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Photovoltaic Power Systems Programme

Task 15 Enabling Framework for the Acceleration of BIPV

PVPS

Analysis of the Technological Innovation System for BIPV in Sweden 2024

Report IEA-PVPS T15-18:2024

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What is IEA PVPS Task 15?

The objective of Task 15 is to create an enabling framework to accelerate the penetration of BIPV products in the global market of renewables, resulting in an equal playing field for BIPV products, BAPV products and regular building envelope components, respecting mandatory issues, aesthetic issues, reliability and financial issues.

Subtask A of Task 15 is focused on the analysis of the Technological Innovation System (TIS) for BIPV on national levels in order to identify systemic problems and recommend actions for industry and/or policymakers that want to support the development of the BIPV market and innovation system. This document is one of the national TIS-analysis reports. A synthesis of national TIS-analyses will be made based on this and other national reports.

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Citypassagen Örebro, photo Malin Unger

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IEA PVPS
Task 15

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LIST OF ABBREVIATIONS

1G	First generation photovoltaic technology, i.e. crystalline silicon
2G	Second generation photovoltaic technologies, i.e. established thin film technologies like amorphous silicon, cadmium-telluride, copper-indium-(germanium)-selenide.
3G	Third generation or “emerging” photovoltaic technologies, mostly newer thin film technologies like perovskites, organic PV, dye-sensitized cells.
BAPV	Building Applied Photovoltaics
BIPV	Building Integrated Photovoltaics
BOS	Balance of System. All components in a PV system, but the PV modules.
IEA	International Energy Agency
IEA PVPS	International Energy Agency Photovoltaic Power Systems Programme
TIS	Technological Innovation System
TRL	Technological Readiness Level

EXECUTIVE SUMMARY

This report provides an analysis of the Technological Innovation System (TIS) for Building Integrated Photovoltaics (BIPV) in Sweden for the period 2021-2023, following the guidelines of the IEA PVPS Task 15. (Report T15-16:2023)

The first known BIPV systems in Sweden were installed in 2001. However, BIPV has largely been an exception to the country’s primary PV market of building-applied PV. Initial BIPV applications focused on solar shading solutions, but rooftop BIPV systems have since become more prevalent. More recently, façade BIPV systems have started to gain attention. Research related to BIPV has been limited and primarily linked to second and third-generation PV and to (BI)PV applications in urban areas.

The BIPV market in Sweden is considered to be in a niche phase, with discontinuous roof applications nearing commercial market development. In contrast, shading devices, parapets, and canopies are still largely in the demonstration phase. The functioning of the TIS is evaluated against the goal of achieving commercial market development, with approximately 10% of all building-related PV becoming building integrated.

To achieve this goal, knowledge development could be sufficient, with moderate fulfilment. Much of the knowledge development has been established abroad or by a limited number of actors, and knowledge diffusion is weak. There is a lack of engineering and product knowledge in the broader PV installation sector, as well as among architects, technical consultants, and potential clients. This adds up to a weak legitimacy of the technology, together with little technical guidance and a mismatch with construction industry practices. Entrepreneurial experimentation is also weak and limited to a few actors with little diversity in background and few holistic concepts or standardized solutions in their offerings. Furthermore, guidance for new actors to the BIPV TIS is very weak due to strong competing TISes (BAPV, utility scale PV) and an unlevel regulatory playing field. Among existing actors in the TIS, social capital development is weak due to a low number of specialized events. Financial and infrastructural resources are mostly sufficient, but there is a lack of suitably trained human resources.

The report concludes with recommendations, grouped into five categories: to increase diversity and focus of BIPV actors; to improve technical guidance and assurance for BIPV installations; to level the playing field between BIPV and other PV applications; to promote cultural change in the construction and real-estate sectors; and to enhance social networks. More detailed recommendations are directed to different actor groups. Industry actors are recommended to increase cooperation between PV and construction industry; define best-practice in trainings and demonstration projects; apply for external financing of lab tests and verifications; and to collaborate on road-mapping, public campaigns, or market reports. Market actors (public or private) that want to support BIPV development can join collaborative efforts with industry; engage in demonstration projects or innovation procurement for reproducible BIPV concepts; or require cross-sector cooperation in tenders. Public authorities can enhance BIPV deployment by investigating how to address the unlevel regulatory playing field; encourage BIPV in municipal planning; clarify building code requirements; and support other actors’ initiatives such as demonstrations, tests and verifications, workshops, etc. Finally, supporting and research or education actors can also get involved in investigating the unlevel playing field, or organisation of technical and scientific workshops; run BIPV courses for professionals or students; and support demos, tenders, lab tests, etc.

1 INTRODUCTION

This report presents an analysis of the Technological innovation System (TIS) for Building Integrated Photovoltaics (BIPV) in Sweden. It's main aim is to facilitate and support the implementation of BIPV in Sweden and to support the innovation and industrial development of BIPV solutions.

The report follows the IEA PVPS Task 15 Guide for Technological Innovation System Analysis for Building-Integrated Photovoltaics [1]. This guide, in its turn, builds upon the academic TIS framework as defined and developed by Bergek et al. [2], Hekkert et al. [3] and Hellsmark [4]. The report and underlying analyses consist of six steps, presented in the following chapters of this report.

Initially, the scope of the TIS is defined and a brief historical background of it is presented in Chapter 2. The next section, Chapter 3, contains the structural analysis that describes the actors, networks and institutions that constitute the TIS. Based on the structure and market situation, the market development phase of the TIS and its sub-technologies is assessed in Chapter 4. The same Chapter also defines a development target for the concurrent functional analysis. The essence of that functional analysis (Chapter 5) is the assessment of the performance of the TIS in terms of eight functions: knowledge development, knowledge dissemination, entrepreneurial experimentation, resource mobilization, development of social capital, legitimation, guidance of the search and market formation. From the structural and functional analyses, systemic weaknesses and opportunities are identified and described in Chapter 6. Finally, Chapter 7 provides recommendations for different actors in the TIS on how to overcome the problems and reach the target.

Most of the data gathering was in forms of interviews with representatives from the value chain (listed in Table 1), performed in 2021. Furthermore, a patent search, historical market and application data analysis and minor consultations with interviewees and RISE colleagues were performed in 2022 and early 2023, as was the main analysis work. The report therefore primarily represents the situation of the TIS in 2021, but major changes in institutions or other parts of the structure after that year are also included. The authors have tried to clearly state the time of occurrence for all developments that took place after 2021.

Several authors of this report have been actively involved in PV and BIPV industry or applied research during the last one or two decades, adding additional insights to the data collected in interviews, etc.

Table 1 List of the interviewees' organisations and roles

Organisation	Role	Category
Castellum	Project developer	Real estate owner/developer
Byggföretagen	Responsible for energy	Supporting actor (Industry association; Construction)
Energimyndigheten (Swedish Energy Agency)	Administrator Research innovation and business development	Policy maker/Supporting organisation
Smartfront	CEO	Construction product developer/Installer
Senergia	Sales Manager	Supplier (Wholesaler)
Glava Energy Center	CEO/Executive Director	Supporting organisation
Skanska	Purchaser façades	Construction company/Real estate developer
Aktea Energy	Consultant, lecturer vocational education	Energy consultant / Education
Einar Mattsson	Project Manager, Electrical & Plumbing	Real estate owner
Boverket (National Board of Housing, Building and Planning)	Administrator/Project Manager Sustainable Cities and Energy Performance Certificates	Policy maker (building codes and other legislation and policies)
Fiskarhedenvillan	Chief Technical Officer	Construction company
KP Energy (Kraftpojkarna)	Product manager	Supplier (Wholesaler)
White Arkitekter	Architect	Architects
InnoEnergy	Business developer	Supporting actor
AddSolar	Architect/Entrepreneur	Architects / BIPV product manufacturer
Dalarna University	Senior Lecturer Energy and Environmental Technology	Education / Research
Lund University	Senior Lecturer Energy and Building Design	Education / Research
SAPA Building Systems Sweden	Sales Manager	Construction product manufacturer / installer
Svensk Solenergi	CEO	Supporting actor (Industry association; Photovoltaics)
Midsummer	Business Area Manager	BIPV cell/module/product manufacturer
Benders	Product manager	Construction product manufacturer
Wästbygg	Business developer	Construction company
Stadsfastighetsförvaltningen, City of Gothenburg	Energy engineer/Expert solar cells	Real estate owner/developer

2 DEFINITION OF THE TECHNOLOGICAL INNOVATION SYSTEM FOR BUILDING-INTEGRATED PHOTOVOLTAICS

This section provides an introductory overview of building-integrated photovoltaics (BIPV) in Sweden. It outlines the scope of the analysis and describes the development of the technology and its innovation system, including actors, networks, and institutions. The aim is to clearly define the technology that is the focus of the analysis.

2.1 Scope of this analysis

This TIS analysis concerns BIPV modules and BIPV systems as well as PV modules and PV systems for purely aesthetical integration, where the following definitions are used:

- A BIPV module is a PV module and a construction product together, designed to be a component of the building. A BIPV product is the smallest (electrically and mechanically) non-divisible photovoltaic unit in a BIPV system which retains building-related functionality. If the BIPV product is dismounted, it would have to be replaced by an appropriate construction product [5].
- A BIPV system is a photovoltaic system in which the photovoltaic modules satisfy the definition above for BIPV products. It includes the electrical components needed to connect the PV modules to external AC or DC circuits and the mechanical mounting systems needed to integrate the BIPV products into the building [5].

No further delimitations are made regarding BIPV application types. All major application categories, as defined in EN 50583-2:2016 [6] and IEC 63092 [7], are relevant for Swedish building types, even though market development is varying.

This study focuses on building-integrated photovoltaics (BIPV) in Sweden, considering both Swedish and international companies active in the Swedish market. International regulations and standards applicable to Sweden are also taken into account. The study acknowledges the influence of international market dynamics on actors operating in Sweden, but these are considered as static boundary conditions for this analysis. The global process of knowledge development is recognized, and the international state of the art is used to distinguish between needs for knowledge development or dissemination in Sweden. For more insights on international trends and dynamics, readers are referred to an upcoming synthesis report by IEA PVPS Task 15.

2.2 Historical technological development

The Swedish photovoltaic (PV) market has historically been dominated by building-related applications. From around 2005, the market focus shifted from off-grid to on-grid systems. The market for centralized, ground-mounted applications remained marginal until 2017 and started to take off in 2020 [8].

Building-integrated photovoltaics (BIPV) applications initially (2000-2009) had a significant share (estimated >50% of BIPV installations) of solar shading systems with crystalline silicon (c-Si) PV modules (example in Figure 1). These systems were typically customized for either the mounting system (using series produced modules) or the modules (integrated in “conventional” shading systems) or for both. Some roof and façade BIPV systems were also installed during this period, but without a clear dominance of any particular application type.

The majority of PV installations were building added PV (BAPV) on rooftops or off-grid domestic PV systems [9], with PV systems using modules with black backsheets and black frames being relatively common compared to other European markets.[i]

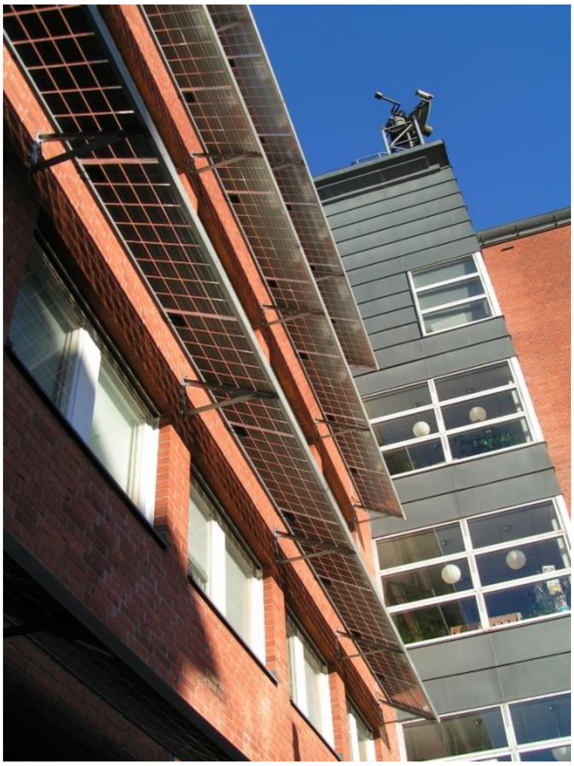

Figure 1 Solar shading installation on Ekologihuset in Lund (architect: M. Pusterla, Fojab; contractors: Switchpower, Gaia Solar; image: M. van Noord)

In the decade from 2010 to 2019, various discontinuous roof-integrated solutions found their way into many installers' and wholesalers' product portfolios, but the number of installations remained (very) low initially. These solutions included regular and tile-sized modules using crystalline silicon or thin-film technologies, and they were often developed for foreign markets with FIT-bonuses. A Swedish-developed solution with glass tiles combined with underlying thin-film modules was offered starting in 2014. Over time, more PV roof solutions were developed for both tiled and metal sheet roofs, and their installation numbers are estimated to have increased. Façade solutions remained uncommon, maybe with a slight increase towards the end of the decade. Meanwhile externally integrated PV systems, such as solar shading and parapets, became more incidental and continued to rely on customized solutions.

In recent years, there have been a few applications of coloured modules. These include transparent thin-film-based façade elements with coloured interlayers and crystalline silicon modules with a coloured top layer, which have been used on facades and rooftops.

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[i] As no (historical) market statistics for BIPV are available, estimates are based on highlighted projects in IEA PVPS National Survey Reports and personal impressions from two RISE employees (O. Hemlin and M. van Noord) who were employed by two different leading project developers during this period. At that time the market was small and dominated by public tenders and therefore highly transparent.

Swedish research on photovoltaics has primarily focused on thin film and newer technology generations. However, there has been limited research and development efforts directed specifically towards building-integrated photovoltaic (BIPV) applications.

2.3 Historical development of the innovation system

The first known BIPV installations in Sweden that were two solar shading installations at the start of the millennium. One was at a multi-family dwelling “Harmonihuset” in Malmö (8 kWp semi-transparent mc-Si, 2001) and the other was at the Almedal library (“Almedalsbiblioteket”) in Visby, Gotland (5 kWp mc-Si, 2002) [10]. The latter was designed by Malmström Edström Architects Engineers and delivered by Colt International [11].

From 2002-2004, three more BIPV projects were realized in the newly developed Hammarby Sjöstad neighbourhood in Stockholm. These installations were all developed on multi-household dwellings by three different developers. Project developing company JM included two BIPV skylight glazings. Construction company NCC integrated PV in the façade, balcony railings and windows on two buildings (Figure 2). Municipal housing company Familjebostäder added a layer of PV louvres to a façade, partially functioning as shading devices (Figure 3). These activities (in Hammarby Sjöstad) were linked to a national research project, developing an online planning and design support tool (now discontinued), and a European demonstration project for BIPV, PV-NORD [10], [12].

Figure 2 BIPV facade and balcony parapets in Hammarby Sjöstad, Stockholm (image: M. van Noord)

From 2005-2008, during the running period of the first national investment subsidy scheme for PV on public buildings, incidental BIPV installations were performed. This was the birth age of a niche market for PV, with the city of Malmö as an early lead customer, requesting not only BAPV (including façade PV systems) but also solar shading PV systems on several buildings. PV system suppliers at this time (around 7 in total) were not specialized in BIPV, but some actors were representatives for – or otherwise relying on – international players with BIPV experience such as Schüco, Gaia Solar, Schweizer and Ertex Solar. Most PV system suppliers were also offering consultancy services and were the main source of engineering knowledge on the market, apart from a single specialized PV consultancy firm.

After the initial subsidy scheme for public buildings, a more general investment subsidy was established 2009 and continued in similar forms until 2021. Since these schemes were all covering grid connected PV in general, the number of BIPV installations remained incidental and PV system suppliers focusing exclusively on BIPV did not arise.

Figure 3 BIPV louvres in Hammarby Sjöstad, Stockholm (contractor: Gaia Solar; image: M. van Noord).

Leading customers and projects during the last decade include Skanska (Väla Gård roof PV system), Uppsalahem (Frodeparken façade PV system), the Vallastaden area in Linköping and Vasakronan.

In the late 1990s and early 2000s, PV cell research in Sweden was initially dominated by the Ångström Solar Centre at Uppsala University and its spin-off company, Solibro, who produced groundbreaking research results on thin film CIGS-cells. The same Ångström Solar Centre started working on dye-sensitized solar cells (DSC, or Grätzel cells) early on. Other universities, such as KTH Royal Institute of Technology, Chalmers University of Technology, and Linköping University have also focused their research on CIGS and third-generation technologies like DSC, quantum dot, organic, and more recently, perovskite solar cells. This research has mostly been funded by governmental agencies for research, innovation, or energy. Manufacturing company Exeger (formerly NLAB Solar), which is developing DSCs, initially had a clear BIPV focus and attracted investments from the glass construction sector but is currently focusing on small modules for the electronics industry and consumables and wearable accessories.

The SolEl program, which began in 2000 and was co-financed by industry associations and individual companies from the energy, real estate, and construction industry along with governmental research funding organisations, has been instrumental in propelling applied research on a (BI)PV system level. The Department of Architecture and Built Environment of Lund University has established a leading role in BIPV system level research nationally and internationally through participation in several related IEA Solar Heating & Cooling tasks, often in cooperation with White Arkitekter (one of Scandinavia's leading architectural practices). The SolEl program also financed an international best practice outlook report on BIPV in 2010 [13].

