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International Energy Agency
Photovoltaic Power Systems Programme

Task 15 Enabling Framework for the Acceleration of BIPV

PVPS

Analysis of the Technological Innovation System for BIPV in Spain

2022

Report IEA-PVPS T15-13:2022

What is IEA PVPS TCP?

The International Energy Agency (IEA), founded in 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD). The Technology Collaboration Programme (TCP) was created with a belief that the future of energy security and sustainability starts with global collaboration. The programme is made up of 6.000 experts across government, academia, and industry dedicated to advancing common research and the application of specific energy technologies.

The IEA Photovoltaic Power Systems Programme (IEA PVPS) is one of the TCPs within the IEA and was established in 1993. The mission of the programme is to “enhance the international collaborative efforts which facilitate the role of photovoltaic solar energy as a cornerstone in the transition to sustainable energy systems.” In order to achieve this, the Programme’s participants have undertaken a variety of joint research projects in PV power systems applications. The overall programme is headed by an Executive Committee, comprised of one delegate from each country or organisation member, which designates distinct ‘Tasks,’ that may be research projects or activity areas.

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What is IEA PVPS Task 15?

The objective of Task 15 of the IEA Photovoltaic Power Systems Programme 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 issues, and financial issues.

Subtask A of Task 15 is focused on the analysis of the Technological Innovation System (TIS) for BIPV on national and multi-national levels 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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COVER PICTURE

Detail of the Titania Tower in Madrid. Courtesy of N. Martin Chivelet

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IEA PVPS
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LIST OF ABBREVIATIONS

AENOR	The Spanish Association for Standardization and Certification (aenor.org)
BAPV	Building Applied Photovoltaics
BIPV	Building Integrated Photovoltaics
CENELEC	European Electrotechnical Committee for Standardization (cencenelec.eu)
CIEMAT	Centre for Energy, Environmental and Technological Research (ciemat.es)
CTE	Technical Building Code (CTE: *Código Técnico de la Edificación*)
EIB	The European Investment Bank (eib.org)
FOTOPLAT	The Spanish Photovoltaic Technology Platform (fotoplat.es)
IEC	International Electrotechnical Commission (iec.ch)
IEA	International Energy Agency
IREC	Catalonia Institute for Energy Research (irec.cat)
MCI	Ministry of Science and Innovation (mci.gob.es)
MITECO	Ministry for the Ecological Transition and the Demographic Challenge (miteco.gob.es)
nZEB	Net Zero Energy Building
PNIEC	The Spanish Integrated National Energy and Climate Plan 2021-2030
PTEC	The Spanish Construction Technology Platform (plataformaptec.es)
PVPS-IEA	Photovoltaic Power Systems Program of the International Energy Agency
TIS	Technological Innovation System
UNE	The Spanish Association for Standardization (une.org)
UNEF	The Spanish Photovoltaic Association (unef.es)

EXECUTIVE SUMMARY

This report analyses the Technological Innovation System (TIS) of the Building Integrated Photovoltaic (BIPV) technology in Spain as it was in March 2022; the analysis aims to facilitate and support the implementation of BIPV and the innovation and industrial BIPV solutions development. It starts by identifying the actors, networks, and institutions to perform the structural analysis. Then, the functional analysis includes a review of the BIPV-related publications, projects, and patents. Interviews with relevant experts in the field and tailored surveys addressing each stakeholder group have completed the experimental basis for the eight defined TIS functions assessment.

Results show that BIPV knowledge development in Spain has sufficient quality, although it is mainly limited to the scientific and academic fields; the innovation system needs further technological and market knowledge, more in BIPV roofing than in BIPV façade solutions. Also knowledge dissemination is weak, especially between the photovoltaic and the construction sectors.

Entrepreneurial experimentation, also identified in the construction sector, is slowly increasing, and more companies' competency is needed. When it comes to resources, there are funds for PV research, development, and innovation projects, but aids are not specific to BIPV. Besides, there is a lack of BIPV-qualified technicians; BIPV is directly competing with building added photovoltaics (BAPV), usually with lesser costs and faster growth due to the PV self-consumption's success.

