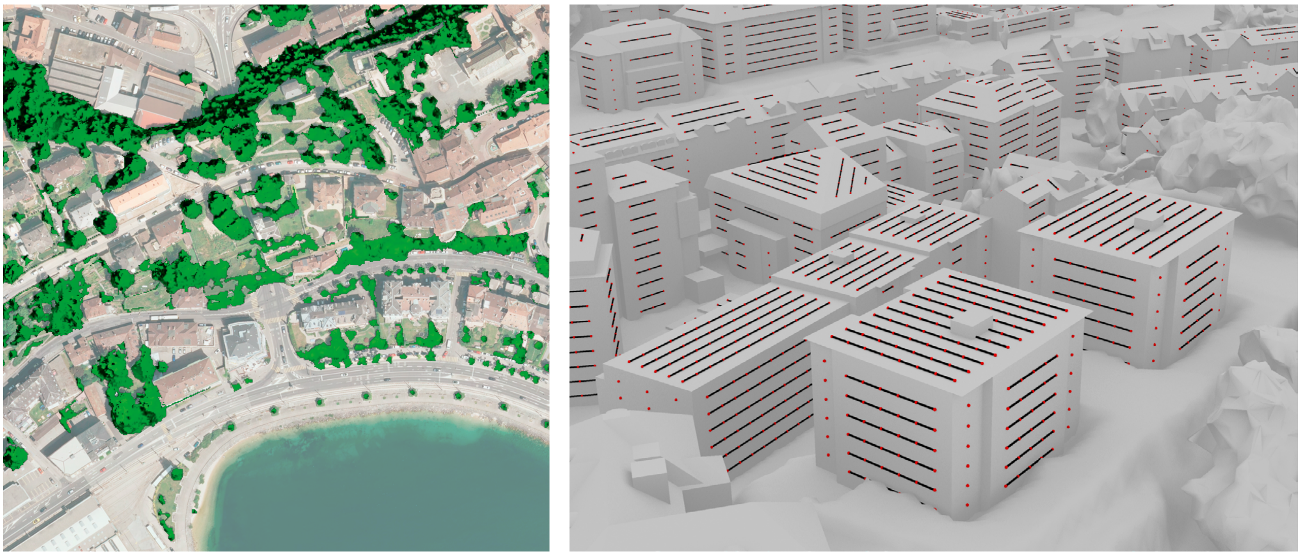

Fig. 2 Visualization of the 3D city model (City of Neuchâtel, Switzerland) [2].

An interactive 3D map indicates the priority level of energy refurbishments and/or PV installations in buildings at different spatial aggregation scales (e.g. building surface, building, urban block) expressed as a solar score. It is then possible to easily detect which spatial locations would benefit most from a solar installation and a retrofit intervention. This could help local authorities to target investments where they are most needed, as well as large building owners to prioritize the refurbishment of their building stock.

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