Research on PV technologies in Sweden has led to the emergence of several start-ups, often focusing on second and third generation PV technologies. Although thin film technologies are not specifically linked to BIPV, they were often considered to be particularly fit for building integration. This could be a reason that actors like Solibro Research[ii] or Midsummer, which worked with thin film CIGS, have made efforts towards BIPV applications. Solibro Research developed a slide-in mounting solution for roof-integration. Midsummer, that initially focused on creating manufacturing equipment for CIGS cells, started small scale production of flexible PV modules for demonstration purposes in 2012 and shifted its main focus to production of modules and BIPV solutions around 2017-2018.

[ii] Solibro was sold to German Q-Cells 2009 and only research activities remained in Sweden.

Several manufacturers of crystalline silicon (c-Si) PV modules have existed in Sweden since the late 1990's with a peak of activity in the early 2000s. The largest of these manufacturers were (partly) owned by large international companies, such as Solar World (Gällivare Photovoltaic AB, also GPV) and REC (REC ScanModule AB), and they focused on standard modules in series production rather than BIPV applications. Still, GPV used its flexibility in supplying all black modules as a competitive edge for BAPV rooftop applications. Another manufacturer, Arctic Solar, did produce customized modules. However, this was only a side activity, and the company never produced these modules in large quantities. Competition from mainly Chinese manufacturers led to many Swedish manufacturers going bankrupt between 2008-2010. Some tried to niche towards BIPV modules including custom-made modules, e.g. PV Enterprise Sweden AB (2010), Solar Design AB (2011), Jowa Energy Vision (2012-2017), but these initiatives either did not survive or did not take off [9], [14]–[19].

One of the current market leaders in BIPV, Soltech Energy, initially relied purely on thin film (CdTe) in their BIPV solutions. Another main BIPV industry actor, Midsummer, has ever since its start focused purely on thin film (CIGS). This may have affected the general perception in Sweden that BIPV has lower efficiency at higher cost and perhaps it also delayed the awareness that BIPV can also comprise high-efficient Si-technology. However, Soltech expanded its BIPV portfolio to include CIGS and c-Si technologies around 2019, partly through acquiring installer companies like MeraSol, that offered such solutions. Other companies like SunRoof and Raymond Solar (formerly GruppSol) demonstrated that c-Si-panels in mass-produced sizes could also be used in BIPV roofs, often at a more competitive price (per Watt peak). Recently, companies like ML-Systems, Roofit, and Solar Stone have entered the Swedish market with high-efficiency c-Si panels in various shapes, sizes, and colours. All together this means that, since 2017, several new supply actors turned up and the number of companies marketing different BIPV solutions increased from 2-3 to 5-10. Most of the afore-mentioned companies claimed that they offered both BIPV roofs and facades. However, to our knowledge, Soltech and ML-Systems are the leading suppliers of BIPV facades, whereas other companies have done incidental projects only. In the past 2-3 years there has been a growing interest in PV facades and in 2021 some ground-breaking BIPV façade projects were concluded on more or less commercial terms.

Out of the BIPV products offered on the Swedish market today, approximately half are based on thin film (CdTe and CIGS) and half on crystalline silicone.

Creation of networks on BIPV have, to a certain extent, been driven by Soltech because of their active external communication and their business strategy of acquiring companies in complementary parts of the PV, BIPV and installation markets, more recently also adding companies specialized in storage and charging technologies to their group. Other, mostly informal networks have developed around the actors participating in international activities around BIPV or PV and architecture within IEA's technology collaboration programs (SHC or PVPS): Lund University, RISE – Research Institutes of Sweden, Mälardalen University, and the companies Solkompaniet and White Arkitekter. Since 2015, the latter four actors have also been engaged in a number of national research projects on BIPV including interaction with companies in different parts of the value chain, notably construction companies and real estate owners.

Despite these advancements, there have been no significant institutional drivers for BIPV, such as targeted subsidies or legal requirements. On the contrary, several BAPV applications have been exempted from building permit requirements since 2010, but most BIPV still does require building permits. National building codes (Boverkets Byggregler) have not specifically addressed BIPV.

3 STRUCTURAL ANALYSIS

3.1 Technologies and areas of knowledge

Within the Technological Innovation System for BIPV in Sweden the following technologies and knowledge areas are included – meaning that active knowledge development or use of existing knowledge by academia, research institutes, industry and market actors is present. The presence or absence is assessed based on projects, publications and patent (application) lists (see Appendix 1 and Appendix 2) as well as market actor presence, interviews and the authors' own knowledge of the market (from previous BIPV-related projects).

The activity level for different knowledge areas within the TIS are listed in Table 2, using the following four activity levels: None – no activity; Low - low number of actors with limited activity; Medium - low number of actors with high activity, or medium to high number of actors with low activity; and High - medium number of actors with high activity, or high number of actors with medium to high activity.

Table 2 Activity levels for different knowledge areas within the BIPV TIS in Sweden

Categories	1G PV (i.e. c-Si)	2G-3G PV (i.e. thin film, organic, ...)	BOS (i.e. mounting systems, electronics, …)
Material supply	None	Low	None
Manufacturing			
BIPV-targeted solar cells	None	Low	n/a
BIPV Product manufacturing	Low	Low	Low
BIPV supply and installation	Low		Low
Business development	Low		
Logistics	Low		
Sales & marketing	Low		
Design and application			
Architectural integration	Low		
Engineering – moisture/climate shell	Low		
Engineering – fire safety	Low		
Engineering – electrical	Medium		
Engineering – construction	Low		
Engineering – energy	Medium		
Sustainability	Low		
Economics	Low		
User behaviour	None		
Operation & Maintenance	Low		
End of life	None	Low	Low

In terms of technical applications, PV-roofs (Mounting category A according to EN 50583) and especially discontinuous roofs [20] have by far the largest market share among BIPV applications in Sweden and the dominating market segment is single family houses. PV-facades (Mounting category C) are becoming more common, mainly on commercial buildings, although only a few are more than just aesthetically integrated. Applications such as parapets, balustrades, and solar shadings, still only appear in rare one-off projects and no series produced products exist, although series produced modules can be used in some applications.

In Swedish cell technology research, no clear BIPV focus is present, other than that thin film, DSC, organic solar cells, and perovskites sometimes are considered to be extra fit for BIPV.

3.2 Actors and networks

This section describes the different actors in the BIPV value chain as shown in Figure 4 and how some significant networks are connecting them.

<u>**Actors**</u>

- **Research Institutes and Universities (2-3 active, 2-3 low activity)**. Since 2015 RISE Research Institutes of Sweden have continuously conducted applied research on BIPV systems in several multidisciplinary projects involving several relevant actors from the demand and supply sides. Lund university is the only university that has a longer track record on research on solar energy integration in the built environment. Several Swedish universities, e.g. Mälardalen University, Uppsala University, Dalarna University and Chalmers Technical University, have been or are active in BIPV research but typically with much lower activity than in other PV-related research fields. Of these, Uppsala University has been focusing more on cell technologies, while other actors have rather had a PV system perspective.
  RISE and Mälardalen University participated in the IEA PVPS Task 15 collaboration on BIPV scheduled to end in 2023.
  Glava Energy Center is a member-based organisation running mostly innovation and development projects and have (had) some BIPV-related activities.
  In 2022 a national centre of excellence on PV called Solar Electricity Research Centre Sweden, SOLVE, was initiated, involving more than fifty organisations from academy, industry, and the public sector. One of seven themes is dedicated to building integration which is expected to boost industry interest in BIPV research and collaboration with academy partners mentioned above.
- **Supporting actors (2-3 national).**
  - **Financing**. There is a multitude of options for regional, national, and European financial support available to actors dedicated to developing BIPV, however it is not specifically targeting BIPV. E.g., concept development, verification and market introduction, development of innovation ecosystems, business models, international collaboration, start-ups etc, etc. The competition for such funding can be fierce and many of the publicly financed research programs require or encourage co-operation between academics or research institutes and industry or market. Public funding dedicated to the BIPV sector comes mainly from the Swedish Energy Agency (Energimyndigheten) and the National Innovation Agency (VINNOVA) in the form of research grants and to a minor extent to support demonstration projects or business development support. An increased interest in providing public support to pilot and demonstration projects has been noted in recent years. The Energy Agency's support to RISE, Mälardalen University, White Architects and Soltech has enabled a strong commitment to the Task 15 project. There have never been any public monetary or regulatory incentives specifically targeting BIPV installations in Sweden and no such plans are known. General incentives for PV do include BIPV. We have not identified any major private investments in the private Swedish BIPV sector but the successful stock exchange introduction of Soltech is likely to have taken advantage of their high profile in BIPV. Some of RISE research projects on BIPV were also supported by the two business organisations Svensk Solenergi and SBUF representing the construction sector.
    Banks and mortgage institutes have, to our knowledge, no specific policies for PV or BIPV, but many do give a rebate for energy efficient or environmentally labelled houses, where BAPV or BIPV can be a part in

the labelling. 2023 at least one mortgage institute offers additional mortgage with rebate for investments in energy efficiency, such as PV. [21]

  - **Networking and lobbying.** The PV industry association "Svensk Solenergi" has a number of BIPV-oriented manufacturers and suppliers as member and generally supports BIPV, but no recurring BIPV networking activities or seminars are organised. Similarly, several of Glava Energy Center's members are involved in BIPV activities.
    For additional information about networks see the section on Networks.

- **BIPV-targeted cell manufacturers. (1)** Midsummer is the only Swedish company producing (CIGS) solar cells. The cells are only used in Midsummers own BIPV products and BIPV systems. Midsummer is also supplying manufacturing equipment for the same type of CIGS cells.
  To our knowledge, all Si- or CdTe-based cells used in Swedish BIPV products or BIPV systems, except Solitek cells are produced outside of Europe. Still in the research stage but having a similar scope on production equipment for c-Si/Perovskite tandem cells is the young company Evolar, working closely together with Uppsala university. It is yet unclear whether Evolar targets BIPV applications.
  The company Dyenamo is a chemical company supplying chemicals for DSC and perovskite research and development and has been involved in a Horizon 2020 project related to BIPV.
- **BIPV product manufacturers**
  - **Modules and integrated construction products (6).** Except for Midsummer there are no Swedish producers of BIPV modules with in-house manufacturing. Midsummer currently manufactures three BIPV products: a polymer encapsulated laminate for application on top of conventional roof tiles ("wave"); a folded metal roof with polymer laminate ("slim"); and a flexible laminate ("bold).
    Other Swedish BIPV "manufacturers" are in general building BIPV systems based on foreign ODM/OEM PV modules (standard or slightly customized) and OEM mounting- and sealing components that are sometimes produced in Sweden, sometimes abroad. Lindab is a producer of metal-sheet-based products for construction and ventilation that produces a sheet metal roof, initially with CIGS modules but currently switching to crystalline Silicon. Raymond Solar, Sunroof and Soltech Energy produce roof solutions comprising glass-glass regular modules with a proprietary mounting system. In 2023, Raymond Solar started production and sales of prefabricated BIPV roofs (outer roof). Soltech and S:t Eriks produce solar roof tiles. UBAB is a producer of prefabricated concrete elements including sandwich load bearing wall elements. In 2021, the company presented a "Solar wall" where the outermost concrete slab has been replaced by a PV rain screen that can be joined to any other façade material. The solar wall so far hasn't been demonstrated in a construction project.
    Some of these companies are or have been involved in publicly financed research and development activities on BIPV: Midsummer, Soltech, Raymond Solar and Lindab. The research is most often driven by academia and directed at market issues rather than at technical challenges.
  - **Mounting solutions (5).** Solisten has developed a mounting system for in-roof mounting of regular PV modules. As mentioned above Raymond Solar, Sunroof and Soltech Energy have mounting solutions for similar purposes but sell them solely packaged with their own modules. Sapa Building System (est. 1963) is a Swedish producer of aluminium building systems who provide sub-structures and profiles targeted towards BIPV.
    Out of all companies mentioned in this category the following have been involved in publicly financed research and development activities on BIPV: Soltech, Raymond Solar and Solisten. The research is most often driven by academia and directed at market issues rather than at technical challenges.

- **BIPV suppliers**
  - **PV installation or project development companies.** Solkompaniet and Svea Solar are examples of big PV contractors that used to offer BIPV (2021) but appear to have removed BIPV from their portfolio. Several other contractors, e.g. Ecokraft or Sellpower, do offer BIPV solutions but their main business is BAPV or ground mounted installations. Sunroof, Roofit.solar and Midsummer are examples of contractors that, in

their PV-activities, are smaller but have a clear focus on building integration of PV. Also, foreign actors like ML-Systems have a clear focus on BIPV in Sweden. PLW Energihus, Soltech Energy Sweden, Otovo (Sunstyle) and Raymond Solar are actively working with (development and) marketing of BIPV however their core business is still BAPV. Lindab, being mainly a manufacturer of construction products, is also offering BIPV installations based on their own BIPV products.

  - **Construction companies.** The companies that plan and deliver the PV products often have a limited knowledge of building construction and therefore often act as sub-contractors for a major contractor, such as NCC or Skanska. These large contractors sometimes hire foreign sub-contractors to handle the actual PV contract while maintaining responsibility for waterproofing and assembly systems themselves.
    Soltech Energy have acquired a façade builder as subsidiary.
  - **Other.** Some wholesale companies for PV, like Co2Pro, Solar or Solelgrossisten offer solutions for discontinuous roofs with regular modules, such as Solitek modules with Solrif framing, Sunstyle modules or IRFTS Easy Roof.

- **Real estate developers.** A few real estate developer companies with strong sustainability goals are involved in driving the development forward, for example Skanska, Fabege, Castellum, Vasakronan and ETC Bygg (several of which are also long-term owners). Several active actors develop properties for long term ownership and management.
  Supplier of “standard” single family houses, Fiskarhedenvillan, have initiated a cooperation with BIPV supplier Raymond Solar (previously GruppSol).
- **Architects.** So far, there are few architects in Sweden who work actively with solar cells. White Arkitekter, Kaminsky Arkitektur, Tengbom and PE are the national companies that have slightly more realized projects with well-integrated solar cells, but no more than a handful each. Most of the other architects have none or possibly one single realized project.
- **Engineering consultants.** The PV industry has grown and lived alongside the construction industry. Where many electrical or energy consultants have gained some experience with PV, BIPV is something unfamiliar for the vast majority. Mostly it is specialized PV consultants (e.g. Solisten, Solkompaniet) or PV contractors that support real estate developers or owners in planning BIPV solutions. Also other engineering expertise, such as electrical, constructional, or fire safety consultants, which can be part of the same company or external, are typically involved in BIPV projects. In many cases these are not specifically experienced in BIPV, but rather have an existing business relation with project owner or main contractor. A few larger consulting companies with in-house PV and other expertise have been involved in BIPV projects, such as AFRY and WSP.
- **Real estate owners.** Many real estate owners with long-term commitment to their properties invest in solar PV, but then often BAPV. Some of these have also invested in more integrated PV systems, such as HSB, the City of Gothenburg’s Stadsfastighetsförvaltningen (formerly Lokalförvaltningen), Akademiska Hus, Vasakronan and Uppsalahem. Mostly these are projects with a high level of internal demonstration purposes. Vasakronan has taken first steps to develop a highly replicable façade concept.
  Private house owners are likely the most active group of BIPV customers, predominantly buying BIPV roof systems.
- **Service/O&M consultants.** A small number of companies exist that offer service contracts or O&M services for PV systems, but to our knowledge none of them specialize in or actively recruit BIPV systems. We do not know if they actively avoid BIPV systems.
- **Education.** Lund university is the only higher education organisation with courses in BIPV technology. Two-year educations for PV system designers or installers have been established in several parts of Sweden in the past five years but BIPV is getting very little, if any, attention in these curricula.
- **Politics and policymakers**. Relevant policymaking actors for BIPV exist on different geographical levels. Nationally, there is the legislative power in the parliament, followed by several state agencies defining regulations for energy (Swedish Energy Agency), building and urban planning (Boverket), electrical safety (Elsäkerhetsverket) and energy markets (Energimarknadsinspektionen). On a local level, municipalities are responsible for all urban planning and for building permit decisions.

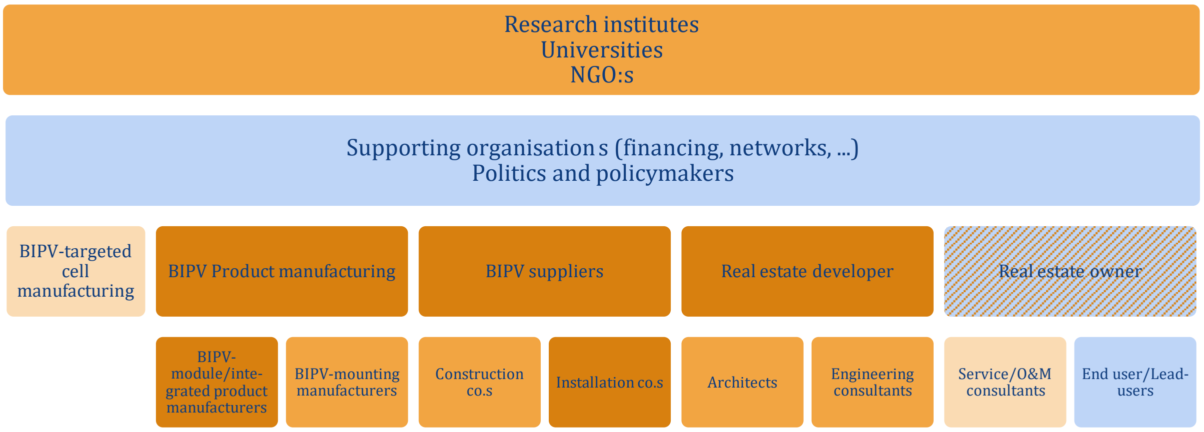

Figure 4 Value chain for BIPV. Orange colour intensity indicates the approximate number of actors actively involved in the BIPV TIS: light = 0-1; medium = 2-5; dark = 6-10. A blue colour indicates that the actor group is too diverse to quantify, e.g. where private house owners are included. Real estate owners are blue (due to private consumers) but with a medium orange line to indicate the amount of professional real estate owners actively involved (2-5).

