A post-evaluation of social dimensions of BIPV adoption in case studies buildings across diverse European contexts

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Abstract

Building-Integrated Photovoltaics (BIPV) are building skin cladding components that combine technical and economic functions through photovoltaic elements for energy generation with aesthetic, cultural and symbolic values to raise architectural identity of buildings. This dual function renders BIPVs both innovative and complex, posing technical, aesthetic, and social challenges for designers, users, and for both private and public stakeholders during the design, construction, and operation phases of building projects. While existing literature widely focuses on BIPV technical performance, energy generation and profitability, there is still way long path to address social factors and stakeholder dynamics shaping BIPV adoption. Framed within IEA PVPS Task 15 – Subtask A3 "BIPV in our society", this study aims to provide a post-evaluation of social dimensions of five BIPV case study buildings across diverse European contexts through a qualitative analysis of a total of 21 semi-structured interviews conducted with public and private stakeholders and end users. The data analysis mapped recurring challenges and documented perceived social impacts. Findings reveal that BIPV consistently generates social value beyond energy performance, and case study buildings are demonstrators reinforcing institutional identity and stimulating public discourse on urban sustainability. However, case study buildings face interconnected technical, regulatory, financial, and procedural barriers amplified by low social awareness and fragmented stakeholder coordination. The findings suggest: i) the development of Key Performance Indicators for the post-evaluation of social dimensions to allow private and public stakeholders and people to assess the BIPV adoption; ii) the need for co-participation processes to address contextual factors in the early design phases of the project. Such practice can raise the social awareness on BIPV adoption and facilitate highest social impacts.

Keywords: BIPV Social impact; Case Studies Challenges, Public and Private Stakeholders, People

1. Introduction

Building-integrated photovoltaics (BIPV) represent a paradigm shift in sustainable urban design, transcending their role as mere energy generators to become multifunctional building envelope components (Singh et al., 2021). By seamlessly replacing conventional construction materials in roofs, façades, and glazing, BIPV systems are pivotal in the pursuit of net-zero energy buildings, offering the dual advantage of material savings and enhanced architectural aesthetics and building's architectural identity through customized colors and patterns (Martín Chivelet et al., 2024; Martín-Chivelet et al., 2022) . However, a paradox hinders the widespread adoption of BIPV. While extensive research has established a robust foundation for BIPV's technical performance, profitability, and material properties, there is still a research gap in exploring the assessment of social dimensions of BIPV adoption as technical and economic factors have proven to be insufficient drivers for mass-market penetration (Curtius, 2018; Zhang et al., 2022). The decision-making processes of key public and private stakeholders (e.g., architects, installers, producers, policymakers, municipalities) and people (e.g., end users communities) are important actors influenced by social acceptance, users' experience, and values perception (Sleiman et al., 2024). Studies on user perception (Bao et al., 2017; Hille et al., 2018) highlight aesthetics and visibility as key acceptance factors but focus largely on residential contexts. Therefore, there is a pressing need to investigate the social impacts, challenges, and benefits arising

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from integrating energy-producing components such as BIPV in a systematic way into diverse geographical, economic, cultural contexts. Such a contribution provides decision-makers with a broader perspective and actionable insights derived from practical experiences on the one hand. On the other hand, by addressing the gap of social dimension of BIPV adoption, the research brings empirical evidence to inform strategies to scale up BIPV mass-market and mass-acceptance. In this context, this study has a twofold aim: i) identify the most common challenges and barriers encountered in the deployment of BIPV and ii) conduct a post-evaluation of BIPV adoption in selected European case study buildings by examining the contextual and social factors from public and private stakeholders and end users.

2. Material and methods

Framed within IEA PVPS Task 15 – Activity A3 "BIPV in our society" this study, structured in four main steps (Figure 1), conducts a qualitative analysis of five completed or near-completed BIPV projects across Europe constructed from 1970 to 2025. The methodology consists of semi-structured interviews with stakeholders including Public (e.g., municipal authorities,), Private (e.g., solar providers, architects, contractors,) and People (e.g., end users, occupants) (PPP). This aimed to capture both BIPV challenges and social impacts in the case studies to identify social drivers and metrics that inform further comparative studies.

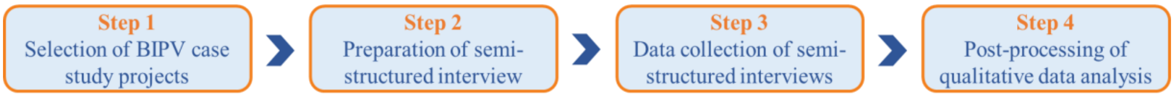

Figure 1 Workflow and research design steps

2.1. Step 1 – Selection of BIPV case study projects

The five European BIPV case study projects (Table 1) were selected based on three criteria to ensure diversity through building type and function, geographical and climate context and BIPV application (e.g., roof, façade).