About the development of social capital, smooth communication and trust are essentially limited to just the known agents, so some initiatives are necessary to improve this market driver. Concerning legitimation, there is good acceptance and perception of BIPV from architects and general society; however, two main barriers increase the customers' resistance to including BIPV: costs and lack of related regulations.

Two major difficulties are that BIPV is not explicitly in the Technical Building Code, and there are no specific financial incentives or subsidies for BIPV. The BIPV market in Spain is still a niche market, slowly growing and with good future perception. The search guidance is not clear but starts from a general framework that, despite all, could be favourable to BIPV development; BIPV can benefit from the support addressed to PV self-consumption and buildings' energy retrofit projects.

To further develop BIPV towards a commercial market, it is recommended to include BIPV in building codes and get in place BIPV-specific incentives. Other suggestions to boost BIPV in Spain are at the end of the report. The annexes contain lists of BIPV projects, patents, publications, and relevant stakeholders.

1 INTRODUCTION

The aim of this Task 15 Technological Innovation System (TIS) analysis is to facilitate and support the implementation of BIPV in Spain and support the innovation and industrial development of BIPV solutions. The TIS framework provides a tool that enables a structured and objective perspective on the entire value chain of BIPV, including the interaction between its parts (networks) and its stakeholders (actors). Thus, the analysis identifies what actors participate in the Spanish Technological Innovation system, the networks they use to interact and the institutions that condition all of them.

The report structure is based on a well-established analysis procedure based on a methodology presented in more detail in, e.g. (Bergek et al., 2008; Hekkert et al., 2011; Hellsmark, 2014). The experimental basis of this Spanish TIS analysis is based on the Master Thesis of García (García, 2021). The basic structure and interactions between the main components of the TIS are shown in Figure 1.

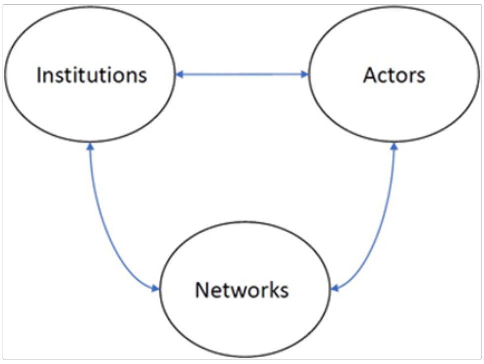

Figure 1: Basic structure and interactions between the main TIS components.

Apart from identifying the actors, institutions, and networks, it is necessary to analyse several functions related to the knowledge development, knowledge diffusion, entrepreneurial experimentation, resource mobilization, social capital development and legitimation, guidance of the search, and market formation of BIPV in Spain. Figure 2 shows the process for analysing the TIS. The functions are first studied separately, obtaining a pattern that facilitates the implementation of goals within the development of the TIS. Positive and negative aspects surrounding the technology enable the identification of barriers and drivers. Eventually, key policy issues emerge, and this information is fed back to the TIS (Figure 2).