Networks

In the past five years, there has been a surge in BIPV-related activities in Sweden. This has led to the formation of an informal network of stakeholders interested in BIPV, where ideas and results are periodically discussed, and collaborations are established for research applications and projects.

The Swedish Task 15 participants form a smaller network focused solely on BIPV. They have created a mirror group with representatives from both supply and demand sides to discuss results from international collaborations and provide input. This group had its first meeting in June 2022.

There are also several formal networks in Sweden where solar energy, including BIPV, is discussed. These include the Swedish business organisation “Svensk Solenergi”, the center of excellence SOLVE, and customer networks representing real estate owners in general (“Samling for solel”), in multi-family houses (“BeBo”), in commercial buildings (“Belok”) and in single family houses (“Besmå”).

3.3 Institutions

Institutions can also be described as the rules of the game, describing why actors act as they do. They can be categorized into two types: hard and soft. Hard institutions include laws, standards, support mechanisms, and regulations; while soft institutions encompass norms, values, beliefs, and culture.

3.3.1 Hard institutions

In Sweden, hard institutions aimed at facilitating the introduction of PV in the energy system are mainly focused on implementing PV on buildings. The focus is predominantly on BAPV although BIPV are often included under the same terms. This preference for BAPV is due to its typically lower complexity and cost compared to BIPV and because the emphasis have mostly been on rooftops and less on facades (e.g. only 2 out of 8 solar potential maps for the 10 largest Swedish cities include façade areas).

Energy and Climate policies have prioritized subsidies for solar PV in general, without specific emphasis on the integration or aesthetic aspects of the implementation. To date, there have been no public monetary or regulatory incentives specifically targeting BIPV in Sweden and none are planned for the future.

Existing regulations that impact BIPV are listed in Table 3.

Table 3 Regulatory institutions that concern BIPV in Sweden

Regulation, aspect	Responsible authority	Relevance for BIPV
Building permits Planning and Building Act **[22]**	Act: Ministry of Rural Affairs and Infrastructure; Practice: Municipalities	Building permits are typically required if the appearance of a building is significantly altered and if a roof or façade material is changed. Few exceptions exist regarding change of materials (to BIPV). Multiple exceptions exist for changing appearance by adding PV (BAPV). Plans to investigate new permit exceptions for BIPV were announced in 2023 by current government and supporting parties [23].
Physical planning Planning and Building Act **[22]**	Act: Ministry of Rural Affairs and Infrastructure; Practice: Municipalities	Municipalities have the authority to create detailed development plans (“detaljplaner”) covering parts of their geographical area. These plans can require roofs or facades to be of a particular colour if the area is of higher cultural heritage. The same plans can also prohibit PV on certain buildings or define exceptions or requirements for building permits for PV.
Climate Declaration Act [24]	Act: Ministry of Rural Affairs and Infrastructure; Practice: Boverket (National Board of Housing, Building and Planning)	Compulsory climate declarations (for new buildings) should cover BIPV, while BAPV is currently excepted. A proposed future change suggests a level-playing field for BAPV and BIPV: excluding both in limit value calculations but including them in climate declarations.
Tax deduction for green technologies Income Tax Act **[25]**	Act: Ministry of Finance; Practice: Installers; Skatteverket (Swedish Tax Agency)	Tax deduction on income tax for investment for PV in buildings (as well as electrical storage and EV charging stations). Concerns private house owners on their own house, using PV electricity for their own purposes. Tax deduction of 15% (from 2023: 20%) on labour and material costs. Cannot be combined with the ROT tax deduction.
Tax deduction for renewable electricity Income Tax Act **[25]**	Act: Ministry of Finance; Practice: Skatteverket (Swedish Tax Agency)	Tax deduction on income tax for solar (or wind) electricity fed-in to the grid by prosumers (or “microproducers”). Value of 0.60 SEK/kWh with a cap of 30 000 kWh/year per person or grid connection point (i.e. 18 000 SEK/year). Only for electricity production in grid connections up to 100 A (230/400V_{AC}). Until 2022 there was a requirement of the prosumer being a net consumer per calendar year.
ROT tax deduction Income Tax Act **[25]**	Act: Ministry of Finance; Practice: Installers; Skatteverket (Swedish Tax Agency)	Tax deduction on income tax for labour costs in repairs, conversion, or extension on housing for private house owners. Tax deduction of 30% of labour costs. For PV installations a default value of 9% of the total investment applies (i.e. 30% of investment is assumed to be labour costs). Cannot be combined with the Tax deduction for green technologies.

Building Regulations ("Boverkets Byggregler", BBR) [26]	Boverket (National Board of Housing, Building and Planning)	Defines (functional) requirements of buildings and building parts and therefore also BIPV. No specific rules or mentions of BIPV.
Guarantees of Origin (GO)	Act: Ministry of Climate and Enterprise; Practice: Energimyndigheten (Swedish Energy Agency)	Producers of electricity are entitled to having Guarantees of Origin issued for each MWh produced. GOs are traded on an open market.
Energy tax Tax on Energy Act **[27]**	Act: Ministry of Finance; Practice: Skatteverket (Swedish Tax Agency)	Electricity produced in PV plants with a capacity below 500 kWp,DC are exempted from energy tax, if the plant owner owns less than 500 kWp,DC of PV capacity (or 250 kW wind or wave power generators, or 100 kW of other generators). If the plant owner owns generating capacities above the latter limits, but the individual plant is smaller than 500 kWp, the energy tax is reduced by 100%.

In some instances, regulations may inadvertently favor BIPV and aesthetic installations. For instance, certain city plans necessitate that PV installations conform to specific color requirements, such as red roofs. These local regulations could either promote BIPV or pose a hindrance to PV installations in the respective area.

Another potential regulatory advantage is the introduction of subsidies for private homeowners, known as the "Green deduction", effective from 1 January 2021. As a private property owner, you are eligible for a tax deduction of approximately 20% (up from 15% prior to 2023) of the investment cost (including labor and materials) when constructing a photovoltaic system. In the case of integrated PV systems, there have been instances where some of the (roof) sub-structures are considered part of the PV system, resulting in a marginally larger refund. However, these benefits are relatively minor and have not significantly impacted the market thus far.

Conversely, there are also initiatives that either knowingly or unknowingly counteract integrated installations. Since 2018, an exception has been made to the building permit requirement for photovoltaic systems if they are installed on the exterior of a building's facade cladding or roofing material and are in alignment with the building's shape (this does not apply to culturally and historically valuable environments, national interests for total defense, and if the city plan states otherwise) [28]. This provision applies to BAPV but not to BIPV, thereby making it more convenient for owners of existing buildings to opt for BAPV.

Starting from 1 January 2022, a new law in Sweden requires a Climate declaration for new buildings [24]. This declaration includes the complete climate shell, i.e., BIPV, but not BAPV [29] (5§). This implies that the climate footprint of BAPV is excluded from the calculation, while the footprint for BIPV is included. It remains to be seen whether this will impact the market for BAPV vs BIPV. However, it certainly provides short-term gains for BAPV. If BAPV can credit their positive impact on the building's energy system in the Energy Performance Certificate (EPC), its negative impact (in terms of increased global warming potential) should also be included in the climate declaration to ensure fairness. Recently in 2023, Boverket published a report recommending an increase in the application of climate declaration and obligatory limit values. The report suggests treating BAPV and BIPV similarly: including both in climate declarations but excluding both when limit values are implemented (no earlier than 1 July 2025) [30].

Economic factors can deter real estate owners from covering entire roof or facade surfaces with solar cells. Until 2022, one had to be a net-consumer of electricity (annually) to qualify for a tax deduction for each kWh of electricity fed into the grid. This limitation was removed in 2022. However, this tax deduction is only available to those with a main fuse (for grid connection) of 100 A or lower. Another economic threshold is at 500 kW. Below this limit, all self-produced and internally consumed electricity is exempt from energy tax. Above the 500 kW threshold, tax is levied on self-produced electricity used by oneself. Neither of these economic limits benefits BIPV or aesthetic solutions.

Each standard produced within CEN, CENELEC, or ETSI is typically adopted as a national standard in Sweden. The Swedish building regulation (BBR) aligns with or adapts to European regulations and directives such as the construction product regulation (CPR). There are no specific requirements for PV in buildings. However, the absence of detailed rules does not imply that there are no requirements; overarching requirements for fire protection, mechanical stability, and weather protection in the legislation must still be met.

There is ongoing uncertainty about how to interpret fire safety requirements in relation to PV and particularly BIPV. This uncertainty affects both supply and demand side actors. Firefighters (“Räddningstjänsten”) have varying (non-binding) recommendations regarding PV installations across different regions. Insurance companies have different requirements for installations. For instance, roof fire test methods do not consider that the major fire risk lies beneath the surface layer itself (the connectors). The perceived difficulty in accessing connectors and cables for inspection in BIPV facilities contributes to this uncertainty. While solutions may exist, a lack of national consensus creates uncertainties.

The Swedish Standards Institute (SIS) has published a handbook on the mounting of BAPV on roofs, but no similar guidance exists for BIPV [31]. In a similar way, there is a CEN Technical Report on the requirements for structural connections for solar energy systems for roofs, but this report is explicitly not covering weather tightness, precautions against fire, and electrical, thermal or mechanical characteristics of the solar panels [32].

The electrical installation code (SS 436 40 00) does not include specific requirements for BIPV. However, general requirements are sometimes seen as more challenging for BIPV than for BAPV, such as the accessibility of electrical connections for inspection and maintenance.

In 2021, RISE spearheaded a project with the initial goal of developing a national certification scheme for BIPV. However, as the project progressed, it became apparent that an objective of the upcoming revision of the European standard EN 50583 was to align it with the construction product regulation, thereby enabling CE-marking of BIPV products as construction products. This revelation prompted a shift in the RISE project's direction towards preparing the Swedish industry for a likely upcoming CE-marking.

Exploration of this new direction made it clear that both the Swedish building code and the European Construction product regulation were undergoing significant revisions. For the Swedish code, the overarching aim is to eliminate all references to standards and recommendations, leaving only functional requirements in the code. This change is expected to spur innovation in the construction sector as the onus for developing technical solutions will fall more on the industry. The transition of the code commenced in 2020 and is anticipated to be fully implemented by 2024.

As for the new CPR, its first draft is currently under review. The timeline for its finalization remains uncertain, and it is unclear whether it will influence the further introduction of PV in the construction sector.

While these may appear as minor disincentives when considered individually, collectively they paint a picture of authorities not advocating for BIPV. Similarly, strong existing markets, such as BAPV in this case, are the ones reaping benefits from general PV incentives. To foster growth in innovative new technologies and products, hard institutions need to evolve.

In 2021, national authorities responsible for implementing the interdisciplinary initiative "New European Bauhaus" began organising a platform called "Hållbara städer" (Sustainable cities). This initiative encompasses several aspects of "A European Green Deal" and could play a pivotal role in merging different political interests to make the transition "beautiful, sustainable, together". This initiative could pave the way for more innovative and aesthetically pleasing green creative solutions.

3.3.2 Soft institutions

The acceptance of PV in general is high in Sweden [33]. Some interviewees cite good aesthetics as a crucial factor for maintaining this high acceptance, but not all agree (Interviews Benders, Lund University, Kraftpojkarna, Soltech, Fiskarhedenvillan). Studies on the motivations and barriers to installing PV reflect a similar viewpoint. Aesthetics is mentioned as a relevant factor by some, but it is not dominant and could become less important as PV becomes increasingly common [34]–[38]. There have been no public campaigns demanding aesthetic requirements for PV installations on buildings.

The construction sector and the solar energy sector are distinct industries with different cultures. The construction sector's dominant culture is risk-averse, viewing innovative solutions like BIPV as a risk. Project developers in the construction industry seek knowledge, such as proof of safety, reliability, and sustainability, but their requests are often not adequately addressed by the PV industry.

With BAPV being the prevalent solution in relation to the built environment, the two sectors can remain relatively separate. The reluctance to change perspectives and sticking to traditional methods can be a barrier. Many issues with PV on buildings stem from the sectors' differences and lack of understanding of each other's norms, perceptions, and practices.

The construction industry, including architects, typically does not involve other expertise, such as solar energy expertise, in early planning phases. It is simpler to keep the topics separate and consider solar energy as an add-on feature when planning all technical installations. At this stage, proposing changes in the fundamental design of the building is often seen as off-limits. Moreover, the construction sector generally does not favor lower lifetime costs in investments but aims to reduce upfront costs. This is because those who construct a building are often different from those who will own and manage it.

On the other hand, PV installers also tend to stick to their habits. Many prefer to suggest BAPV even if the client's representatives initially prefer BIPV. Opting for BAPV is less complicated as they do not have to engage with construction practices and guarantees. Since BAPV is seen as an easier way to achieve the main goal - onsite solar electricity production - and is accepted by most contractors/property owners, there are no strong incentives to change and address the cultural differences.

Public procurements in Sweden usually involve technical consultants who prepare technical (functional) requirements based on the demands of the public organisation's project manager. Like PV installers, many solar energy consultants prefer BAPV over BIPV. Another role involved is a procurement officer who is primarily concerned with limiting the risks of appeals for the tender. Evaluating tenders based solely on price is considered the safest solution, while adding multiple other evaluation criteria could face resistance. Many public organisations also rely on centralized procurement organisations like Adda and HBV. Both have developed support for procuring BAPV facilities but not BIPV, which inevitably influences the types of facilities procured in the public sector.

4 PHASE OF DEVELOPMENT AND TARGET DEFINITION

In the absence of available market statistics for BIPV installations in Sweden, the current market phase is defined based on somewhat subjective and qualitative assessments by the authors, which have largely been confirmed by interviewees. Results for different application categories are illustrated in Figure 5.

The development for discontinuous roofs with regular-sized modules (A2) is assessed as being closest to commercial growth, with several commercial solutions available on the market. However, this type of BIPV system is applied in low absolute numbers and is small relative to BAPV roof installations, which are experiencing a rapid market increase. Therefore, A2 is assessed as a niche market.

Discontinuous roof solutions with tile-sized modules (A1) are not as common on the market as A2, but commercial products do exist and have been used in commercial BIPV systems. Thus, A1 is also considered a niche market.

A third roof application, consisting of continuous roof coverage and large-sized modules (A3), such as metal sheet or membrane roof solutions, is in a similar situation as A2: some commercial installations have occurred and there is more than one supplier of these kinds of products, especially for metal sheet solutions.

Skylight or atrium BIPV roofs (B), however, are not as common as the previously mentioned roof types, nor are there any packaged solutions offered on the market. Any projects realized are based on project-specific planning and solutions. The development phase for skylight roofs is evaluated to be in the demonstration phase.

Moving away from roof solutions towards BIPV facades, external applications such as rainscreens or masonry walls (C) seem to be slightly more common than curtain walls, windows, or double skin facades (D). Still, the difference is small and neither of these can be considered to have advanced much further than the transition zone between demonstration and niche-market. One or two commercial offers exist but are in early development, which places these facade applications in an early niche-market phase.

Despite some of the earliest Swedish BIPV installations comprising solar shading solutions (E3), the development has turned and no systemized commercial solutions are available today. Working prototypes have been demonstrated in early installations and research projects, but the development is stuck in the early demonstration phase.

Parapets and balustrades (E1) also lack standardized commercial applications. However, some projects have been realized both historically and recently, placing these applications into the demonstration phase.

Finally, canopies (E2) may be a solution with potential for carport solutions. However, few PV carports offered on the market today have integrated PV. Some concepts exist but the solutions are not considered to have passed beyond the demonstration phase.

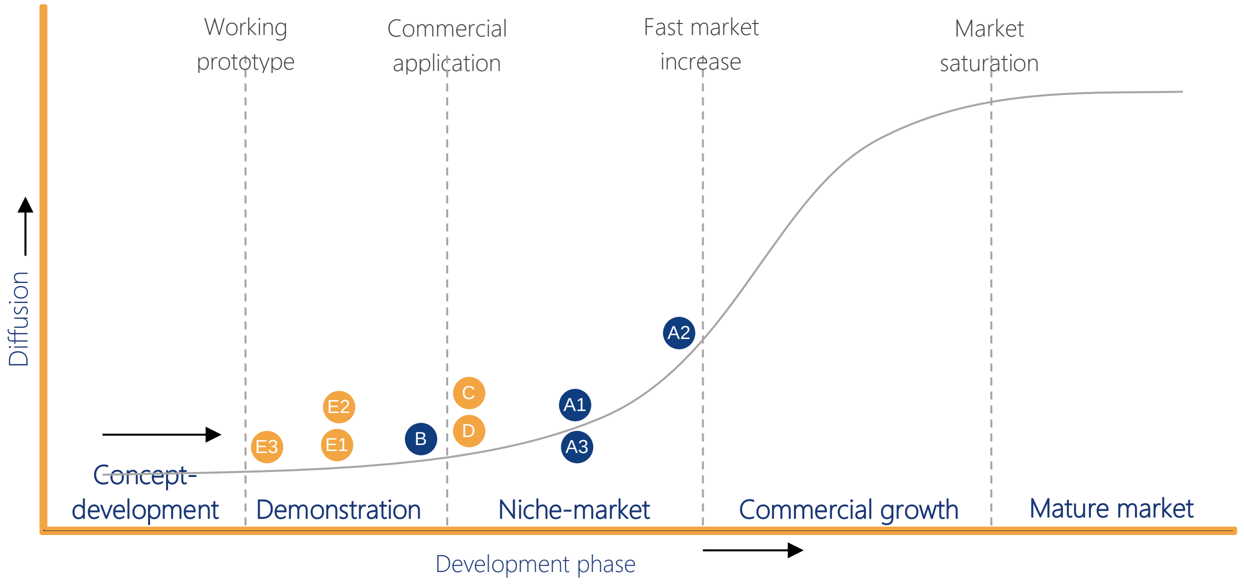

Figure 5. Development phases for BIPV in Sweden. Blue circles indicate roof-integrated solutions while orange circles indicate façade-integrated and external integrated solutions. The sub-divisions are indicated by the numbers in the circles: A1. discontinuous roof, tiles; A2. Discontinuous roof, regular modules; A3. Continuous roofs, large modules; B. Skylights; C. Rainscreen and masonry wall façades; D. Curtain wall, windows, and double skin façades; E1. Parapets and balustrades; E2. Canopy; E3. Solar shading.