Table 1 BIPV case study projects, highlights and interviewees: Private (Pr): Architect (Ar), Solar provider (Sp), Building owner (Bo), Consultants (Co); Public (Pu): Researcher (Re), Municipality (Mu) Heritage (Ho) and Energy office (Eo); People (Pe): End user (Eu).

ID	Case study projects	Highlights		Interviewees Pr	Interviewees Pu	Interviewees Pe
01		Name, place	**CIEMAT Building**, Madrid, Spain	1	1	1
		Function	Administrative	Ar	Re	Eu
		Year	Built in 1970-80; integral renovation in 2015			
		Technology	Crystalline silicon BIPV modules			
		Application	West, south and east ventilated façades.			
		Energy data	20 MWh/yr, 27.2 kWp grid 4.8 kWp stand-alone			
02		Name, place	**Hallenbad**, Verl, Germany	3		1
		Function	Sportive function	Ar Sp Bo		Eu
		Year	2025			
		Technology	CIGS-based green PV modules (651)			
		Application	681 m² of ventilated curtain wall façade and roof			
		Energy data	39 MWh/yr, 87 kWp facade, 83.5 kWp rooftop			
03		Name, place	**Voldsløkka Skole**, Oslo, Norway	2	3	
		Function	Educational	Sp Co	Mu Re	
		Year	2023			
		Technology	Green shades BIPV			
		Application	BIPV on facades and BAPV on roof			
		Energy data	230 MWh/yr, ~100 kWp			
04		Name, place	**Franklin University Switzerland**, Sorengo,	2	1	1
		Function	Educational	Ar Bo	Re	Eu
		Year	2023			
		Technology	Dynamic white glass-glass PV louvres			
		Application	Vertical PV louvre system			
		Energy data	9 MWh/yr, 18 kWp			
05		Name, place	**Firmenich Tower**, Geneva, Switzerland	2	3	
		Function	Commercial/Office	Ar Sp	Ho Eo	
		Year	2022			
		Technology	Coloured bluish green/blue tones glass PV			
		Application	Façade			
		Energy data	~57 MWh/yr, 141 kWp,			

Moreover, practical criterion was the accessibility of data and the agreement of project owners to participate

2.2. Step 2 – Preparation of semi-structured interviews

The semi-structured interviews were designed and developed to ensure consistency across all case studies while allowing for necessary contextual adaptation. The interviews were structured in two parts: i) five general common questions focusing on stakeholders' role in the project, key challenges encountered, perceived social impacts, community perception and lessons learned; ii) five professional questions tailored to the distinct perspectives of key stakeholders representing PPP (Figure 2).

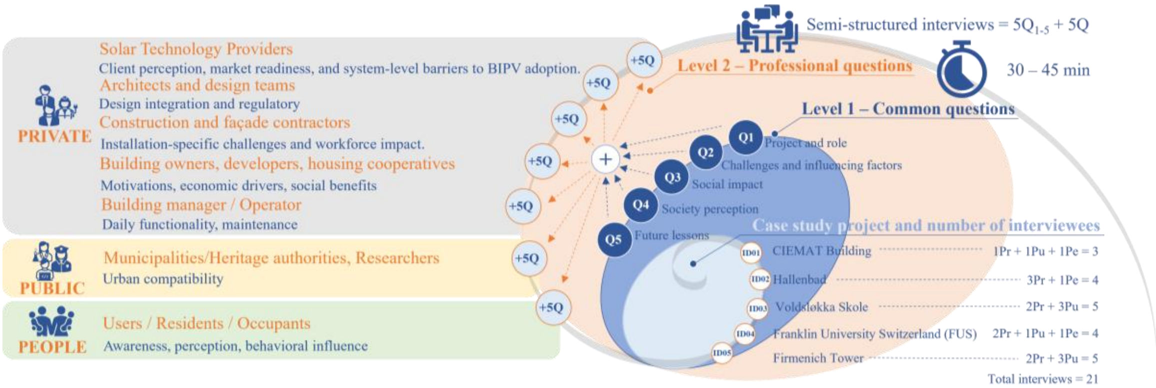

Figure 2 Scheme of two levels interview questions designed and conducted by IEA PVPS Task 15 for the BIPV case study projects.

The questions were distributed to international experts participating in the IEA PVPS Task 15 – Activity A3 for review. Each expert identified successful BIPV cases within their countries and consulted professionals involved in the design, construction, or operation phases. The interviews were conducted in the experts' native languages to ensure clear understanding of the questions, cultural appropriateness, and relevance to the levels of expertise within each national context. The semi-structured interviews were designed to ask about the challenges that they had and their perception and possible social impact of this technology. Facilitating flexible and open-ended discussions allowed interviewees to move beyond by answering predefined questions, and encouraging them to introduce new aspects, unanticipated challenges, and novel terminology.

