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COMPARATIVE PROFITABILITY ANALYSIS OF BIPV ARCHETYPES IN DIFFERENT EUROPEAN COUNTRIES: A MULTI-MARKET STUDY

Summary

This study assesses the economic competitiveness of four building-integrated photovoltaic (BIPV) archetypes (roof tiles, insulating glass units, solar blinds, and facades) integrated into three building typologies (residential, commercial, and industrial) across five European markets (Italy, Germany, United Kingdom, Switzerland, and the Netherlands). Using 3D simplified models, hourly energy matching, and net present value (NPV) optimization over a 25-year lifecycle, the research identifies the most viable BIPV integration scenarios per country and sector, considering key aspects as extra-cost of the archetypes and site-related energy economics. Results show that rooftop BIPV is profitable across all markets, while facade and shading systems depend on local electricity prices and feed-in tariffs. The Netherlands leads the residential sector (NPV up to 256 €/m²) while Italy dominates commercial applications (NPV up to 134.9 €/m²). The study concludes that supportive energy policies and tailored business models help as profitability drivers than solar irradiation alone.

Keywords: building-integrated photovoltaics, BIPV, net present value, energy economics, self-consumption, European energy markets, building envelope, solar energy, sensitivity analysis

Field of application for the findings: Building design, urban energy planning, renewable energy investment, construction industry, energy policy development, BIPV product commercialization across European markets.

Addressed audience: Architects, building engineers, energy consultants, urban planners, policymakers, BIPV manufacturers, real estate developers, and researchers working in sustainable construction and renewable energy integration

1. Introduction

Building-integrated photovoltaics (BIPV) serve a dual function: they act as essential elements of the building envelope while generating electricity. Unlike building-applied PV (BAPV), BIPV modules replace conventional construction materials, fulfilling structural, technological, and aesthetic requirements alongside energy production [1], [2], [3]. Europe had 314 MWp installed in 2023, with France leading with ~86 MWp (>3% of distributed PV market), followed by Austria (65 MWp, 3%), and Switzerland (>60 MWp). Germany reached 30–40 MWp [4]. Forecasts aim to reach 371 MWp by 2028 [4]. Despite this growth, large-scale adoption remains constrained by high initial costs and uncertain economic profitability across diverse regulatory contexts. This study presents a comprehensive techno-economic assessment of four BIPV archetypes (PV roof tiles, PV insulating glass units (IGUs), PV solar blinds, and PV facades) across three building typologies (residential, commercial, industrial) in five European markets: Italy, Germany, United Kingdom, Switzerland, and the Netherlands), to map profitability thresholds and policy levers for accelerating BIPV adoption.

2. Methodology

The methodological approach involves several integrated steps: firstly, the 3D geometric modeling, by realizing simplified 3D geometries were to represent specific building types, each representing residential, commercial, and industrial category. Secondly, energy performance simulations were conducted using weather data (solar irradiation, temperature, and shading) and specific hourly electric load profiles derived from the Eurac Research database. An example is reported in **Figure *1***. Further, an economic analysis was performed, including grid electricity costs from 2023/2024, feed-in tariffs, and battery storage expenses for each target country.

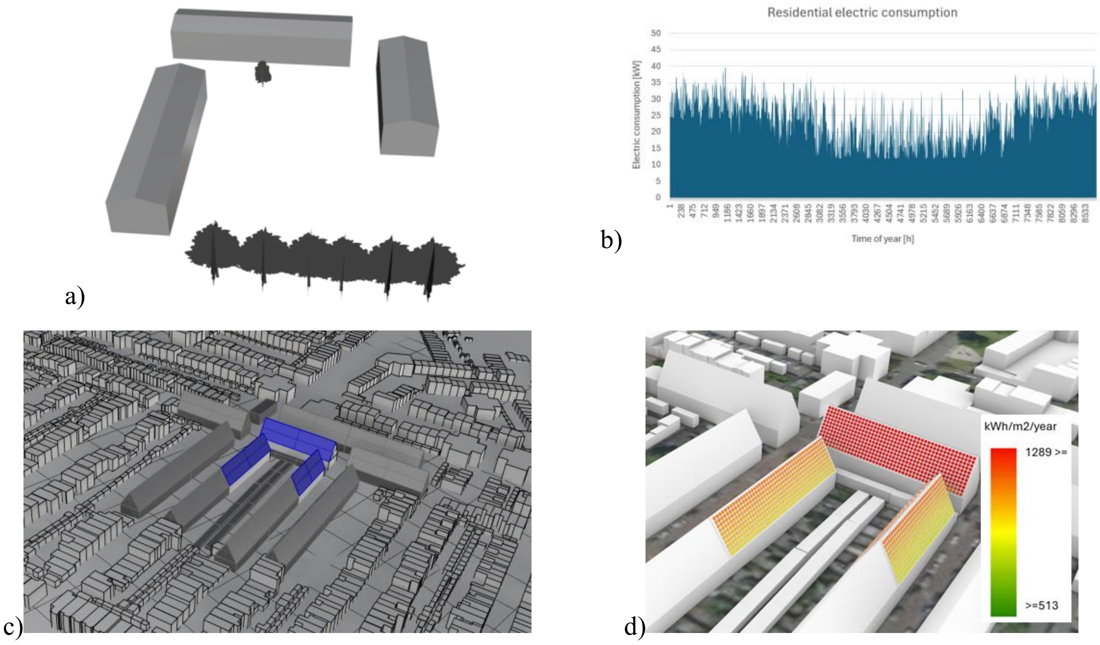

Figure 1: Optimization key inputs: example of PV solar roof tiles integration. a) simplified 3D model; b) residential electric load profile; c) selection of area available for PV installation; d) irradiation map.