In general, the status of BIPV in Sweden is considered to be in a niche-market phase. The next step would involve several application categories moving into commercial growth. To make this target more tangible, the functional analysis of the Technological Innovation System (TIS) in the following chapter uses an analysis target defined as: BIPV reaching a 10% market share relative to the total market for PV on buildings (i.e., BAPV + BIPV).

5 FUNCTIONAL ANALYSIS

The functional analysis presented here primarily draws on interviews with 24 representatives from various links in the value chain and supporting organisations. Additionally, project and patent databases, as well as a literature search, have been utilized (see Appendix 1 and Appendix 2). The authors' own experience and insights on the BIPV innovation system have also been incorporated.

5.1 Knowledge Development

According to interviewees, knowledge is developed by those who develop products and markets (mainly practical/engineering knowledge) and by universities and research institutes (mainly theoretical knowledge). While knowledge development in the Swedish BIPV Technological Innovation System (TIS) does exist, there are some knowledge gaps that affect its evolution and growth.

In terms of formal academic knowledge development, there are fewer scientific publications compared to other European countries[iii], and recent or ongoing projects (five) on BIPV linked to Swedish universities or research institutes (see Figure 6, Appendix 1). About half of these publications and projects are related to fundamental PV material research. The connection between academia and industry is present, with a total of seven industry actors involved in five BIPV-related projects (four out of five overlapping with academia), most of which are related to PV material research. Industry actors have also filed ten BIPV-related patent applications, most of them addressing discontinuous rooftop applications (see Appendix 2). However, given the global existing knowledge in products and materials, this type of knowledge is deemed sufficient for driving the TIS forward.

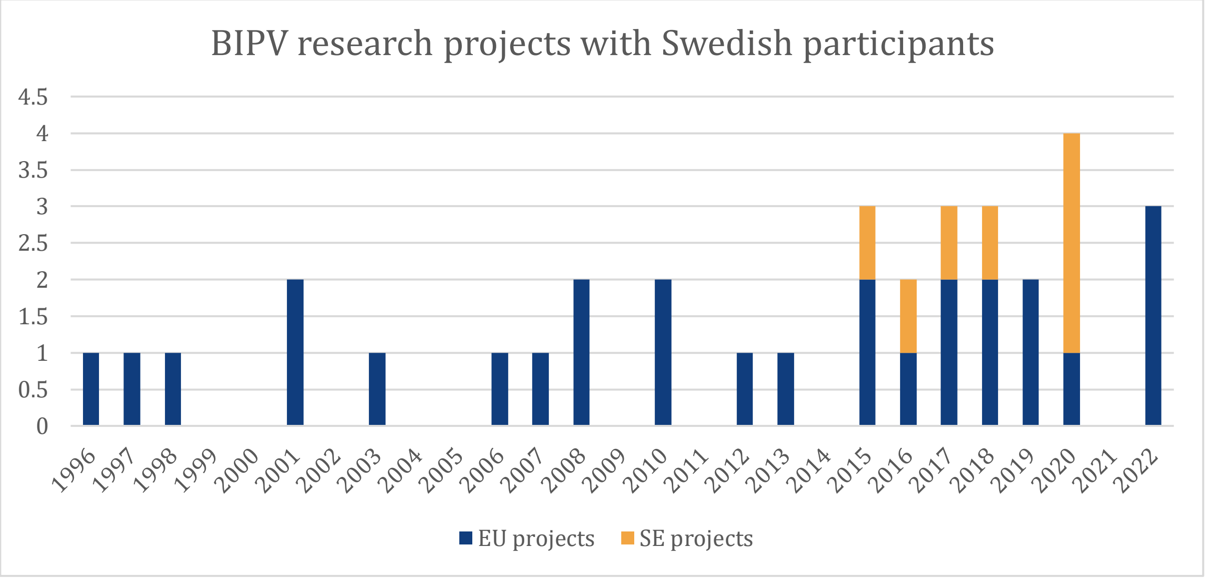

Figure 6. Granted BIPV-related projects by public financing bodies in the European Union and Sweden. Data from [39] (keyword: BIPV) and [40] (keywords: 'building' AND 'integrated' AND ('pv' OR 'photovoltaics'))

[iii] A Scopus search on "bipv" in title, abstract or keyword, for publications in or before 2021, yields 6 results with affiliation in Sweden, while leading European countries have 156 (UK), 136 (Italy), 97 (Spain), 95 (Switzerland) and 66-51 (Germany, Netherlands, Norway, France). Out of 26 European countries listed (incl. Sweden) only Finland, Estonia and Slovakia score lower than Sweden.

So far, there has been substantial testing, demonstration, and prototyping of BIPV products in various research and development projects as well as actual ordered installations. However, many respondents call for more demonstration projects to build applied knowledge about BIPV. RISE and LTH (Lund Technical University) argue that such projects need better resources for thorough follow-up, analysis, and compilation of knowledge and experiences. This implies that the problem is only partly related to knowledge development but also significantly to knowledge dissemination.

Furthermore, there is a need to further explore and structure certain areas (e.g., create regulations, certifications) to gain the required confidence and acceptance from clients (such as building owners) and from the building industry (e.g., architects, engineers, designers). Important examples of such areas of lacking knowledge frequently pointed out in our interviews, networking events, and seminars are in the field of:

- Sustainability (economic, environmental, social) and life cycle assessment: This is a topic where it is important to find good answers not only when it comes to BIPV. However, embedded carbon emissions for BIPV have to be declared in new buildings' climate declaration. Additionally, one of the often-quoted arguments in favor of BIPV is that it is a resource-efficient solution compared to BAPV. To convince clients and the construction industry, these arguments still need to be further substantiated e.g., confirmed by scientific studies and reported in environmental performance declarations.
- Fire safety and strategies for firefighting in PV installations: This is another topic with relevance and a need for more knowledge related to both BIPV and BAPV. There is a general understanding in Sweden that BIPV presents a somewhat higher risk for fire incidents, mainly due to elevated temperature and the fact that maintenance and fault detection becomes more challenging.

Summary: Knowledge development in Sweden is somewhat limited, with few scientific papers and patents or patent applications, and a significant focus on fundamental PV research. The development of more applied (engineering) knowledge reveals gaps in sustainability and fire safety aspects. However, much of the necessary knowledge is available internationally, although it may need to be adapted to local conditions. Pilot and commercial demonstration projects are in place. The functional fulfillment is assessed as moderate (3).

5.2 Knowledge dissemination

Relevant knowledge exists in many areas, but access to this knowledge is lacking among various actors. This issue, often a source of frustration, is explicitly stated by multiple interviewees. Key actors such as architects, project developers, and real estate owners often lack knowledge about the market's offerings in terms of product variety, performance, prices, etc. There is ample knowledge within the industry that should be better or more intensively communicated to the market and technical consultants. The responsibility for information distribution primarily falls on the manufacturer and supplier. Actors want suppliers to reach out and visit them. New solutions are adopted hesitantly due to fear of increased costs. Product manufacturers must present feasibility and profitability through outreach activities.

Another viewpoint suggests that the knowledge problems do not lie with the producers, but with those who work with building renovations and new constructions. Dissemination of knowledge to these actors is expected to occur as the market gains momentum. However, currently there are hardly any established sources for independent knowledge, i.e., only one university and no dedicated professional courses.

Finding information about actual products for facades, solar shading, balcony railings, etc., is perceived as difficult. Actors experiencing a lack of knowledge do not know where to turn. Some demand-side representatives refer to Google as their main source of information about BIPV. However, without a basic understanding of the market and efficient source criticism, this is not an effective way to gather knowledge.

While some lists of relevant producers and companies exist, there is a need for BIPV manufacturers and suppliers to better exploit mainstream marketing and information channels for building materials by using existing product databases and providing design and planning guidelines and support. Many architects prefer to see sample products or real-life applications before incorporating BIPV into their designs to better understand the material's visual properties. However, BIPV samples are more difficult to obtain than many other materials [White Architects]. Therefore, more good examples are needed, and additional BIPV demonstrations or physical product libraries could be beneficial. Product exhibitions and actual installations to visit are also relevant for other actor groups like engineers (e.g., electrical, construction, fire) and potential customers since today "the wheel is often reinvented". Moreover, results and learnings from testing, demonstrations, and prototyping research projects are not managed in a way that can be easily disseminated. Processes, costs, drivers, and challenges should be documented, analyzed, communicated in education, trainings or seminars, and eventually transferred into guidelines and codes. Cost analyses are particularly needed if costs are to be decreased, which is a clear barrier to increased BIPV diffusion.

Architects can suggest BIPV, but only a handful of architects have enough knowledge about PV to feel confident doing so. If the client agrees with the architect's proposal, there is a chance it can be realized. If the client disagrees or if the architects lack the knowledge, there will be no BIPV. Having the right contacts for seeking knowledge throughout the whole design process is important. It's worth noting that Swedish architects rarely have financial responsibility for the building project; thus initiatives with economic uncertainty need approval from the client.

Some architects express skepticism towards integrating solar cells and technology in general into architecture due to uncertainties regarding economy, longevity, and aesthetics. This could be partly due to limited knowledge, but also due to the low legitimacy of the technology (see Section 5.6). If the client expresses interest in BIPV, the architect will ensure to gather the necessary knowledge. The same applies to standard BAPV consultants. Consultants typically do not interact with contractors during the design process. In most projects, consultants are limited to prescribing the function and property of a PV system solution rather than delivering a detailed technical solution based on specific products.

BIPV is a complex product that requires cross-sectoral competence and knowledge spanning several areas. Manufacturers of mounting systems for BIPV are usually not electricians or knowledgeable in fire safety. Roofing companies lack knowledge about electricity or PV, and PV or electricity companies are unfamiliar with roofing. There is a gap between installers and electricians. The involvement of several different actors presents a challenge, and there is a demand for a coordinating actor with cross-sectoral knowledge.

For private individuals, installation suppliers play a significant role as it is a much shorter process than in larger projects.

There is also a knowledge gap on the supply side (industry) related to their clients' preferences and requirements, likely due to the lack of communication channels between industry and market. For instance, data on climate impact needs to be communicated in a way that suits the construction industry, per kg or m2 PV module.

There is a demand for more and improved education around BIPV. For example, one of the vocational schools provides only one afternoon (3-4 hours) about BIPV in their two-year PV education program. Knowledge about construction engineering on waterproofing layers, air gaps etc., should also be part of a "BIPV syllabus". Electricians are better prepared, but they believe carpenters and builders are not interested enough to learn. One interesting idea was targeted training for roofing companies.

The Swedish representatives in IEA PVPS Task 15 are among the few actors actively disseminating BIPV knowledge.

At the construction industry- and employer organisation Byggföretagen, knowledge dissemination is available through websites, newsletters, physical meetings, showcases, pictures, calculation examples e.g., showing that renovating a roof with PV can be a roof that pays for itself. Zoom meetings have become an efficient tool for spreading and discussing information since it enables participation by "heavily occupied and remotely located people in small- and medium-sized companies".

The National Board of Housing, Building and Planning (Boverket) takes over the Information Centre for Sustainable Construction (ICHB), which is planned to become active during 2023. This could be an opportunity to promote BIPV. The industry organisation Svensk Solenergi does not have much information about BIPV today, but some information is disseminated through the association's webinars. There is a strong belief that the industry itself solves the challenges by approaching architects and consultants, presenting good examples, providing references, etc.

Summary: The perception is that knowledge dissemination is limited, and the construction value chain is fragmented. While there are numerous ideas about knowledge dissemination amongst interviewees, relatively little has been implemented in practice. There is a lack of BIPV-products in material databases and libraries, and a lack of dissemination from demonstration projects, education, and training. Industry associations and public authorities have few BIPV-related dissemination activities. Therefore, the function fulfilment status is judged as weak (2).

5.3 Entrepreneurial experimentation

In general, the Swedish market has a limited number of BIPV product suppliers. The most entrepreneurial activity is seen around rooftop BIPV systems for single-family (and multi-family) dwellings, with the highest number of companies (4) actively developing and offering full roof, in-roof, or solar tile/slate solutions, and three companies offering metal sheet roof solutions. Recently (around 2021), a producer of standardized single-family houses [Fiskarhedenvillan] entered into cooperation with a BIPV supplier [Raymond Solar]. However, there has been less activity for larger rooftop BIPV systems, such as multi-family dwellings and commercial or industrial buildings. This difference could be related to a lower legitimacy of BIPV among professional customers than among consumers (see Section 5.6).

While BIPV occurs at the intersection between the PV and construction industry, there is very little entrepreneurial activity originating from the construction sector, such as roof and façade constructors or construction product manufacturers. Typical construction companies are defined as focusing on execution rather than sales, according to their industry association’s representative. Given the legitimacy issues related to functional (climate shell) performance and unclear responsibilities when multiple contractors are involved in building a roof or façade, there should be benefits for the construction industry that speaks the right language and has more competence on these topics.

What would be needed is more or stronger cooperation between PV suppliers and/or installers and construction companies, or else with technical consultants within these fields. However, the majority of these actor groups are taking a reactive position, waiting for clients’ requests. Therefore, present cooperation is mostly project-wise and customer-initiated.

Prefabricated facades or roofs are mentioned by some interviewees as promising solutions [Fiskarhedenvillan, Wästbygg, UBAB]. Prefabricated solutions could be a way to address the legitimation issue mentioned above, even though module mounting might still have to be done on-site to cope with some technical challenges (e.g., higher dimension tolerances for prefab elements compared to BIPV; and module warranty conditions regarding transport to site). Meanwhile, on-site mounted BIPV on prefab facades could be a solution to hide joints between prefab elements that are an aesthetic hindrance for prefab. Currently, only UBAB is offering a semi-prefab solution (for façades).

Architectural firms are assessed to show low entrepreneurial activity on BIPV. Other relevant development areas, such as wooden constructions or circular economy (reuse/recycling), are considered to be closer to the origin of the profession and thus attract more interest and focus. Still, solar PV in general is one of the most common ingredients when architects aim for sustainable buildings. BIPV might therefore well be part of sketches or proposals even when architects do not have full understanding of the practical implications or possibilities. What is needed is architects who can design aesthetical BIPV solutions including dealing with shading and glare risks. Not all interviewees are convinced that today’s BIPV products give architects the required degrees of design freedom while maintaining decent PV efficiency levels.

High costs for BIPV solutions are identified as a challenge for the industry by several interviewees. BIPV manufacturers struggle to keep up with the cost reductions of standard BAPV modules and systems. Various ongoing entrepreneurial experiments are expected to help address this challenge: The use of innovative business models that convert or link high upfront costs to lower recurring fees could be realized both on the supply side (e.g., leasing, pay-off through energy bill) and on the demand side (e.g., shifting funds between different budgets); An increase in standardization and upscaling of BIPV solutions; And more focus on facades, which typically involve more expensive material use. In 2023, a slight increase in interest from property owners and developers is observed, especially for facades, for example, Vasakronan and Fabege. One driving force could be the better alignment of solar electricity production with electricity consumption (and thus higher electricity prices) during morning and evening hours.

Established building product manufacturers highlight two problems they face when engaging in BIPV technologies. Firstly, they perceive a risk of damaging the company’s reputation if BIPV innovations fail. Secondly, they typically sell their products through wholesalers, while recognizing that BIPV requires delivering solutions or taking responsibility for more than just a product. As the innovation system develops and market size increases, this might become less of a problem, with more competent installers present, but currently, this complicates innovation from these actors.

Internationally, more products and solutions are available, and interest from foreign manufacturers and suppliers in the Swedish BIPV market is rising. There is potential room for BIPV-specialized importers/wholesalers that also provide BIPV-specialized consultancy services.

Summary: Overall, the amount of entrepreneurial experimentation for BIPV (in terms of the number of companies, focus, and diversity) is considered too low to reach the 10% market share target. Especially actors from the construction sector need to get more involved in order to develop more holistic BIPV propositions. Also, experimentation in financial business models is lacking. On the upside is considerable activity on rooftop BIPV for private households and an increasing activity from international manufacturers. Given these limitations and needs, we judge the fulfillment of the Entrepreneurship function to be weak (2).

5.4 Resource mobilization

To begin, companies that produce or supply BIPV require capital in their initial phases, which might need to be acquired externally. Apart from the obvious capital requirement for product development and marketing, the typically long project cycles for BIPV projects add to this need. In real estate development projects, BIPV companies should likely get involved from early design phases, advising on BIPV specifics, while the actual construction phase where the products are sold can take place several years later. For renovation projects, the project cycle would typically be shorter. Furthermore, installation companies in the broader solar PV industry have very small profit margins and therefore limited own resources for research and development or experiments directed towards BIPV.

According to the Swedish research project database Swecris, seven research projects on BIPV (search term "bipv") were funded by national public financing offices where project start was in the period 2015-2022, with a total value of about eight million SEK. Three of those projects were granted in 2020 (5 MSEK). The same database lists 107 projects for the search term "photovoltaic" (same start year period), with a total value of 309 MSEK [39]. Thus, BIPV-related research accounted for 6.5% of funded PV research projects and 2.6% of total PV project budgets. In addition to this, the Swedish Energy Agency has also funded certain research and knowledge dissemination through participation in IEA PVPS Task 15.