2.3. Step 3 – Data collection of semi-structured interviews

In this study, 21 semi-structured interviews were conducted online between May and September 2025 with key stakeholders directly involved in the five selected case study project. Each session lasted 30–45 minutes and was recorded via Microsoft Teams with prior consent. For one case interviews were conducted by sending the questions electronically and receiving written responses. Transcriptions were subsequently prepared, translated into English, and compiled into a single master file to ensure a consistent and comprehensive data collection for analysis. The interviews were conducted by co-authors in accordance with ethical guidelines and with emphasis on confidentiality, voluntary participation, and compliance with GDPR protocols (Braun & and Clarke, 2006). Personal data was anonymized, and the interviewees agreed to share their affiliated organization named in the research.

2.4. Step 4 – Post-processing of qualitative data analysis

All interview data were compiled in an Excel database and grouped by case study project and stakeholder role. Thematic analysis followed Braun & and Clarke, 2006 with combining deductive coding extracted from predefined themes from the designed questionnaire (e.g., technical, regulatory, financial, managerial, and social aspects) and with inductive coding which provided by interview results in data-driven subthemes to emerge (e.g., supply chain fragility, grid-injection limits, user communication gaps, or identity-related perceptions). Accordingly, the main categories were deductively defined, while the specific challenges and social impacts within each category emerged inductively from interview insights. Challenges in Table 2 and social impacts in Table 3 in the result chapter integrate both coding dimensions.

3. Results

This section presents the findings of the 21 semi-structured interviews of the stakeholders involved in the selected BIPV case study projects included in this research in terms of the challenges they faced and the social impacts of BIPV. The cases include: CIEMAT Building (Spain), Hallenbad (Germany), Voldsløkka Skole (Norway), Franklin University Switzerland (FUS)and Firmenich Tower (Switzerland).

3.1. Case study project 01 - CIEMAT Office Building

The CIEMAT Office Building demonstrates how BIPV projects involve layered stakeholder perspectives. From the interviewed private stakeholder (architect, researcher and end user), the main driver was focused on improving energy performance by ensuring that the BIPV modules were visible as a symbol of sustainability. The design of a ventilated façade with integrated crystalline silicon modules (Figure 3), provided both a technical and a communicative solution by addressing challenges on the regulatory uncertainties around grid connection and restrictions related to building aesthetics. The architect highlighted that early coordination with PV specialists was critical, although modules availability constrained design flexibility.

Figure 3 CIEMAT Building in Spain with the details of BIPV ventilated façade (Photo by N.Martín Chivelet © CIEMAT)

The CIEMAT PV research team considered the project as a unique opportunity to turn a building into a "living laboratory". The BIPV integration allowed to collect data, monitor shading effects from the surroundings and generate valuable knowledge for future BIPV applications. On the other hand, the collaboration with the architect helped balancing electrical efficiency with visual coherence. However, some challenges included the shortage of skilled BIPV installers and limited regulatory support for self-consumption at that time. Beyond the technical outcomes, the building served as an educational site to attract students serving as pilot project for doctoral and master's theses, and for both scientific and popular science publications. Moreover, the CIEMAT building is a demonstrator of BIPV adoption for local policymakers and professionals. This reflects the high social impact of the CIEMAT Building case study project. From the end users' perspective, the renovation was perceived as disruptive during the execution phase since BIPV systems were unknown. However, over time during the operational phase, the presence of BIPV modules became a source of awareness and inspiration. One of interviewees even implemented a PV pergola at home, crediting knowledge gained from the CIEMAT Building project. The building thus fostered social value beyond energy savings and it increased literacy around BIPV adoption, reinforced CIEMAT's identity as a sustainability leader and demonstrated that BIPV can act as both an institutional showcase and a catalyst for individual behavior change.

3.2. Case study project 02 - Hallenbad

The Hallenbad project (Figure 4) demonstrates how BIPV can transform a highly energy-intensive public facility like a swimming pool into a symbol of sustainability and architectural innovation.

Figure 4 Hallenbad Swimming Pool with shimmering green BIPV façade, outdoor and indoor views (Photos by Christopher Arnoldi)

Through an iterative design process and ongoing consultation with the client, the architects explored a series of façade typologies ranging from green façades and metallic panels to BIPV. In this case, the shimmering green façade, shifting from black to iridescent hues depending on light, was deliberately chosen to avoid the clichés of "blue swimming pool architecture" and to create a strong architectural identity. Planning and construction were challenged by tolerance limits in material composition, logistics, and the integration of two trades-façade and electrical aspects. However, this is one of those projects that aimed to prove BIPV could be both technically rigorous and aesthetically distinctive. The project's overall costs remained within budget because of the successful integrated planning process and close cooperation between all participants.