For BIPV, the extra cost approach was employed. The extra cost of a BIPV solution is the difference between the cost of the photovoltaic cladding plus the accessories to make it active (i.e. the balance of the system, or BOS) and the cost of a similar solution without the photovoltaic components [5]. Extra cost has been identified by considering only the BIPV elements that produce a cost increase compared to a similar traditional system, which represents a building envelope solution with the same properties of the BIPV system (thermal, weather protection, etc.) [6]. An optimization function was derived to maximize the net present value (NPV) over a 25-year lifecycle, accounting for initial investment costs, yearly maintenance, and savings from directly offset electricity consumption.

A final sensitivity analysis was performed to test the robustness of the results by varying the "extra cost" of the BIPV technology by ±10%.

3. Results

The simulations produced a heterogeneous map of profitability across the European markets, based on sector-specific profitability, as can be seen in **Figure 2**. In the residential sector, the Netherlands emerged as the market leader with an NPV per installed area ranging from 227 to 256 €/m². This is primarily driven by high grid electricity costs (€0.39/kWh) and favorable feed-in revenues (€0.12/kWh). In comparison, Italy showed more moderate residential NPV values of 33 to 45 €/m², while the United Kingdom proved highly sensitive to cost reductions, showing a 186% increase in NPV if BIPV extra costs dropped by just 10%.

For the commercial sector, Italy (Milan) significantly outperformed Germany (Cologne), with NPVs of 63.9 to 134.9 €/m² versus 9.12 to 28 €/m². The higher solar irradiation in Milan (up to 1236 kWh/m²/year) combined with high commercial energy costs makes BIPV shading and facade solutions particularly attractive there.

Lastly, for the industrial sector, Switzerland (Möhlin) displayed a higher NPV (92.2 to 124.2 €/m²) than Germany (52.8 to 89.5 €/m²). Although Switzerland has a lower feed-in tariff, its higher grid electricity price maximizes the direct value of self-consumed energy.

Further key findings observed on self-consumption highlighted that across all commercial and industrial case studies nearly all produced energy is self-consumed. This high level of direct utilization makes the investment not only financially viable but also highly effective at reducing the building's carbon footprint and grid dependency.

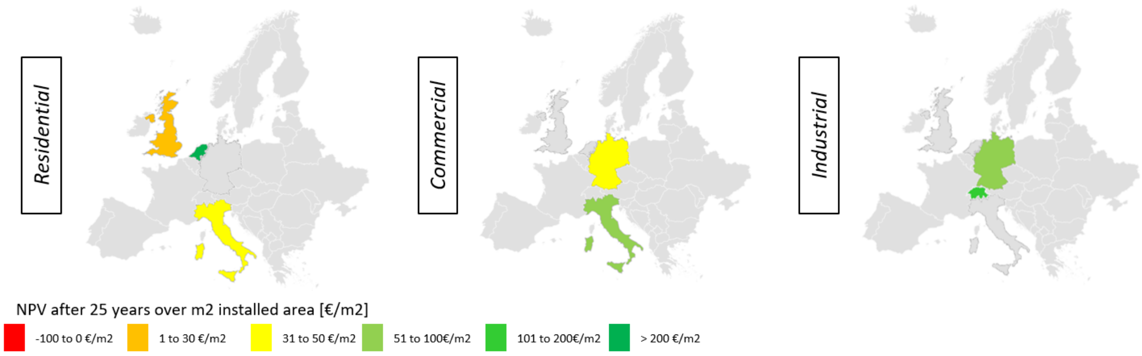

Figure 2: Net present value (NPV) after 25 years over square meter of installed area [€/m^2], considering a decrease in the extra cost of the BIPV technologies of 10%, divided per country and per sector.

4. Conclusions

The study concludes that rooftop BIPV remains the most reliable entry point for integrated solar due to its consistent cost-effectiveness and optimal orientation. However, for vertical facades and shading, a lower "extra cost" of the technology represents a driver to achieve widespread success.

While irradiation can tip the balance when BIPV extra costs are equal, the research highlights that supportive economic policies, tailored business models, and high grid electricity prices can help in making these technologies more competitive and attractive. Future research should focus on exploring additional high-irradiation/low-cost scenarios and further integrating sustainability KPIs into the optimization process to ensure a comprehensive energy transition.

5. References

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