Assessments of the ease of capital access for company financing (start-up, expansion, etc.) vary somewhat between interviewees. The majority does not expect capital access to be a hindrance for the TIS, based on the existing and increasing interest of venture capital firms and public in cleantech in general and solar PV firms in specific. This can be illustrated by two examples. One is the leading BIPV actor, Soltech Energy, that has successfully raised capital through public offerings. The other is that one of Sweden’s larger private company groups, Axel Johnson Group, has started a specific investment company for solar energy, which has invested in five leading solar energy companies (not BIPV-focused).

However, there is another group of interviewees that sees a lack of access to capital, especially for innovation and seed capital. After the regulation of aids granted by states of the European Union (Treaty on the Functioning of the European Union, 2012), government organisations have fewer possibilities to finance promising start-ups. In 2022, the main public PV research and development funding program ("El från solen" by the Energy Agency) was merged with other programs focusing on wind power, electricity grids, etc., increasing the total budget but also diversifying competition. Therefore, companies must rely much on private investors who might be keener on financing companies with a certain track record than start-ups on a niche market such as BIPV.

In terms of human resources, a challenge for BIPV is its multidisciplinary nature, requiring knowledge in solar energy principles and materials, electrical engineering, architectural design, and building physics. University degrees tend to focus on one of these disciplines, largely ignoring the others. Most university curricula on solar or renewable energy lack courses on building integration. Higher vocational education and training directed towards the solar or construction industry also overlook the specific needs of BIPV.

Product manufacturers and BIPV system planners are compelled to gather multiple people and create a common understanding to apply the appropriate knowledge or to rely on professionals with broad experience from multiple fields, which might be challenging for small or start-up companies. Also, the installation of BIPV solutions typically requires a combination of several competencies, often meaning several professionals, although some challenges can be overcome by in-house training. The multidisciplinary and often customized nature of BIPV systems requires a higher level of precision and on-site problem-solving than, for example, BAPV, implying the need for more experienced or specialized personnel.

A rough estimate of the number of labor places needed to realize 10% of PV in buildings is given below. Assuming that all installed distributed PV is on buildings (probably a slight overestimation), a 10% BIPV share of the 2021 market would correspond to 145 MWp/year. Given average labor places per installed MWp in Sweden (for 2018-2021) this would require about 1100-1500 FTE (full-time equivalents), the large majority (ca 70%) in installer and retailer companies [8]. Likely, the actual figure could be in the upper part of that interval or even higher, as BIPV can be assumed to be more labor-intensive than utility-scale installations or BAPV.

This is assessed to be a barrier given the current education infrastructure since the broader PV industry is (still) in an expansive phase and the industry has seen a need for more system designers, technicians, installers, etc. Training of installers was often done in-house by companies for educated electricians or construction workers. For other, more theoretical roles, specialized higher vocational education programs (typically two-year programs) were started for solar energy technicians (“solenergitekniker”) and planners/designers (“solenergiprojektör”) in 2018. Since then 21 solar energy technicians and 30 planners/designers have graduated until the end of 2021, which equals about 38% and 57% respectively of enrolled students. The numbers of new students have increased so that about 40 technicians and about 55 planners/designers per year are expected to graduate in the coming years [41]. However, these graduates are intended to meet the increased needs of existing market segments (BAPV, utility) and their educations are not very well suited to the BIPV segment as the programs covered no or insignificant education on BIPV. And as the BIPV segment is small, very few existing professionals have a chance to gain working experience with BIPV. Starting up education programs for BIPV, or including it in existing programs, would take one to two years in preparation and an additional two years before the first students graduate.

Infrastructural resources are not significantly limiting BIPV development in its current state. Energy network capacities are becoming a challenge (2023) for distributed solar PV in general, but most PV projects on buildings are not limited by these. For BIPV to reach a market share of 10% of PV on buildings, we don’t anticipate this to be a main barrier. Studies suggest that 20%-40% of annual electricity consumption can be provided with PV without major capacity problems [42], [43]. By the end of 2021, about 1.5 GWp of distributed PV was installed [8], while 30% of distributed electricity consumption (100% for 2021: approximately 74 TWh [44]) would correspond to around 25 GWp of installed PV capacity. This does not consider a potential increase in electricity consumption due to electrification. At the current installation pace, this would take around 30 years to achieve, but if the historical exponential growth continues, it would be achieved by 2030-2031. A more realistic estimate seems to be in 20-30 years' time, based on an annually added capacity that maximally corresponds to 0.6% of electricity consumption [45]. In the future, expansion can also occur by replacing existing PV. Furthermore, if grid capacity is limited, local grid owners are obliged to reinforce grid capacities within two years. Similarly, the increased competition for roof area (from e.g., green roofs) could slow down the expansion of PV on buildings, but the effect for BIPV is expected to be small for rooftops and could give rise to a positive drive for other building areas.

Test beds, as in laboratory infrastructure, are deemed to be sufficiently present as BIPV can share test facilities with other construction or electrical products. Challenges seem to lie in the cost of performing tests and available financial resources for laboratory tests, as several interviewees prefer more basic in-house tests and pilot projects. For fire safety testing, a clearer need for lab tests is expressed by interviewees. Fire safety test requirements can vary between different national regulations and current standards might not be representative for typical use cases, which creates uncertainty about whether lab capacities are sufficient. As RISE is the only player offering fire tests in Sweden (and Norway), internal estimates suggest that capacity is sufficient for incidental tests, but not if fire testing would become a de-facto requirement for all BIPV products on the market.

There is no complete data on production capacity and utilization rate for BIPV products, neither in Sweden nor internationally. The only local manufacturing facilities are Midsummer's, with a ramp-up to 4MWp/year capacity in 2023 and additional activities to reach 50 MWp (internationally) in 2023 and a multiple of that in the coming years. 10% of distributed PV for the year 2022 corresponds to approximately 80 MWp annual installed capacity, so Midsummer has a large capacity relative to the targeted BIPV market. Other suppliers rely on OEM manufacturers abroad. Key manufacturers of thin-film PV, a technology used by Soltech Energy in many of its BIPV installations, have production capacities of around 100 MWp each [46]. Capacities for other foreign manufacturers currently supplying to the Swedish market are unknown, but given the relatively small Swedish market volumes it is reasonable to believe that manufacturing capacity is not the main limiting factor. Of course, there are other factors impacting manufacturing capacity limitations, such as international markets. However, the current conditions for upscaling of PV manufacturing capacity are positive, with high government interest in Europe, USA, India, etc.

Events such as the blocking of the Suez Canal, Covid lockdowns, and the Russian invasion of Ukraine have contributed to challenges or bottlenecks in resource and material supply for many industries, including the PV industry. These events have also heightened awareness of the risks associated with highly centralized global supply chains. The issue of material supply was not specifically investigated in the interviews conducted in 2021, but as awareness increased and situations became more critical during 2022, the authors believe this could become a limiting factor.

Summary: The most significant resource challenge for BIPV to reach the defined 10% target is the availability of suitably trained human resources. This is due to the multidisciplinary needs and competition with other Technological Innovation Systems (TISes). Early phase risk capital might be somewhat harder to find, but otherwise, BIPV should be able to benefit from investors' interest in cleantech and climate mitigation technology. As long as market growth is mostly organic, infrastructural resources should largely suffice to reach the target. Overall, the functional fulfillment is assessed to be weak to moderate (2.5).

5.5 Development of social capital

The responses can be summarized around the following main findings:

Firstly, there is no formal association or network for BIPV and a lack of community around BIPV. The larger PV community, in general, used to be a small group where everyone knew each other, but recent developments and high growth have introduced many new actors which is difficult to overview. With BIPV, rather few actors are active and there is a general feeling of lack of community [Soltech, GEC]. Only a handful of individuals could have sufficient established relations.

Secondly, the Technological Innovation System (TIS) is still in an early development phase, where the knowledge on BIPV solutions amongst suppliers, market, consultants, and architects is generally low. This requires a focus on onboarding new people to a BIPV community, rather than investing in an existing community. This onboarding is done by increasing knowledge and explaining basic concepts and fundamental issues around integrated solutions, such as the added values and logics behind higher prices, compared to Building-Attached Photovoltaics (BAPV) [Addsolar, Stadsfastighetsförvaltningen Göteborg, Castellum, Soltech].

Thirdly, BIPV is dependent on a successful meeting of the PV and the construction industry, with different cultures and industrial logics. The PV industry is more focused towards energy production and climate benefits, there is a long-term perspective, and the industry is rather progressive and looking for new opportunities. The construction industry is much older and more focused on risk mitigation and shorter-term perspectives where saving up-front costs is more important than lowering total costs of ownership.

The two latter findings make it difficult for PV and construction industry actors to interact and share the same language [Stadsfastighetsförvaltningen Göteborg].

Finally, some experiences from BIPV construction projects and collaborations give ambivalent perspectives on whether there is trust and good relations among participating actors [Addsolar, Benders].

Summary: It seems as the social capital function displays early development where interaction in the social group is based on explaining the functions and benefits and assurance that BIPV is an interesting solution, despite drawbacks such as higher costs and increased complexity. Apart from a small number of experienced people, there is a lack of formal and informal communities and a lack of common language and culture to gather PV and construction industries. Social capital development is assessed to being weak (2).

5.6 Legitimation

Many respondents highlight several advantages with BIPV, most notably aesthetics and PV products as construction material. These could create incentives to connect climate impact measures with aesthetics in visions or strategies for new building areas. However, the fact that BIPV is often used as part of the building envelope presents challenges, as it is exposed to more rules and standards towards the building sector (Interviews, White, Soltech) and would require additional certifications or guarantees [InnoEnergy]. In theory, some of the requirements on BIPV that originate from building product rules and standards might be equally relevant for certain BAPV applications, but in practice, they are often not considered for BAPV (e.g., due to lack of knowledge or clear legal requirements) and mostly just impact legitimacy for BIPV.

The often-higher costs associated with BIPV products and installations also reduce legitimacy among real estate developers, and the alternative BAPV is considered [Lund University]. Aesthetics have always been the prominent selling argument for BIPV, but with the fast development of aesthetically improved BAPV panels (e.g., sober black look) and people getting more used to regular BAPV, some interviewees question the importance of BIPV's aesthetic benefits nowadays [Benders, Wästbygg]. Some architects take a skeptical stance towards integrating solar cells and technology in general into architecture due to ambiguities regarding economics, longevity, and aesthetics.

Still, aesthetics is indeed a selling argument and interest in BIPV is often present in initial project development phases. However, it often fails to uphold interest due to its higher costs [Kraftpojkarna]. Here some BIPV advocates argue that there is a lack of understanding among several actors of the total costs since comparisons are made with other materials without payback time [Addsolar], or that the added values in terms of e.g., aesthetics are not valued and only Levelized Cost of Electricity (LCOE) is compared with BAPV [UBAB]. Other experiences have been that many actors within real estate development are still unfamiliar with BIPV altogether, so when solar PV is discussed, the natural reference is BAPV [SAPA, Dalarna University].

There are indications that legitimacy could be higher amongst consumers than amongst professional customers [Midsummer, LTH]. Professional customers are typically bound by stricter contracting regulations, explicit technical requirements and monitoring of technical requirements. Consumers might be less aware of some of the technical challenges related to BIPV. Moreover, it is possible that consumers can allow their decisions to be based on soft arguments (e.g., aesthetics, personal identity) to a higher degree than many professionals. This might also be related to differences between early adopters and early majority. If compared to BAPV, early consumer adopters allowed non-financial arguments (sustainability, lifestyle, etc.) to steer their decisions to a much higher degree than early majority. Apart from economics, early consumer majorities were rather influenced by encountering BAPV in their surroundings [38]. Similarly, it could be the case that soft arguments weigh strong for early consumer adopters of BIPV. For owners of multi-family dwellings, their organisation's environmental targets and economics were main motives for BAPV adoption [35], but it is unclear whether this varies between professional early adopters and early majorities. Professional customers tend to have organisational routines for decision making that include economic and often environmental values but may less often consider aesthetic or marketing values.

(Professional) real estate owners and developers perceive a significant risk: ending up with a poorly performing building envelope and divided responsibilities for its various sections [Skanska, Smartfront, SAPA, UBAB]. This could result in complicated warranty claim processes and, in the worst-case scenario, no legally accountable party. When uncertain about long-term performance, professional customers seek contractors who adopt a holistic approach, assuming responsibility for the entire roof or façade solution over time. This includes PV performance and replacements, insulation, moisture barrier, load-bearing elements, etc., in accordance with local building codes and their own perceived needs. Currently, this demand is scarcely met by entrepreneurs, although one PV supplier and installer company has incorporated façade and electrical contractors into its enterprise group.

Interviewees mention another risk: BIPV projects are more likely to delay installation and construction projects due to ill-prepared consultants or BIPV systems with a high proportion of ad-hoc solutions. Delays increase costs and foster aversion towards BIPV among real estate owners and other potential customers.

Some interviewees also highlight the risk that BIPV installations are challenging to service. For example, if a module needs to be replaced or if there's a need to comply with electrical code requirements on accessibility for inspecting electrical contacts. The latter requirement isn't specific to BIPV; however, it's generally not considered an issue in BAPV installations even if connections are located behind/below the PV modules.

In general, Swedish authorities do not promote any specific BIPV strategies. Several BIPV research projects have received public funding, indicating awareness, but no dedicated research program for BIPV exists [Energimyndigheten].

Some installers express a negative attitude: "What can you gain from BIPV?". This suggests that the benefits of BIPV are either poorly communicated or limited for certain target groups. As benefits are primarily aesthetics and potentially resource efficiency but often come at a higher price per installed Wp and increased project complexity, actors' final judgements on BIPV heavily depend on how they value these different aspects. Also, some actors might not be updated with the state of the art and what solutions are available and base their attitude towards BIPV on outdated assumptions.

Potential clients often perceive BIPV projects as high-risk due to potential delays, uncertain responsibilities/warranties, more complex operation and maintenance (e.g., replacing failing modules), and compliance with building codes in areas like fire safety (Interview Skanska, Stadsfastighetsförvaltningen Göteborg).

Summary: On a higher level, attitudes towards PV and BIPV are positive. However, when it comes to actual applications, many fear additional costs, delays, and complexity (risks). Authorities do not promote any specific strategies supporting BIPV, and guidance on how to comply with building codes is lacking. Therefore, we assess legitimation to be weak (2).

5.7 Guidance of the search

BIPV encompasses numerous applications and functions in the building envelope (and the energy system), some of which overlap with BAPV. This makes it difficult to provide clear guidance towards BIPV technologies, and in many cases, guidance towards the BAPV TIS is stronger.

There are no market statistics for BIPV, and there's a lack of coordinated communication or a common vision for its future potential.

As noted in the structural analysis, climate declarations unintentionally apply to BIPV. However, potential climate benefits in downstream life cycle phases, such as replacing other electricity in the energy system, are not included [Soltech, Fiskarhedenvillan, Skanska]. These rules currently make BAPV or regular climate shell materials more desirable than BIPV for new buildings. However, proposed changes that will level the playing field between BIPV and BAPV could make BIPV more attractive than other climate shell materials, as the BIPV product will be exempt from any compulsory limit values.

Another institution that benefits BAPV more than BIPV in practice is tax deductions for private households. Both technologies receive essentially the same support, but BIPV is in an earlier market development phase with less economy of scale and thus higher production costs than BAPV.

The choice between BAPV or BIPV might influence the type of certification a building can receive, such as BREEAM, LEED, and other environmental certifications. In general, choosing a certification is difficult since definitions vary between different certificates [White]. Therefore, no clear guidance is provided here.

A potentially positive aspect is building permits and municipal guidelines concerning aesthetics and building expression. These often restrict options for BAPV solutions in urban historical districts but may be open to specifically designed BIPV [Addsolar]. However, in practice, BIPV is subject to stricter building permit rules than BAPV, and application on cultural heritage is often not allowed by local governments.

Overall, strong guidance towards BAPV is likely to lead to guidance away from BIPV. Similarly, the centralized PV TIS has a market that is taking off and is likely to attract some of the human and financial capital that could have been used in the BIPV TIS.

A possible reason to focus on manufacturing BIPV products rather than conventional PV products could be that BIPV is a specialized niche where competition isn't just based on price per Watt or efficiency. This offers several smaller-scale (European) manufacturers an opportunity to be competitive. This has been the case for several Swedish PV module manufacturers in the past (see Section 2.3), but with little success.

The construction sector generally isn't structured to include lower lifetime costs in investments but aims to reduce up-front costs. Hence, it doesn't choose BIPV over other alternative materials with lower costs [Soltech, InnoEnergy]. This can also be seen as one of several ways where the TIS of the construction industry isn't yet framed at adopting BIPV as a standard construction product.

Some stakeholders are optimistic that forthcoming updates to EU directives on renovation and energy efficiency will open new opportunities for BIPV market development. The "Solar Energy Strategy," unveiled by the Commission in May 2022 as part of the RePowerEU plan, underscored the significance of solar energy in buildings as a solution to the energy crisis. The EPBD (Energy Performance of Building Directive) is proposed to be revised in line with this strategy. Once implemented, it will establish new standards for PV technology in the building stock of member countries. However, there is currently no specific language promoting BIPV.

Summary: The guidance of the search directions for actors in the BIPV business is fragmented, uncertain, and occasionally contradictory. The BIPV TIS lacks market statistics, clearly communicated market potential, and shared visions. Moreover, TISes of other PV applications are functioning much better, and some regulations benefit BAPV more than BIPV, thereby diverting potential interest away from BIPV. As a result, the function Guidance of the search is assessed as almost absent in the TIS (1.5).