The municipality of Verl interviewed as public stakeholders, mentioned the building represented more than a swimming facility in this city: it was a political statement about energy and public value. The interviews highlighted council debates initially questioned the cost of a BIPV façade. However, consensus grew around its role as a forward-looking investment during a time of energy insecurity. In this project by feeding surplus summer electricity into the interconnected school campus, the BIPV façade addressed concerns of self-efficiency while ensuring that benefits extended beyond the use of the pool only. Moreover, the municipality emphasized that public buildings should set a target example in climate action, and collaboration with Helmholtz-Zentrum Berlin and it's Consultancy office for BIPV as consultancy office for BIPV further reinforced the vision of the swimming hall as a "living laboratory," opening opportunities for research, monitoring, and educational outreach. The City of Verl envisions this project as the foundation of a new cultural and architectural legacy that reflects the demands and responsibilities of the present era. The architecture, in this sense, is intended to unite generations both through shared use of the facility and through its role in fostering education for sustainability.

The inclusion of real-time energy displays and the possibility of school workshops are designed to translate this technological innovation into public awareness specially devoted towards young generation. For the end users of the building, early responses from swimming clubs and local citizens pointed to pride, curiosity, and a sense of ownership. While the social impacts are still emerging now as the pool opened to the public in mid-2025 but still the building has generated strong public attention during visit tours and open days as the nearby residents were originally unaware about the existence of BIPV façade. Then, the swimming clubs anticipated that hosting competitions in a modern sustainable venue will enhance their visibility and similarly the schools see opportunities to link energy literacy with daily activities. However, the interviewed expressed concerns about vandalism and long-term maintenance, while the municipality believes that the case study project represents a valuable opportunity to familiarise the community with emerging sustainable technologies. These findings from the interviewed highlight that BIPV can simultaneously enhance architectural quality, municipal identity, and social-technological learning, showing that renewable energy in the built environment provides cultural presence and value beyond the kilowatt-hours produced.

3.3. Case study project 03 - Voldsløkka skole

As demo project in the EU ARV Climate Positive Circular Communities initiative (*ARV - EU Projects*, 2025), the Voldsløkka Skole is the first plus-energy school in Oslo in Norway where the BIPV on the facades and Building-Applied Photovoltaics (BAPV) on the roof produce an annual surplus beyond the building's needs (Voldsløkka Skole, n.d.; Voldsløkka Skole Solcelleanlegg - Norconsult, n.d.) (Figure 5). The design balance aesthetic expression and performance, using green-colored modules for architectural distinctiveness and black modules where maximum efficiency is required.

Figure 5 Voldsløkka skole with green and black BIPV façade (Photo by https://nerligruppen.no/)

From the perspective of the municipal developer, the school represents both ambition and compromise. Previous projects shown the pitfalls of irregular PV panel sizes and late-stage integration, so Voldsløkka since the beginning aimed for adopting more pre-designed and standardized PV modules. However, architectural ambitions reintroduced complexity: dual-colored façades, angled orientations, and custom mounts stretched supplier capacity and required fallback planning. As one contractor explained, the challenge was "*not the solar cells themselves, but the façade's complexity*" - hundreds of unique elements, irregular cuts, and constant quality checks made the process highly resource-intensive. In this context, the designer developed a modular strategy with four different orientations of the same panel type using identical anchoring on all sides, to minimize the number of unique elements while preserving the architectural intent. The researcher involved in ARV project mentioned that and confirmed these constraints were magnified by regulation: the planning framework set a baseline school design without specific energy requirements, meaning the plus-energy ambition had to be retrofitted onto façades that were poorly oriented for solar gain. Parametric tools were therefore used to simulate thousands of combinations of panel color, tilt, and window placement before the final configuration was set.

Socially, Voldsløkka became a testbed for community engagement and awareness-raising. Since the design was largely fixed before ARV's involvement, public participation during planning was minimal. Instead, post-completion activities became central: Living Lab workshops for students using recycled construction waste, gamified learning on carbon emissions, and interactive tools like augmented reality (AR) to visualize material and energy choices were the tools adopted. The municipal perspective emphasized that the school should operate as a "*Meråpen skole*" ("More open school") and keeping its cultural spaces and sports facilities open to the neighborhood (Nyjordet, 2024).