5.8 Market formation

BIPV products have been around for a while and are seen as a promising application, but the market has never really taken off. Recent developments in solar PV, including significant cost reductions and global growth, have sparked increased activity in Sweden's BIPV market and heightened interest. This is partly due to a greater appreciation for the aesthetic features of solar panels, leading to more common questions like: "What colour can my roof be?" [Soltech]. However, cost barriers and the complexity of installations continue to impede market development. Many customers are seeking providers of integrated roof or facade system solutions rather than individual product vendors [AddSolar, Stadsfastighetsförvaltningen Göteborg].

Certain applications are more advanced and exhibit a more developed market phase. For residential roofs, several suppliers now exist (e.g., Raymond Solar, Soltech, Energihus/Roofit, Sunroof) who offer commercial solutions in the same market as traditional BAPV products. While the number of installations remains low, it is growing [Svensk Solenergi]. Other commercial applications are linked to prestigious projects such as hotels and premium buildings that demand both ecological and aesthetic features [White, Svensk Solenergi]. According to respondents, this application represents a viable BIPV market today, albeit small and insufficient to achieve the previously stated 10% goal.

For other applications like facades, solar shading, and balcony integration, there are few, if any, suppliers and not much market demand currently. However, some interviewees believe the application potential is good [Aktea, SAPA, White, UBAB]. When it comes to new buildings versus renovations, interviewees agree that it's easier to apply BIPV products to new buildings. However, the potential for renovation is high as BIPV can offer integrated and aesthetic solutions that fit existing property designs and appearances, especially in areas with high cultural or historical preservation value. For the residential sector, full roof solutions are often installed on existing villas as part of a roof renovation project, making both new buildings and renovations commercially viable today.

There are also factors related to the organisation of the purchasing customer. For larger real estate developers and managers, there is a willingness and motivated individuals, but realizing BIPV is still challenging due to organisational structures, timing, and in-house competence [Stadsfastighetsförvaltningen Göteborg]. Therefore, better experience and routines are needed to accomplish more projects. Currently, external consultants are often required for BIPV projects, which increases costs and decreases the likelihood that the project will be realized [Stadsfastighetsförvaltningen Göteborg]. This situation could potentially improve with an integrated facade or roof system solution provider.

In Sweden, government-driven market initiatives are limited. There are some general policy measures for solar PV, but not specifically for BIPV. Instead, support is provided for research and knowledge development in research programs [Energimyndigheten]. Some interviewees point out that rules and regulations for building permits and urban development plans could potentially favor BIPV over BAPV, as sustainability and aesthetic/cultural appearance are important factors and could be more permissive for integrated solar PV [Boverket, Benders, UBAB, Einar Mattson]. However, existing rules also create uncertainties and may deter investment in BIPV [Einar Mattson, Smartfront]. In general, building rules related to energy efficiency, climate impact, and permits are being updated and will influence the scope for investing in BIPV solutions [Castellum, Byggföretagen, Boverket, Fiskarhedenvillan].

At the time of the interviews, a support scheme for energy-efficient measures in new rental apartment buildings was in place and created a space for BIPV solutions. This support was utilized by one real estate developer [architect ETC]. Simultaneously, a new energy efficiency support, which could potentially support a facade switch to BIPV, was planned and started in August 2021 [Boverket]. However, both these support schemes were closed for new applications by December 31, 2021.

On the business side, there are some actors driving the market forward, often in the category of discontinuous roof residential applications. However, many interviewees agree that actors should do more to stimulate market uptake [Aktea, Glava, Skanska, InnoEnergy]. One real estate developer, ETC, is testing a business model that raises funding for multi-family dwellings through crowdsourcing and offers PV through rental/leasing, where customers pay per kWh until their installation is paid off.

Those who started early with PV have already installed BAPV on the best roofs. Therefore, one of these proactive market actors (Vasakronan) is keen to use BIPV on facades and is exploring possible replicable solutions. There can be a bit of a stigma associated with BIPV, as engineering challenges (e.g., cabling) are described as being more complicated than for other facade-based installations such as lighting, even though it requires about the same effort. Ground-based PV plants will be a competing market to BIPV, which may seem more attractive with much larger plants and simpler installations, thus posing less risk for PV companies and investors.

Summary: All in all, the market for some applications, especially the residential full roof solution, has started to grow, while there are still several issues for other applications. New buildings are considered to have higher potential since it is easier to plan BIPV earlier in the process. Therefore, the assessment score for the function Market formation is weak to moderate (2.5).

5.9 Summary of the functional analysis

The fulfilment scores and main results of the functional analysis for BIPV in Sweden are presented and summarized in Figure 7 and Table 4.

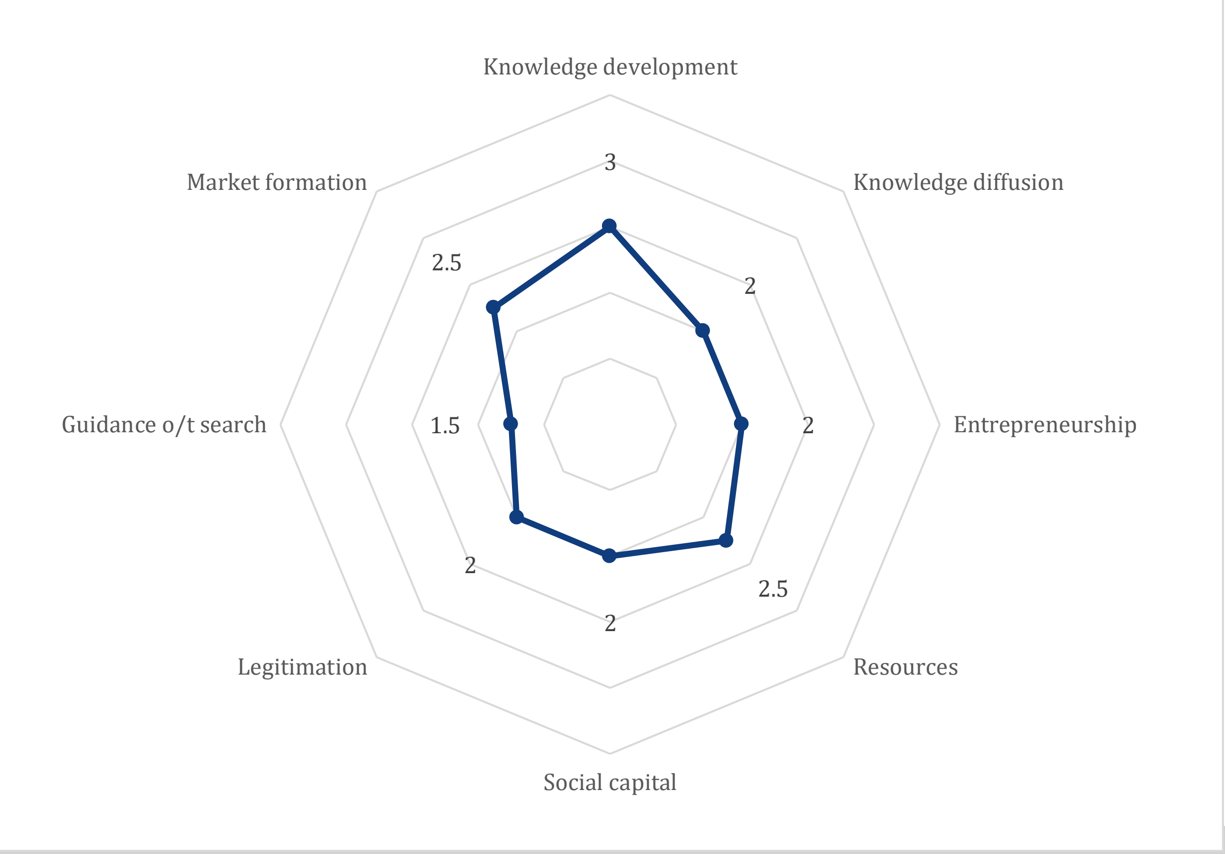

Figure 7 Results of the fulfilment assessment of the TIS functions. Numbers indicate the degree of fulfilment: 1 – absent; 2 – weak; 3 – moderate; 4 – strong; 5 – excellent.

Table 4 Summary of the results of the functional analysis

Function	Strengths/Opportunities	Weaknesses	Assessment
Knowledge development	Knowledge development by Swedish academics and manufacturing industry is present. Considerable focus on fundamental PV material research. Much of the knowledge needed exists within (international) research (but might need adaptation). Individual pilot or demonstration installations are being conducted.	Knowledge gaps on sustainability and fire safety aspects. Less knowledge development on engineering knowledge. Low number of patent applications and scientific papers from Swedish actors.	3
Knowledge dissemination	Dissemination of product knowledge is increasing. Dissemination activities by Task 15 representatives.	Low knowledge levels in the market and amongst (technical) consultants. Low activity from construction industry, authorities, and solar industry. Low availability of BIPV-products in product/material databases and libraries for construction sector. Limited dissemination from pilot/demonstration projects. Very few education or training opportunities.	2
Entrepreneurship	Increasing interest from international BIPV manufacturers Considerable activity in rooftop BIPV systems (discontinuous, large modules) for private households.	Low activity from construction industry. Little experimentation with financial business models. Few specialized BIPV-actors.	2
Resources	Good general interest of investors in cleantech and climate mitigation technology. Infrastructural grid and manufacturing resources not limiting (nearest future).	Lack of suitably trained human resources Hardly any education-infrastructure for BIPV More difficult to raise funding for lower TRL levels.	2.5
Development of social capital	Smaller number of experienced individuals have established relations.	No formal BIPV association Lack of community and meeting points	2

Function	Strengths/Opportunities	Weaknesses	Assessment
		No common language for PV and construction industry. Different cultures need to be overcome. Varying levels of mutual trust within the value chain.	
Legitimation	High acceptance of PV in general. Aesthetic solutions are valued (but not that important).	BIPV is seen as more risky (functional performance, project delays), more expensive and less mature than BAPV. No specific BIPV strategies forwarded from authorities. Unclear how to comply with building codes (e.g. in fire safety).	2
Guidance of the search	General climate action and policies.	Climate declaration and building permit regulations currently more beneficial to BAPV than BIPV. Lack of common visions for BIPV. Lack of market statistics and communicated market potential. Financial incentives for PV agnostic for BIPV’s lower development phase. Other PV TISes much stronger	1.5
Market formation	Rooftop BIPV systems (discontinuous, regular modules) on detached houses approaching take-off. Facade BIPV systems commercially feasible on certain commercial buildings. Potential for existing buildings with renovation deficit. Easier application on new buildings.	Professional buyers ask for complete roof or façade systems with high replicability, but such offers are rare. Few suppliers of BIPV facade and external applications. Prices often much higher than alternative solutions. No clear institutional stimuli for commercial market. No certifications for BIPV Low customers awareness No collective marketing of BIPV Few (local) government authorities take a lead with BIPV installations.	2.5

6 IDENTIFYING SYSTEM WEAKNESSES AND STRENGTHS

The functional analysis reveals that several functions are deemed too weak to achieve the set assessment target for BIPV. Out of the eight functions, only Knowledge Development is considered to be sufficient (moderate), while Market Formation and Resource Mobilisation are not far behind. The remaining functions are assessed as weak or nearly absent (Guidance of the Search).

According to the IEA PVPS TIS guide [1] and [3], the most crucial function for further development of a TIS in a niche market phase - as is the case for BIPV in Sweden - is Entrepreneurial Experimentation. This is followed by (in no particular order) Development of Social Capital, Legitimation, Guidance of the Search, Resource Mobilisation, and Market Formation. Some BIPV applications in Sweden are more so in a demonstration market phase. For this phase, the primary function to focus on should again be Entrepreneurial Experimentation, but all other functions are also relevant.

This implies that the main systemic weaknesses to address are:

- Entrepreneurial Experimentation,
- Guidance of the Search,
- Legitimation,
- Development of Social Capital,
- and to some extent:
    - Knowledge Dissemination (for external applications and skylights, and possibly facade applications)
    - Resource Mobilisation

Based on the main weaknesses and strengths of the above five functions of the TIS, systemic problems and opportunities have been identified. In the following sub-sections, the weaknesses (problems) and opportunities are discussed, based on whether the underlying problems relate to the presence or quality issues for actors, institutions, interactions, or infrastructure.

All systemic weaknesses and opportunities are numbered as "SW#" and "SO#" respectively, for further reference.

6.1 Actors' problems and opportunities

The presence and capabilities of actors are closely tied to Entrepreneurial Experimentation. There are very few existing actors (manufacturers, suppliers, installers/contractors, technical consultants, architects) who specialize in BIPV or have BIPV as their core activity and competence (SW 1). While diversification may be a survival strategy for manufacturers and suppliers, it can also lead to less dedication and drive to develop BIPV. For consultants and architects, a lack of BIPV specialization or general BIPV knowledge leaves professional customers with limited opportunities to properly integrate BIPV into their processes and buildings. Moreover, a limited engagement by actors from the construction industry (SW 2), who better understand construction processes (technically, organisationally, and legally) than today's predominantly PV-based actors, is considered another weakness that limits the match between offers and customer demand.

Another challenge in Entrepreneurial Experimentation is related to a limited diversification of business models that address high (initial) investment costs for BIPV clients (SW 3). For discontinuous roofs, a rationalization has taken place with value offers taking advantage of large-scale module production facilities. Other applications, such as skylights and facades, still rely heavily on specialized or customized solutions - and have done so for many years. Other ways to address high upfront costs, such as new types of ownership or payment models, have not been subject to experimentation.

Many existing BIPV suppliers lack the capacity to convince potential customers of the legitimacy of the technology (SW 4). Also, supporting actors (e.g., research/academia, insurance companies, industry organisations) are not very active or lack the capacity to support the industry in creating legitimacy (SW 5). Typically, one or several of the following aspects are unclear or do not meet demands for (certain) customer groups:

- Conformation with building regulations regarding fire safety and climate barrier;
- Conformation with electrical installation codes regarding accessibility for inspection and maintenance, as well as more general aspects regarding serviceability of the installations;
- Liability in case of performance issues for any part of the BIPV wall or façade;
- Lifecycle environmental performance, specifically regarding global warming potential.

Likely, actors from the construction industry are more suited to address (some) of the problems above, but they are not very active in this TIS (see SW 2 above).

Weaknesses in Guidance of the Search can partly be attributed to the lack of industry actors to (collaboratively?) communicate on the size and future potential and vision of the market (SW 6).

Educational actors (including event organisers) are hardly engaged in the BIPV TIS (SW 7). This contributes to competence and information gaps within actors along the value chain. To a certain extent, these gaps can also be counteractive for legitimacy creation. Furthermore, the lack of events also contributes to low social capital.

While the rapid expansion of adjacent TISes for centralized PV and BAPV could attract BIPV actors, in the long run the increased number of PV suppliers, installers, etc. could be beneficial for BIPV when these competing TISes approach saturated markets and their actors might look out for adjacent TISes to engage in (SO 1). Furthermore, some initial examples of combining PV suppliers/installers and construction companies (or close collaboration between the two) (SO 2) could lead the way for more similar initiatives if they prove to be successful.

6.2 Institutional problems and opportunities

A lack of legitimacy for BIPV is likely the main systemic weakness, stemming from both soft and hard institutional problems.

In terms of soft (informal) institutions, the construction sector's dominant culture is focused on risk elimination (SW 8), which does not support new and innovative solutions such as BIPV. Another cultural barrier is the reluctance to involve (BI)PV expertise in the early planning phases of building projects (SW 9). Furthermore, the construction industry tends to focus more on minimizing upfront costs rather than total costs of ownership (SW 10). From the PV industry side, there are habits that are counterproductive for BIPV, as established PV installers and consultants asked for BIPV often guide their clients towards BAPV (SW 11). A cultural upside, albeit not that strong, is that architects and most of the general public prefer aesthetic and sustainable solutions, where BIPV has a better potential than BAPV (SO 7).

The main hard (formal) institutional problem is also related to legitimacy: the weakness or absence of (technical) guidance on how to implement BIPV within the current institutional framework (SW 12). The European standard for BIPV (EN 50583) and its international counterpart (IEC 63092) are the only hard institutions directly addressing BIPV. These standards present relevant tests and technical performance requirements for BIPV products and BIPV systems. Building and installation codes do not refer to BIPV in any way. Meanwhile, the need for technical guidance is assessed as high, and the mentioned standards do not adequately fill that gap. However, this situation is improving due to two ongoing initiatives: the ongoing revision of the European "BIPV standard" EN 50583 (2023), which adds further explanation and deep assessment, and provides more performance tests (SO 3); and an extensive technical guide on BIPV that is currently being developed in IEA PVPS Task 15 (to be published in 2023 or 2024) (SO 4).

Furthermore, the regulatory playing field between BIPV and BAPV is not level, to BIPV's disadvantage (SW 13): The aforementioned standards' (EN 50583 and IEC 63092) tests and requirements are generally not applied to BAPV, even though they might be equally relevant for some BAPV applications. Building permit regulations allow BAPV to cause significant changes in a building's appearance often without permit requirements, while a change of roof or facade material (i.e., BIPV) mostly does require a building permit. The current government is, however, planning to investigate the removal of building permit requirements for BIPV (SO 5). Climate declarations of new buildings consider BIPV to be a part of the building and therefore within the scope of the climate declaration, while BAPV is considered an installation and excluded from that same scope. Here, a new report by the responsible government agency suggests creating uniform rules for BAPV and BIPV (SO 6). Financial incentives (in this case primarily tax deduction on PV investments by private house owners) are formulated with the goal of being "technology neutral" and therefore open to BIPV as much as BAPV, but they lack awareness of the differences in maturity between the two PV applications which often leaves BIPV as the economically inferior alternative (SW 14).