Public perception of the project has been strongly polarized. The building's distinctive façade sparked lively media debate with critics questioning whether such a striking exterior suited a school while others praising its symbolic ambition. As the researcher observed, many passersby do not even recognize solar technology at first glance as an advantage for architectural integration, but as a limitation for public visibility. For the contractor and developer, this controversy nonetheless played a positive role: by sparking civic discussion, Voldsløkka normalized BIPV in Oslo's urban landscape, even if acceptance remains on the debate. In summary, Voldsløkka demonstrates both the possibilities and limits of urban BIPV adoption. It proved that plus-energy schools are achievable even under challenging orientations, but only through non-standardized solutions that raise costs and risks. At the same time, it showed how post-completion engagement via Living Labs and AR tools and open school models can anchor a technical project in its social context. For Oslo, the project functions less as a blueprint for replication and more as a reference point and illustrating the trade-offs between design ambition, technical feasibility, and community.

3.4. Case study 4- Frankin University Switzerland

The Franklin University Switzerland (FUS) campus in Sorengo integrates a dynamic shading system with white glass PV louvers installed in 2023 (Figure 6) (SolAR, 2023). Early monitoring recorded 9,040 kWh/year, below the expected energy of 18,700 kWh/year, due to temporary downtime and the unexpected shading from a new adjacent building. Despite this shortcoming, the system advanced mobile PV louvres from prototype testing to real-world deployment and showcases the potential of multifunctional building skins in a strong way.

Figure 6 Franklin University Switzerland (FUS) and white rotating photovoltaic louvers (Photo by Leo Torri)

Based on the results of interviews, the building owner mentioned that sustainability was framed as a central institutional value in the project, and the PV louvers became more than an energy device. They symbolized FUS's commitment to environmental responsibility and reinforced the university's identity while delivering tangible improvements in thermal and visual comfort for students.

The scientific partner (SUPSI) focused on BIPV technology for marketing activities from lab validation (trl4) to demonstration in an operational environment (trl7). Simulating and monitoring the dynamic BIPV system, supporting stakeholders in a coordinated integrated process from early design to construction, allowed to optimize the process work stages, to define reference cost-effectiveness scenarios, and to prepare a market implementation plan. Their integrated role, ranging from technology validation, process and cost analysis, stakeholders' coordination to disseminating findings, ensured that the project served both FUS and the wider scientific and professional community as Pilot & Demonstration. Researchers also mentioned the impact of featuring the project in related activities like training and education, dedicated events for engaging architects, training platforms and videos, encouraged interest so that the system was launched by the producer for the market entry and considered for other projects. On the other hand, the architectural team remarked how integration and symbolism were their concept, and the louvers were designed to resemble the turning pages of a book combining shading, energy production, cultural identity and use of the building in a single dynamic gesture and positioning the building as a landmark for both sustainability and design innovation.

Moreover, the end users, including students and staff, experienced the building on a personal level. Occupants valued improved comfort and control of light and some expressed pride in working within an environment that embodied the university's sustainability goals. At the same time, several occupants reported limited understanding of how the system operated. While it was well integrated into architectural design, insufficient user communication highlighted the need for occupant-oriented education in such integrated systems.

3.5. Case 5- Firmenich Tower

The transformation (from industrial to office building) and renovation of the Firmenich Tower in Geneva, Switzerland, achieved in 2022, is a result of an architecture competition where the winning design stood out partly thanks to the deployment of BIPV (Figure 7). This technology was integrated intelligently into a successful architectural project and explained how BIPV on façades are shaped as much by regulation, risk, and institutional identity as by technology. Initially envisioned as a bold chromatic statement, the design was moderated during the review processes. This was a successful collaboration between architects, public authorities, building owner, which is public pension fund, which made approval process doable and secure.

For the architects, the tower was a chance to turn a threatened industrial building into a high-performance office landmark to meet Geneva's energy renovation standards. From their perspective, the PVs were architectural elements integrated in enhancing building's identity. While the solar integrators in the interview highlighted that with late involvement in the process, they experienced the project differently.

Figure 7 Firmenich Tower within urban context, view, elevation and section of façade-integrated BIPV systems (Photos Baud&Fruh)