Apart from hindering the legitimacy of BIPV, many of the above-mentioned problems also lead to a lack in Guidance of the Search, for example by guiding towards the adjacent TIS of BAPV (SW 11, SW 13, SW 14).

6.3 Interaction problems and opportunities

The weak status of Development of Social Capital is closely linked to several interaction problems. Given the multidisciplinary nature of building integration, which combines construction and photovoltaic functions, the TIS requires a higher level of interaction between experts or actors from relevant industries such as construction, PV, electrical engineering, architecture, and property management. However, such interactions are limited (SW 15). Moreover, the solar industry and the construction industry, due to their differing backgrounds and established approaches, typically lack a common language (SW 16). Furthermore, social cohesion is limited as there are no specific BIPV-focused networks (or meeting places), except for the "mirror group" initiated by the Swedish IEA PVPS Task 15 representation (SW 17).

There is supposedly a certain lock-in effect between BAPV installers/contractors and the construction/real estate industry (SW 18) that hampers the Development of Social Capital, as well as knowledge dissemination and legitimation. BAPV has been the dominant PV market in Sweden for many years, and therefore, established (BA)PV installers/contractors have relatively strong network ties with professional customers (real estate owners) and subcontractors (electricians or building contractors). Customers or subcontractors interested in BIPV are likely to turn to their existing PV contractor relations with questions about BIPV. These PV contractors typically have limited BIPV competence and already high demands for their established BAPV business case, making them reluctant to engage in BIPV or advocate the technology. Similarly, most BIPV manufacturers - originating from the PV industry – have been relying on existing downstream value chains for PV (via these same PV installers/contractors to end customers), creating a dependency on the same (BA)PV contractors/installers (SW 19). However, lately, some progress has been made by a small number of leading BIPV manufacturers/suppliers in combining forces with construction and/or real estate companies (SO 2).

Private household customers, often being one-time customers, might be less subject to lock-in effects than professional customers, but even here lock-in effects could play a role as private customers rely on contractor reputations and recommendations by peers.

6.4 Infrastructural problems and opportunities

The knowledge infrastructure for BIPV is notably limited, particularly when it comes to the dissemination or active combination of relevant knowledge areas in university education, vocational training, and national events (SW 20). This impacts Knowledge Development and Resource Mobilisation, and is also critical for the Development of Social Capital. The lack of knowledge infrastructure makes the situation for BIPV more critical at times when the (BA)PV installation sector is already short of trained personnel, such as installers and PV system designers (SW 21).

By working together towards common goals, the existing gaps in physical and knowledge infrastructure could be bridged. The EU initiatives of the Solar Energy Strategy, upcoming updates of the Energy Performance of Buildings Directive, along with the New European Bauhaus (beautiful, sustainable, together), could boost Guidance of the Search, and possibly Legitimation, if well implemented in Sweden (and other member states) (SO 8).

Financial infrastructure is a problem to a certain extent. There is generally high interest from financial actors to invest in the PV industry. While the majority of capital flow is directed towards utility-scale PV, even BIPV manufacturers seem to be able to ride on the general trend and attract investors to expand existing capacities or markets.

For Legitimation purposes, the development of new solutions and systematic verification and testing could be beneficial. However, the financial infrastructure is judged to be more limiting for these purposes, or that the BIPV industry has problems mobilising these resources (SW 22). Furthermore, financial support for regular, reproducible BIPV projects and installations is too weak to attract larger customer groups, scale up production, and make more BIPV business models viable in the long run (SW 23).

By the time of finalising this report, supply chain and transport infrastructures have become a highly relevant challenge. Events such as the Suez Canal obstruction, the COVID pandemic leading to closed factories, and the war in Ukraine have increased awareness of the risks associated with having such a highly centralised supply chain (in China) in the global PV industry (SW 24). When performing interviews and desktop studies for the analyses, the situation was quite different and not specifically addressed. Therefore, more research is needed to fully understand the impact of highly centralised supply chains on the BIPV innovation system.

6.5 Summary of system weaknesses and opportunities

A list of all the identified systemic weaknesses and opportunities for the BIPV TIS, is presented in Table 5 (coming pages). It becomes clear that there is a low diversity in entrepreneurial experimentation, both in terms of actors and business models. Industry and supporting actors could do more to enhance the guidance to BIPV and its legitimacy, although legitimacy problems also stem from the typical culture in the construction (and PV) industry. The lack of technical guidance and an uneven playing field between BIPV and BAPV also pose problems that impact legitimacy. Social capital could play a role in increasing the guidance of the search and legitimacy, but the development of social capital faces obstacles due to strong connections between (external) incumbents and limited opportunities to expand networks.

On the positive side, there are some upcoming publications and regulations that could enhance legitimation and guidance. Some initial examples of closer collaboration between BIPV and construction sector actors could contribute to the above and to the diversity in entrepreneurial experimentation.

Table 5 List of systemic weaknesses (SW) and opportunities (SO) for the Swedish BIPV TIS

Number	*Systemic weakness or opportunity*	*Impacts TIS function(s)*
SW 1.	Very few existing actors (manufacturers, suppliers, installers/contractors, technical consultants, architects) have specialized on BIPV or have BIPV as a core activity and competence.	Entrepreneurial experimentation
SW 2.	Limited engagement by actors originating from the construction industry.	Entrepreneurial experimentation
SW 3.	BIPV offers (business models) for early niche-market and demonstration phase applications are highly similar and do not address the high (upfront) costs.	Entrepreneurial experimentation
SW 4.	BIPV suppliers in many cases lack capacity to convince potential customers of the (technical, liability and environmental) legitimacy of the technology.	Legitimation
SW 5.	Supporting actors (e.g. research actors) are contributing little to the TIS in form of legitimacy creation.	Legitimation
SW 6.	Industry actors fail to communicate a clear status and vision for BIPV.	Guidance of the search
SW 7.	Educational actors (incl. event organisers) are hardly engaged in the BIPV TIS.	Knowledge dissemination (Legitimation, Development of social capital)
SW 8.	The construction sector's dominating culture is highly focused on risk elimination.	Legitimation
SW 9.	Construction and real estate sectors are typically reluctant to involve (BI)PV competence in early planning phases for building projects.	Legitimation
SW 10.	Construction industry is more focused on minimizing upfront costs than on doing so for total costs of ownership.	Legitimation
SW 11.	established PV installers and consultants being asked for BIPV tend to guide their clients to BAPV.	Legitimation (Guidance of the search)
SW 12.	Current hard institutional framework lacks (technical) guidance on how to successfully implement BIPV.	Legitimation
SW 13.	The regulatory playing field between BIPV and BAPV is unlevelled, to BIPV's disadvantage:	Legitimation, Guidance of the search
a)	Technical and safety requirements proposed in standards for BIPV are generally not asked for in BAPV, even though they might be equally relevant for certain BAPV.	
b)	Building permit regulations have more extensive exceptions for BAPV than for BIPV.	

Number	*Systemic weakness or opportunity*	*Impacts TIS function(s)*
SW 14.	Financial support for PV lacks awareness of the lower matureness of BIPV compared to BAPV applications.	Legitimation, Guidance of the search
SW 15.	Interactions between experts or actors from relevant industries, like construction, PV, electrical engineering, architecture, and property management are too limited or weak.	Development of social capital
SW 16.	The solar industry and the construction industry, due to their very differing backgrounds, lack a common language for BIPV.	Development of social capital
SW 17.	Social cohesion is low as there are hardly any BIPV-focused networks nor meeting places.	Development of social capital
SW 18.	Lock-in effects exist between BAPV installers/contractors and construction/real estate industry that hamper BIPV development.	Development of social capital (Knowledge dissemination, Legitimation)
SW 19.	BIPV manufacturers originate mainly from PV industry and have been relying hardly on existing downstream value chains for (BA)PV rather than for construction products.	Development of social capital (Knowledge dissemination, Legitimation)
SW 20.	The knowledge infrastructure for BIPV is very limited, especially regarding dissemination or active combination of relevant knowledge areas, both in university education and in vocational education or trainings and events.	Knowledge dissemination, (Resource mobilization, Development of social capital)
SW 21.	Shortage of trained personnel (installers, PV system designers, etc.) in broader PV sector, including BIPV.	Resource mobilization
SW 22.	Limited or unknown financial infrastructure for developing new solutions or systematic verification and testing of BIPV products and BIPV systems.	Resource mobilization, Legitimation
SW 23.	Financing for regular, reproducible BIPV projects and installations is too weak to allow for necessary scale up.	Resource mobilization
SW 24.	Risks connected to having such a highly centralized supply chain (in China) in the global PV industry.	Resource mobilization
SO 1.	Increasing interest in adjacent TISes (centralized PV, BAPV) might be an opportunity in the long run when those stagnate.	Guidance of the search
SO 2.	Initial examples of combining PV suppliers/installers and construction companies (or close collaboration between the two) seem to be falling out well. Others might follow suite.	Entrepreneurial experimentation (Development of social capital, Legitimation)
SO 3.	The European “BIPV standard” EN 50583 is currently (2023) being revised, providing improved technical guidance.	Legitimation

Number	*Systemic weakness or opportunity*	*Impacts TIS function(s)*
SO 4.	An extensive technical guide on BIPV is currently under development in IEA PVPS Task 15.	Legitimation
SO 5.	The current government is planning to investigate removing building permit requirements for BIPV.	Guidance of the search
SO 6.	A new report by the responsible government agency suggests creating uniform rules for BAPV and BIPV	Guidance of the search
SO 7.	Architects and most of the general public prefer aesthetical and sustainable solutions, where BIPV is considered to have a better potential than BAPV.	Legitimation
SO 8.	The EU initiatives of the Solar Energy Strategy, upcoming updates of the Energy Performance of Buildings Directive together with the New European Bauhaus (beautiful, sustainable, together), could boost Guidance of the search and maybe also Legitimation.	Guidance of the search, Legitimation

7 RECOMMENDATIONS

Based on the identified systemic weaknesses presented in the previous chapter, a selection of prioritized actions is recommended below. As the functional performance of Market formation and Resource mobilisation are close to sufficient, these functions are not addressed directly in the below recommendations. The authors acknowledge that some efforts are needed there in the (near) future but find these to be less urgent. Furthermore, it might be that some of the resource-related challenges (e.g. educational infrastructure) gain a more natural focus after addressing the prioritised functions and problems recommended below.

Recommendations are grouped under main headers, but largely follow the categorisations made in the previous chapter, based on presence and capacity problems related to actors, institutions, interactions, and infrastructure. References (clickable links) to systemic weaknesses and opportunities are made using the numbering from Table 5.

7.1 Increase diversity and focus of BIPV actors

Systemic problems SW 1, SW 2, SW 3, and SW 7 indicate the need for more actors in general, but specifically more specialized (BIPV-focused) actors and more diverse actors, including more construction industry and education actors. Also value offerings and business models from actors should diversify to decrease (upfront) costs, which would also address legitimation problem SW 10.

The following actions are ranked as most relevant to contribute to diversified engagement of new or existing actors as described above. They either demand specific actors to be active, or increase general guidance of the search and building of networks between PV and construction industries (related to Development of social capital):

- R 1 Initiate partnerships between PV and construction companies (taking advantage of SO2), either voluntary or through requirements in tenders or funding calls;
- R 2 Develop and provide trainings on BIPV for professionals, preferably in multi-disciplinary groups;
- R 3 Collaborative road-mapping initiatives;
- R 4 Develop and demonstrate reproducible BIPV concepts (with extensive knowledge dissemination);
- R 5 Innovation procurement[iv] for mass-customized BIPV-solutions;
- R 6 Implement collaboration and mobility schemes for industry experts and researchers;
- R 7 Market potential reports;
- R 8 Joint campaign, by BIPV-actors, to highlight the technology's benefits.

7.2 Improve technical guidance and assurance for BIPV installations

The actor problems SW 4 and SW 5 as well as institutional problem SW 12 (and infrastructural problem SW 22), indicate a need for improvement in technical guidance and quality assurance to increase the legitimacy of BIPV, both by industry actors and supporting actors. his need could be partially met by SO 3 and SO 4 if the upcoming revised standard and the new guidebook are well communicated and implemented by the industry. However, additional actions are recommended, also because the EN 50583 standard addresses only glass-based BIPV products and systems. Therefore, it is recommended to also:

- R 9 Organise technical and scientific workshops on BIPV;
- R 10 Establish harmonized (EU) standards or product certifications for (non-glass) BIPV (preferably based on the European Construction Products Regulation [47]);
- R 11 Increase the use of grants/loans for product tests & verifications;

[iv] *Innovation procurement is a process where one or multiple clients go out with a request for tenders for new, innovative solutions that meet the needs of the client group. By combining multiple clients or projects, a certain critical volume is to be gathered that makes the larger development effort worthwhile.*

R 12 Clarify requirements in, and possible exceptions to, building and electrical code requirements for BIPV;
R 13 Develop LCA reports or Environmental Product Declarations for BIPV products and systems;

As well as previously mentioned recommendations:

R 2 Develop and provide trainings on BIPV for professionals, preferably in multi-disciplinary groups;

7.3 Level the playing field between BAPV and BIPV

With respect to regulations, the playing field should be (more) levelled between BIPV and BAPV, addressing the institutional problems SW 13.a) & b) and SW 14. Some initiatives by government and government agencies are ongoing in this matter (SO 5, SO 6). Exactly what is considered levelized can be debated, but it makes sense to bear in mind the difference in scale and development phase between BAPV and BIPV.

Suggested actions are:

R 14 Investigate which building product-originated requirements also are relevant to (some) BAPV;
R 15 Report and campaign on disadvantages by current institutions;
R 16 Investigate economic incentives (or bonuses) for BIPV installations, e.g. Feed-In Tariff (FIT) or tax reduction;
R 17 Investigate building permit exceptions for BIPV (or ending exceptions for BAPV).

7.4 Promote cultural change in construction and real-estate sectors

On the soft institutional side, cultural changes within the construction and real-estate sectors could act as facilitators for BIPV market development. The changes to bring about involve creating more room for experimentation, considering BIPV in early phase planning, and adopting a lifecycle perspective on costs (addressing SW 8, SW 9, SW 10). The latter is closely linked with existing business models, where the development and the long-term ownership of real-estate are often performed by separate actors or subject to separate budgets.

Upcoming EU regulations and strategies could become a driving force for BIPV, as mentioned in SO 8, depending on the exact formulations and implementation. There is room here to be proactive and take advantage of this opportunity for BIPV:

R 18 Develop (and communicate) an industry-bridging perspective on BIPV in the implementation of upcoming EU regulations (Solar Strategy, EPBD, …) to seize opportunity SO 8;

Driving cultural change is not straightforward, but actions that either stimulate the desired behaviour or target the underlying causes (e.g. lack of trust in technology and/or actors) might contribute and are therefore proposed:

R 19 Encourage (or demand) BIPV solutions in municipal planning (e.g. detailed development plans, land allocation agreements), wherever a significant interest from real-estate developers makes this feasible.
R 20 Organise BIPV networking events aimed at (BI)PV, construction, and real-estate industries.

Including earlier recommendations:

R 1 Initiate partnerships between PV and construction companies (taking advantage of SO2), either voluntary or through requirements in tenders or funding calls;
R 2 Develop and provide trainings on BIPV for professionals, preferably in multi-disciplinary groups;
R 4 Develop and demonstrate reproducible BIPV concepts (with extensive knowledge dissemination);
R 6 Implement collaboration and mobility schemes for industry experts and researchers;
R 9 Organise technical and scientific workshops on BIPV;

7.5 Enhance social networks

Interaction problems are present in multiple parts of the value chain, with main weaknesses in links between the BIPV industry and the construction and real-estate industry (SW 16, SW 18, SW 19). Furthermore, there is a general lack of social interactions due to the non-existence of BIPV-focused events (SW 17). Therefore, a goal should be to increase the general social cohesion among existing TIS actors and towards potential actors from adjacent industries:

- R 1 Initiate partnerships between PV and construction companies (taking advantage of SO2), either voluntary or through requirements in tenders or funding calls;
- R 2 Develop and provide trainings on BIPV for professionals, preferably in multi-disciplinary groups;
- R 3 Collaborative road-mapping initiatives;
- R 4 Develop and demonstrate reproducible BIPV concepts (with extensive knowledge dissemination);
- R 6 Implement collaboration and mobility schemes for industry experts and researchers;
- R 9 Organise technical and scientific workshops on BIPV;
- R 19 Encourage (or demand) BIPV solutions in municipal planning (e.g. detailed development plans, land allocation agreements), wherever a significant interest from real-estate developers makes this feasible.
- R 20 Organise BIPV networking events aimed at (BI)PV, construction, and real-estate industries.

As the goal is to increase the social capital of BIPV, the actions recommended here are likely to have a larger impact when involving professionals from the construction and real-estate that have a high esteem in their industry.

7.6 The role of industry, market, government authorities and supporting actors

Table 6, which starts on the following page, summarizes all recommended actions and categorizes them into actions for public authorities (policy makers, municipalities, public funding, etc.), industry or market actors, and other (supporting) actors (academics, insurance companies, financing, network organisations, etc.). The order of presentation is not intended as a recommended prioritization order. In the same table, it is also indicated which of the systemic weaknesses each recommendation is expected to have a main positive impact on. Apart from the main impacts listed, many actions have some direct or indirect impact on additional systemic weaknesses.

Certain actions, especially those combining networking and legitimacy creation with some kind of knowledge dissemination, can be undertaken by many different actors. These can be existing actors, like the Swedish representation of IEA PVPS Task 15 and the Swedish Energy Agency, in the same way as they have previously worked with PV in general in the Solar Portal at the Swedish Energy Agency. Also, established technical fairs and conferences that attract a broad audience, such as Nordbygg (construction industry), "Mälarmarknaden" or Business Arena (real estate industry) in Stockholm, Gothenburg, Malmö are key events to highlight BIPV and create multi-disciplinary contacts. Moreover, new initiatives like Elmia Solar (fair, first edition planned for early 2024) as well as professional education actors active in PV or construction could play an important role. Dissemination and networking events can also benefit from being regional, to create BIPV nodes throughout the country.