This made them struggle with delays, fragile modules, and quality control issues at times included sending entire batches back to the PV modules manufacturer. From this experience, they learned that BIPV adoption must be planned early in the process with strong coordination and reliable partners. While it is classified as 'interesting' from a heritage and architectural point of view, it did not require protection. In the original renovation project, a more colorful gradient was planned between the façade sections. The Architecture Commission of Geneva and the building owner preferred a simpler solution resulting in a subtle gradient between green and blue tones. They believed installing PV panels on the concrete gables was less appropriate, as gables are typically strong architectural elements and in addition there should have been a risk of sunlight reflection for the surrounding. Meanwhile, the regulator treated the tower as a pilot case. Although Geneva's updated energy law now refers only to "appropriate surfaces" for solar installations, with no particular focus on façades, this project was cited as proof that BIPV façade can work to transform and redevelop a disused or neglected area. The building owner framed the investment as both practical and symbolic. Additional costs due to BIPV are not so high in such a curtain wall because similar glass panels would have been installed in the opaque parts between the windows without solar energy. Costs were built into rents, the project was profitable, and the tower became part of a broader sustainability portfolio. Although they accepted a calculated risk because there is no special access system to maintain the façade and it means any serious failures would be possible to be repaired. Fire safety was another constant concern, especially in the shadow of Grenfell (*Flammability Tests for Building Facades - ScienceDirect*) where authorities were reluctant to provide long-term guarantees. However, the project was designed before fire safety regulations for tall buildings became more restrictive in Switzerland, requiring now very expensive fire tests in real conditions. Finally, the end-users (i.e., employees) were surprisingly unaware of the BIPV façade. One citizen even complained in the local newspaper that "*the renovation forgot solar*".

4. Discussion

4.1. Interconnected BIPV challenges

The interconnected challenges with specific examples is obtained by looking at full columns in **Error! Reference source not found.**.

Table 2 Matrix of mapping challenges in the selected and analyzed BIPV case study projects

Challenge category	Specific challenge	Case study projects				
		01	02	03	04	05
Technical and logistical	Supply chain and component sourcing in module availability, supplier delays/defects, production shutdowns	●	●	●		●
	Complex installation and integration due to heavy/fragile modules, intricate wiring, custom shapes/angles, strict tolerances		●	●	●	●
	Shading and orientation from trees, surrounding buildings, performance trade-offs for aesthetics	●	●		●	
	Grid connection and energy management (e.g., unclear feed-in rules, zero-injection requirements, grid capacity limits)	●	●	●		
	Fire safety compliance (e.g., meeting RF1/RF2 standards for façades, optimizer placement, lack of clear guidelines)		●	●		●
	Long-term reliability and maintenance access (e.g., doubts about electrical components, inaccessible optimizers, complex repairs)		●		●	●
Regulatory and approvement process	Unclear or restrictive regulations in grid connection, self-consumption, initial permit denials	●		●	●	
	Lack of financial incentives and subsides	●				
	Complex approval processes for full PV façades, heritage/visual sensitivity, fire safety			●		●
	Public procurement rules (hindering early involvement of specialized BIPV integrators)		●			
Financial and economic	High perceived and actual cost (BIPV viewed as a premium product, higher initial investment)		●	●	●	●
	Economic justification and return of investment are challenging for public pools, social housing which requires long-term vision		●			
	Budget and tender management to reopen tenders, manage higher costs within public budgets		●			
Project management and collaboration	Interdisciplinary coordination which needs close, continuous collaboration between all stakeholders.	●	●	●	●	●
	Late involvement of key stakeholders			●		●
	Skills and knowledge gaps for PV installers and façade contractors and architects lacking specific BIPV experience	●	●	●		
Social and awareness	Low public awareness (occupants and public do not realize BIPV system exists, limiting demonstrative impact)	●	●	●	●	●
	Lack of user communication and education (occupants not informed about the project or its benefits)	●				
	Aesthetic and social acceptance (strong public/media reactions to appearance; criticism of architectural choice, not solar tech)			●		
	Risk of vandalism		●			

They include technical and logistical, regulation and improvement process, financial and economic, project management and collaboration and social and awareness. The most pervasive challenges are systemic and common to all case study projects even if they are in different cultural and legal contexts in Europe.

The results underscore that the foremost hurdles are socio-procedural, rooted in collaboration and communication. This is compounded by near-universal financial perceptions of high cost and recurring technical complexities in installation and supply chains. A technical hurdle like fire safety compliance is exacerbated by regulatory ambiguity, while a social challenge like public acceptance is directly influenced by the effectiveness of stakeholder collaboration. Therefore, the most significant challenge is the interdependence of these barriers, demonstrating that BIPV deployment is a complex socio-technical endeavor and requires integrated solutions across technical, financial, regulatory, and social fronts. Furthermore, addressing these challenges will enable policymakers to anticipate non-technical barriers, design effective incentives, and capitalize on the full spectrum of BIPV's value beyond energy metrics.

4.2. Social impact of BIPV in society

The interviews across five European cases reveal that the social value of BIPV projects is substantial and multifaceted, though this result represents a segment of the potential impact spectrum that could be realized through mass adoption. Based on the result explained in Table 3 the social impact of BIPV are including: demonstrative and educational value, community and use perception, identity and symbolism, aesthetic and functional integration, behavioral shift and policy and professional influences. The data from the interviews highlight that the analyzed case study projects are perceived as demonstrator and landmark building where the BIPV has a catalyst function for social awareness and cultural change creating essential knowledge capital towards green energy transition of the built environment. The case study projects serve as a tangible reference for students, end users, policymakers and professionals. Moreover, the projects are strategically employed to reinforce the institutional identity of the building owners and aim to prove the commitment of private and public stakeholders to innovation and sustainability. The empirical data identifies several key impact areas.

Table 3 Matrix of documented social impacts in BIPV case study projects

Social impacts		Case study projects				
Categories	**Finding based on results**	**01**	**02**	**03**	**04**	**05**
Demonstrative and educational value	Serve as a public demonstrator / reference project	●	●	●	●	●
	Used for formal education like student theses, workshops, academic research	●	●	●	●	
	Planned or existing public data display by screens or dashboards		●	●		
Community and user perception	High user/occupant pride and positive feeling	●	●	●	●	
	Strong community and media engagement		●	●	●	
	"Invisible" integration and public unaware of BIPV function, sees only architecture		●		●	●
Identity and symbolism	Enhances owner's identity as sustainable project	●	●	●	●	●
	Project is a Source of local/Institutional pride		●	●	●	
	Building as a landmark or symbol of innovation			●	●	
Aesthetic and functional integration	Positive perception of visual aesthetics	●	●	●	●	●
	Appreciation of multifunctionality (e.g., shading + generation)		●		●	
	Improved user comfort (thermal, visual)	●			●	
Behavioural shifts	Inspired environmental behavior	●				
	Fostered internal stakeholder learning (improved inter departmental relations)	●				
Policy & professional influence	Influenced professional practice or local policy discussion			●	●	●
	Project cited as a reference for future projects	●	●	●	●	●

4.3. Connections between challenges and social impact of BIPV in society

The analysis of the connections between challenges and impacts across the five case studies, illustrates how different barriers are shaping the social value of BIPV. The challenges categories and subcodes reveal systemic patterns: technical and logistical issues (e.g., supply chain delays, complex installation, fire safety compliance), regulatory ambiguities, and financial concerns (e.g., high cost, return of investment) consistently emerge. Equally prominent are socio-procedural barriers such as limited public awareness, lack of communication, and late stakeholder involvement. These cross-cutting challenges, present in nearly all case study projects, reinforce the observation that BIPV deployment is deeply shaped by institutional and social conditions. The impacts of pathways highlight how, despite these barriers, BIPV projects deliver significant social value. Impacts cluster around demonstrative and educational functions (e.g., serving as reference projects, public demonstrators, or sites for formal education), symbolic and identity-related benefits (e.g., sustainable identity, institutional pride, landmark status), and community/user-related outcomes (e.g., engagement, pride, comfort). Broader societal impacts that we can expect associated with mass adoption such as significant reductions in energy poverty, large-scale job creation, and enhanced community energy resilience were not the focus of these cases but represent a critical area for future research as the market matures.

4.4. Limitations of the study

This study has some inherent challenges, while the qualitative case study approach enabled rich, context-specific insights through most experienced stakeholders, the sample is limited to five selected case study projects in Europe and 21 interviews which capture only partially the diversity of BIPV applications at European scale. It is important to note that although this study captured impacts from few stakeholders for each case but informed one who had close involvement in the project and also cases studies are pioneering BIPV projects. On the other hand, social impacts were interpreted mostly through stakeholders' perspectives rather than direct measurement of user behavior. In this regard, local surveys to collect the perspective of end users and buildings' occupants are already planned for the next phase of this research. This study can be a basis for the identification and definition of measured Key Performance Indicators (KPIs) in further steps. Moreover, these projects are pioneers in their context, so they reflect early-stage experiences that may differ from mainstream BIPV adoption. Therefore, the findings provide exploratory evidence and transferable lessons for future research and practice even if their limited number cannot be statistically generalized.

5. Conclusion and further developments

This study examined the challenges and social dimensions of BIPV across five European case studies situated in distinct geographical, cultural, regulatory, and architectural contexts. In these cases, while technical barriers such as fire safety compliance, grid connection complexity, and supply-chain instability and high upfront cost remain significant, the findings explain that their impact is often mediated or even amplified by social and organizational conditions. Projects with early stakeholder involvement, clear roles, and cross-disciplinary dialogue managed coordination and approval challenges more effectively, not because social factors removed technical difficulties, but because they enabled faster problem recognition, knowledge sharing, and adaptive solutions. BIPV thus emerges as a socio-material interface where energy transition is negotiated through design decisions, aesthetic values, and institutional practices in each context. These projects demonstrate that trust between stakeholders, communication, and shared purpose specifically acts as an informal infrastructure to support technical performance and regulatory navigation. Moreover, their visible and symbolic roles as demonstrator buildings in each city foster learning, institutional identity, and policy influence. In this condition, BIPV is less a product than a process of alignment between technology, culture, and governance, transforming buildings from technical systems into public artifacts of sustainability and collective innovation. These findings highlight recurring factors as below which helped to make BIPV implementation successful:

- Early stakeholder involvement and clear roles are crucial in BIPV projects. Involving architects, researchers, developers, contractors, and users with explicit role definitions allows preventing unnecessary compromises in design quality and system optimization.
- Multiple cases stressed that BIPV industry constraints should not dictate design. Early alignment of architectural vision and solar engineering reduces costly modules and installation customizations during the construction process.