There is a difference between (mostly industry and/or market targeted) recommendations that call on individual actors' actions, such as the creation of partnerships (R 1) or the development of reproducible concepts (R 4), and recommendations that call for collective action. The latter are often also marked as relevant for supporting (i.e., "Other") actors, which could be industry associations, but sometimes also academics. As an example, a market potential report (R 7) or a report on disadvantages under current regulations (R 15) could be written by a research organisation and supported by industry actors, followed up by an information campaign by one or more industry associations.

Table 6 List of recommendations to mitigate systemic weaknesses, along with the type of actors they are directed towards. An 'X' marks the most relevant actors to take action, and '(X)' marks the actors that could provide support.

Recommended actions	*Main recommendation categories*	*Industry actors*	*Market actors*	*Public authorities*	*Other (supporting)*
R 1. Initiate partnerships between PV and construction companies (taking advantage of SO2), either voluntary or through requirements in tenders or funding calls;	7.1 (diversity and focus), 7.4 (cultural change) & 7.5 (social networks)	X	X	X	
R 2. Develop and provide trainings on BIPV for professionals, preferably in multi-disciplinary groups;	7.1 (diversity and focus), 7.2 (technical guidance), 7.4 (cultural change) & 7.5 (social networks)	X	(X)	(X)	X
R 3. Collaborative road-mapping initiatives;	7.1 (diversity and focus) & 7.5 (social networks)	X	(X)		
R 4. Develop and demonstrate reproducible BIPV concepts (with extensive knowledge dissemination);	7.1 (diversity and focus), 7.4 (cultural change) & 7.5 (social networks)	X	X	(X)	X
R 5. Innovation procurement for mass-customized BIPV-solutions;	7.1 (diversity and focus)		X	(X)	X
R 6. Implement collaboration and mobility schemes for industry experts and researchers;	7.1 (diversity and focus), 7.4 (cultural change) & 7.5 (social networks)	X	(X)	(X)	X
R 7. Market potential reports;	7.1 (diversity and focus)	X	X	X	X
R 8. Joint campaign, by BIPV-actors, to highlight the technology's benefits.	7.1 (diversity and focus), 7.4 (cultural change) & 7.5 (social networks)	X	(X)		(X)
R 9. Organise technical and scientific workshops on BIPV;	7.2 (technical guidance)	X	X		X
R 10. Establish harmonized (EU) standards or product certifications for (non-glass) BIPV (preferably based on the European Construction Products Regulation [47]);	7.2 (technical guidance)	X		(X)	(X)
R 11. Increase the use of grants/loans for product tests & verifications;	7.2 (technical guidance)			X	X
R 12. Clarify requirements in, and possible exceptions to, building and electrical code requirements for BIPV;	7.2 (technical guidance)			X	(X)

Recommended actions	*Main recommendation categories*	*Industry actors*	*Market actors*	*Public authorities*	*Other (supporting)*
R 13. Develop LCA reports or Environmental Product Declarations for BIPV products and systems;	7.2 (technical guidance)	X		(X)	(X)
R 14. Investigate which building product-originated requirements also are relevant to (some) BAPV;	7.3 (level playing field)	X		X	(X)
R 15. Report and campaign on disadvantages by current institutions;	7.3 (level playing field)	X	(X)		(X)
R 16. Investigate economic incentives (or bonuses) for BIPV installations, e.g. Feed-In Tariff (FIT) or tax reduction;	7.3 (level playing field)			X	(X)
R 17. Investigate building permit exceptions for BIPV (or ending exceptions for BAPV).	7.3 (level playing field)			X	(X)
R 18. Develop (and communicate) an industry-bridging perspective on BIPV in the implementation of upcoming EU regulations (Solar Strategy, EPBD, …) to seize opportunity SO 8;	7.4 (cultural change)	X	(X)		(X)
R 19. Encourage (or demand) BIPV solutions in municipal planning (e.g. detailed development plans, land allocation agreements), wherever a significant interest from real-estate developers makes this feasible.	7.4 (cultural change) & 7.5 (social networks)			X	
R 20. Organise BIPV networking events aimed at (BI)PV, construction, and real-estate industries.	7.4 (cultural change) & 7.5 (social networks)	X	X		(X)

In summary, the recommendations provided are expected to offer comprehensive support to the BIPV innovation system and aid various actors in identifying ways they can contribute to the development of BIPV. This approach ensures that all relevant parties are involved and have a clear understanding of how they can support the growth and advancement of BIPV. It's a collaborative effort that leverages the strengths and capabilities of different actors in the innovation system.

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APPENDIX 1. LIST OF HISTORICAL PROJECTS BY ACTOR

The following list of Swedish actors involved in research, innovation and/or demonstration projects related to BIPV is based on the database searches as defined below.

a. European Commission CORDIS database

   Search terms:

   a. “BIPV”; Org. country = Sweden

   b. (/result/relations/categories/collection/code='deliverable','publication','exploitable' OR (/result/relations/categories/collection/code='pubsum' OR contenttype='project')) AND relatedRegion/region/euCode='SE' AND ('building' AND 'integrated' AND ('pv' OR 'photovoltaics'))

b. Swedish SweCRIS database

   Search terms:

   a. BIPV

   b. building int (relevant projects from the first 5 pages – no or very limited relevance was found on pages 4-5)

   c. byggnad integrerad sol (relevant projects from the first 5 pages – no or very limited relevance was found on pages 4-5)

   Note that the SweCRIS database lists only project coordinators and no other involved actors.

c. SCOPUS
   Also actors with authors of publications corresponding to the following search term on Scopus were included:

   a. (TITLE-ABS-KEY (bipv) AND AFFILCOUNTRY (sweden))

Actors involved in ongoing or recent projects (running until 2020 or later)

- White Arkitekter AB
    - IEA-PVPS Task 15.2 (EM 2020-2023)
    - IEA-PVPS Task 15.1 (2015-2018)
    - IEA SC Task 51 Solar Energy in Urban Planning (EM 2013-2016)
    - IEA SHC Task 41 Solar Energy and Architecture (EM 2009-2012)
    - BE-Smart: Innovative Building Envelope for Sustainable, Modular, Aesthetic, Reliable and efficient construction (H2020)
    - Widespread exploitation of building integrated photovoltaics in the Nordic dimension of the European Union (FP5 2003-2004)
    - Miljontak - takrenovering med solceller (EM 2016-2017)
- Uppsala University

    - DISRUPTIVE KESTERITES-BASED THIN FILM TECHNOLOGIES CUSTOMISED FOR CHALLENGING ARCHITECTURAL AND ACTIVE URBAN FURNITURE APPLICATIONS (H2020)
    - ARCIGS-M - Advanced aRchitectures for ultra-thin high-efficiency CIGS solar cells with high Manufacturability (H2020)
    - Effektiv och flexibel lågkostnads byggnadsintegrerad hybrid solcell/solfångare för miljövänliga byggnader (Formas 2015-2017)
- Högskolan Dalarna
    - EnergyMatching - Adaptable and adaptive RES envelope solutions to maximise energy harvesting and optimize EU building and district load matching (H2020)
    - Scientific publication: Quintana, S., Huang, P., Saini, P., & Zhang, X. (2021). A preliminary techno-economic study of a building integrated photovoltaic (BIPV) system for a residential building cluster in Sweden by the integrated toolkit of BIM and PVSITES. Intelligent Buildings International, 13(1), 51–69. Scopus. https://doi.org/10.1080/17508975.2020.1765134
    - Scientific publication: Lovati, M., & Zhang, X. (2019). Impact of electrical vehicle (EV) penetration on the cost-optimal building integrated photovoltaics (BIPV) at a small residential district in Sweden. I Berardi U. & Allard F. (Red.), IOP Conf. Ser. Mater. Sci. Eng. (Vol. 609, Nummer 7). Institute of Physics Publishing; Scopus. https://doi.org/10.1088/1757-899X/609/7/072066
    - Scientific publication: Huang, Pei, Lovati, Marco, Zhang, Xingxing, Bales, Chris, Hallbeck, Sven, Becker, Anders, Bergqvist, Henrik, Hedberg, Jan, Maturi, Laura. Transforming a residential building cluster into electricity prosumers in Sweden : Optimal design of a coupled PV-heat pump-thermal storage-electric vehicle system, Applied Energy, 2019 (Vol. 255). https://doi.org/10.1016/j.apenergy.2019.113864
    Note! This publication was not part of the Scopus search results, but referred to by Dalarna University.
    - Miljontak - takrenovering med solceller (EM 2016-2017)
- Solibro Research AB (Note: Company liquidated 2019; Evolar AB took over some of activities)
    - ARCIGS-M - Advanced aRchitectures for ultra-thin high-efficiency CIGS solar cells with high Manufacturability (H2020)
- Soltech Energy
    - IEA-PVPS Task 15.2 (EM 2020-2023)
- Midsummer AB
    - ARCIGS-M - Advanced aRchitectures for ultra-thin high-efficiency CIGS solar cells with high Manufacturability (H2020)
- Obducat Technologies AB
    - ARCIGS-M - Advanced aRchitectures for ultra-thin high-efficiency CIGS solar cells with high Manufacturability (H2020)
- Sol Voltaics AB
    - Nano-Tandem - Nanowire based Tandem Solar Cells (H2020)
- Dyenamo AB

  - ESPResSo - Efficient Structures and Processes for Reliable Perovskite Solar Modules (H2020) Aiming at BIPV applications: arbitrary shape, flexible, semi-transparent.
- Mälardalen University
  - IEA-PVPS Task 15.2 (EM 2020-2023)
  - IEA-PVPS Task 15.1 (2015-2018)
- RISE
  - IEA-PVPS Task 15.2 (EM 2020-2023)
  - IEA-PVPS Task 15.1 (EM 2015-2018)
  - Test, certifiering och standardisering av byggnadsintegrerade solcellstak (Vinnova 2017-2018)
  - PROOF - Konkurrenskraftiga Industrialiserade Solcellstak (EM 2015-2018)
  - Miljontak - takrenovering med solceller (EM 2016-2017)
- Linköping University
  - Scientific publication: Yao, N., Xia, Y., Liu, Y., Chen, S., Jonsson, M. P., & Zhang, F. (2021). Solution-Processed Highly Efficient Semitransparent Organic Solar Cells with Low Donor Contents. ACS Applied Energy Materials, 4(12), 14335–14341. Scopus. https://doi.org/10.1021/acsaem.1c03017
- Lund University
  - IEA SHC Task 63 Solar Neighbourhood Planning (2019-2023)
  - IEA SHC Task 51 Solar Energy in Urban Planning (EM 2013-2016)
  - IEA SHC Task 41 Solar Energy and Architecture (EM 2009-2012)
  - GREEN SOLAR CITIES - Global renewable energy and environmental neighbourhoods as solar cities (FP6 2007-2012)
  - PV-CITY GUIDE (FP 5 2002)
  - Solar power envelope (FP4 1998-2001)
  - Scientific publication: Imenes, A. G., & Kanters, J. (2017). 3D solar maps for the evaluation of building integrated photovoltaics in future city districts: A norwegian case study. IEEE Photovolt. Specialist Conf., PVSC, 1077–1080. Scopus. https://doi.org/10.1109/PVSC.2017.8366743
  - Scientific publication: Imenes, A. G., & Kanters, J. (2016). 3D solar maps for the evaluation of building integrated photovoltaics in future city districts: A norwegian case study. Conf Rec IEEE Photovoltaic Spec Conf, 2016-November, 3141–3146. Scopus. https://doi.org/10.1109/PVSC.2016.7750245
- Peafowl Solar Power AB
  - IP strategi för Peafowl Solar Power (Vinnova 2020)
- KTH (Royal Institute of Technology)
  - Scientific publication: Amores, A. P., Ravishankar, A. P., & Anand, S. (2022). Design and Modelling of Metal-Oxide Nanodisk Arrays for Structural Colors and UV-Blocking Functions in Solar Cell Glass Covers. Photonics, 9(5). Scopus. https://doi.org/10.3390/photonics9050273

Actors previously involved in BIPV activities – uncertain of current activity

- Exeger (previously: NLAB Solar Laboratories)
    - Scientific publication: Colonna, D., Colodrero, S., Lindström, H., Di Carlo, A., & Míguez, H. (2012). Introducing structural colour in DSCs by using photonic crystals: Interplay between conversion efficiency and optical properties. Energy and Environmental Science, 5(8), 8238–8243. Scopus. https://doi.org/10.1039/c2ee02658a
    - Patent: A TRANSPARENT DYE-SENSITIZED SOLAR CELL AND A METHOD FOR MANUFACTURING THE SOLAR CELL (2015)
- Göteborgs Universitet
    - Implementering av byggnadsintegrerad solel: hinder och möjligheter i praktiken (EM 2017-2019)
- Sunroof AB
    - Utformning av marknadserbjudande och IP Strategi för SunRoof (Vinnova 2018-2019)
    - Test, certifiering och standardisering av byggnadsintegrerade solcellstak (Vinnova 2017-2018)
- Solkompaniet
    - IEA-PVPS Task 15.1 (EM 2015-2018)
    - PROOF - Konkurrenskraftiga Industrialiserade Solcellstak (EM 2015-2018)
    - Miljontak - takrenovering med solceller (EM 2016-2017)
    -
- Elementum ECO
    - PROOF - Konkurrenskraftiga Industrialiserade Solcellstak (EM 2015-2018)
- Ingo Hagemann Arkitekt (DE)
    - PROOF - Konkurrenskraftiga Industrialiserade Solcellstak (EM 2015-2018)
- NCC AB
    - Widespread exploitation of building integrated photovoltaics in the Nordic dimension of the European Union (FP5 2003-2004)
- Familjebostäder AB
    - Widespread exploitation of building integrated photovoltaics in the Nordic dimension of the European Union (FP5 2003-2004)
- KTH
    - IMS - Integrated modular system for energy self-sufficient buildings based on thin film photovoltaic and thermoelectric devices (FP6 2004-2006)
    - Widespread exploitation of building integrated photovoltaics in the Nordic dimension of the European Union (FP5 2003-2004)
    - Prestandardisation activities for the certification of roofs and facades with integrated photovoltaic modules (FP4 1997-1999)
    - Hybrid photovoltaic module for roof integration (FP4 1996-1998)
- Högskolan i Gävle

- PV-COOL-BUILD - Design guide for building integrated Pv to minimise temperature and increase electrical output (FP5 2001-2003)

- Chalmers
    - Alvar Palm
    - Arkitektur: Miljontak - takrenovering med solceller (EM 2016-2017)
    - Utvärdering av större byggnadsintegrerade och byggnadsapplicerade solcellsinstallationer (EM/Elforsk 2014)
        - Conference: BAPV and BIPV Installation Trends in Sweden (2014)
    - SUNFLOWER - SUstainable Novel FLexible Organic Watts Efficiently Reliable (FP7 2011-2016)
- Göteborg Energi
    - Utvärdering av större byggnadsintegrerade och byggnadsapplicerade solcellsinstallationer (EM/Elforsk 2014)
- CIT Energy Management
    - Utvärdering av större byggnadsintegrerade och byggnadsapplicerade solcellsinstallationer (EM/Elforsk 2014)
- Riksbyggen
    - Miljontak - takrenovering med solceller (EM 2016-2017)
- Vätterhem
    - Miljontak - takrenovering med solceller (EM 2016-2017)
- Verisure
    - Byggnadsintegrerad organisk solcellsfilm (Vinnova 2016-2018)
- Linköpings Universitet
    - Byggnadsintegrerad organisk solcellsfilm (Vinnova 2016-2018)
    - SUNFLOWER - SUstainable Novel FLexible Organic Watts Efficiently Reliable (FP7 2011-2016)
- Skanska
    - PROOF - Konkurrenskraftiga Industrialiserade Solcellstak (EM 2015-2018)
    - Skanska Stålteknik AB: Solar power envelope (FP4 1998-2001)
    - Miljontak - takrenovering med solceller (EM 2016-2017)
- AB Jacobson & Widmark (konsult inom byggnadskonstruktion; numera del av WSP)
    - Development of a prototype facade unit integrating natural ventilation, daylighting, solar protection, intelligent local control and photovoltaic power (FP4 1998-2000)
- Helsingborgshem AB
    - NEXT-BUILDINGS - Next Zero Energy Buildings at lowest Cost by using Competitive Sustainable Technology (FP7 2012-2017)
- Boendekomfort i Viken AB
    - NEXT-BUILDINGS - Next Zero Energy Buildings at lowest Cost by using Competitive Sustainable Technology (FP7 2012-2017)

APPENDIX 2. LIST OF PATENTS AND PATENT APPLICATIONS

Results for a patent search for Sweden according to [1] (Appendix B), conducted April 2022.

TITLE	APPLICANTS	PUBLICATION NUMBER
TAK FÖR UPPTAGANDE AV SOLENERGI	BERGKVIST LARS A [SE] TÖRNERFÄLTS FASTIGHETS AB [SE]	SE1250216A1 SE537409C2
VENTILATED SOLAR PANEL ROOF	RAYMOND SOLAR AB [SE]	WO2021096417A1
SOLAR PANEL ROOF	RAYMOND SOLAR AB [SE]	SE2050723A1
BYGGELEMENT OCH DESS ANVÄNDNING	NILSSON LARS [SE]	SE1050825A1 SE536151C2
SOLAR CELL MODULE	SOLTECH ENERGY SWEDEN AB [SE]	SE1551254A1 SE540502C2
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