- Policy and regulatory adaptation for BIPVs include updating fire and electrical codes, and urban planning needs clearer pathways to accommodate BIPV's dual function as both a building material and an energy system to enabling safe, efficient, and innovative deployment.
- Communication and collaboration practices are key factors for successful BIPV adoption. Across the analyzed case study projects, the interviewees in this study emphasized the value of face-to-face workshops and cross-disciplinary facilitation to break down misunderstandings and build trust.
- Educational visibility and user engagement influence social acceptance. It grows when users and the public are aware of the technology. This requires signage, dashboards, or guided tours. Otherwise, seamless integration may reduce recognition and diminish social impact which happens in some cases in this study.
- Custom façades integrating BIPV often result in visually iconic projects but also introduce higher complexity and risks and sometimes cost. While stakeholders argued for greater standardization in panel formats, system interfaces and supply-chain reliability to improve feasibility, they also emphasized that full standardization could constrain architectural expression. ¨
- High costs sometimes can arise from complex façade substructures and control systems rather than the PV technology itself. Early integration of BIPV design and engineering is therefore essential to maintain feasibility while achieving architectural quality.
- The success of a BIPV project depends on whether the initially planned costs and schedules can be effectively maintained. This consideration must therefore be integrated into early design and coordination phases to ensure feasibility alongside innovation.

Results from the interviews and qualitative analysis reveal that the social value of BIPV is realized through its role as a demonstrator, a symbol of identity, and a catalyst for public discourse. However, the findings also highlight a critical aspect described here as the "Awareness Paradox". While seamless integration can enhance architectural aesthetics and social acceptance, it can also make the solar technology of the building less visible, which means it requires additional communication and educational efforts to make its function and value clearer. Thus, well-integrated design (i.e., invisibility) should not be seen as a disadvantage but as a condition that shifts the focus from visual recognition to active engagement and public communication about BIPV's contribution to sustainability. This underscores that the social impact of BIPV should be intentionally designed, communicated and needs to be considered if the decision makers consider it as a driver for the green energy transition of the built environment. In the same case study projects that face coordination, regulatory, or cost challenges can still play a strong catalyst role in social and cultural impacts, underscoring the need to design BIPV with both barriers and benefits. This research suggests that the success and scalability of BIPV depend on a fundamental shift in perspective and facilitating the challenges to implement it. Decision-makers in both the public and private sectors are the most important actors and BIPV must be framed as a strategic, multifunctional investment in a building envelope that pays for itself in energy and durability as well as an investment in an architectural legacy that embodies sustainability and inspiration towards a broader cultural shift embedding clean energy. This highlights the need to facilitate the BIPV adoption when the context has the potential for it, thus it brings social and environmental impact for society. In the context of transformation and refurbishment, BIPV offers additional potential as a facilitator of preservation and allow buildings to retain their visual and cultural identity while upgrading their energy performance. By integrating solar technologies seamlessly into existing façades, BIPV can reconcile heritage conservation with climate goals. The selected case study projects further highlight that schools, universities, and public buildings carry weight in terms of social impact due to their visibility, symbolic role, and educational function. This makes them effective testbeds for both technological learning and cultural diffusion and dissemination of knowledge. However, these cases represent only one segment of the BIPV landscape. In parallel, a large share of the real market in Europe are developing small-scale, in-roof BIPV installations through individual decision-making rather than public demonstration. This study explains that to move from pilot projects to mainstream BIPV adoption, clearer regulatory pathways, better cross-disciplinary collaboration and recognition of multifunctional benefits are needed for BIPV and decrease in costs could facilitate the broader implementation in private buildings. Future progress in BIPV requires expanding the evidence base research through a wider variety of case studies in diverse geographies, building functions, and technological applications. This will lead to a more comprehensive understanding of its social potential for society and by that standardized (KPIs) for social impact can be identified and systematically measured. Such metrics are crucial for moving beyond anecdotal evidence and allow project teams to quantitatively design for higher social yield and provide a foundation for developing targeted local guidelines and support mechanisms.

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