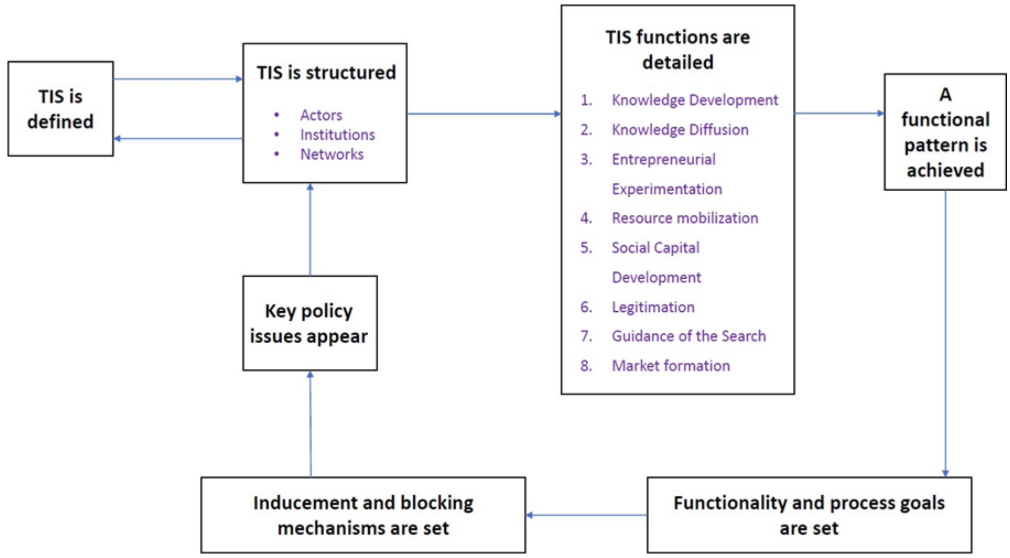

Figure 2: Process overview for a TIS analysis (García, 2021), adapted from (Bergek et al., 2008).

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

This section gives a brief initial overview of BIPV in order to clearly show and define which technology is the focus of the analysis. To do this, we define the scope of the analysis and describe how the technology and the innovation system (actors, networks and institutions) around it have developed over time.

2.1 Scope of this analysis

The scope of this analysis is BIPV modules and systems as well as PV modules and systems for purely aesthetical integration.

Definitions used within the scope (van Noord et al., TBP):

- 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 that retains building-related functionality. If the BIPV product is dismounted, it would have to be replaced by an appropriate construction product (Berger et al., 2018).
- 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 (Berger et al., 2018).

In this TIS analysis, no limitation is made with respect to application categories as defined in IEC 63092 (International Electrotechnical Commision, 2020). However, the different types of BIPV solutions found focus on BIPV façade systems (rainscreens and curtain walls), awnings and skylights.

2.2 Technological development

BIPV technology in Spain has historically developed with the support of different public financial incentives and regulations, national and European. Although the history of BIPV is somehow tightened to the history of PV, BIPV has not been so clearly affected by the Spanish regulation changes.

The first BIPV prototypes were developed by PV companies in the framework of national or European research development and innovation projects. As an example, the BIPV PV-MOBI pioneer European project, coordinated by CIEMAT and starting in 1997, involved the relevant PV manufacturing company ISOFOTON, which developed prototypes of semitransparent BIPV modules, which later evolved as awnings and shading elements in some different buildings.

Although the first BIPV products came from the PV manufacturers, as a side activity, some other companies specifically developed different solutions for building integration. A relevant example was the BIPV multifunctional semitransparent façade development by the company TFM-*Teulades i Façanes Multifuncionals* for a new public library in Catalonia (Pompeu Fabra library, 1996).

In 2009 the Spanish company Onyx Solar entered the market. It was the first BIPV company in Spain devoted to BIPV products and solutions, specializing in “PV glass for buildings”. The company has continued increasing its activity nationally and internationally, and it states total sales in 2021 of 6.2 M€ (4.5 M€ in Spain), 51 staff people (50 in Spain), and 350 projects carried out (65 in Spain) to date. Customized BIPV glazing for curtain walls, awnings, skylights, walkable floors (patented), and coloured BIPV are some of their developments.

There are currently some other incipient BIPV companies, and related activities in a few other companies mainly from the construction sector. The innovation process has started to consider the construction too, now very dependent on the technical and material suppliers.

2.3 Historical development of the innovation system

Most probably, the main milestone for BIPV technology in Spain has been the adoption of the Spanish Technical Building Code (Código Técnico de la Edificación, CTE) in 2006 (Government of Spain, 2006). This reference law, which established the regulatory framework for the basic legal requirements of health and habitability of buildings, required installing PV systems in new and refurbished tertiary buildings. The minimum installed PV power was a function of the type of building, its floor surface and the climatic region; moreover, it favoured BIPV against BAPV (building added photovoltaics). As a first consequence, architects and promoters became interested in BIPV, and the first related workshops, courses, and masters started including BIPV. However, the current edition of the CTE (Government of Spain, 2019a) does not mention photovoltaic energy expressly (see Table 1) but 'electrification with renewable energies'.

Table 1 summarizes the evolution of the different editions of the CTE in respect to BIPV. Since its approval in 2006, this code has only addressed tertiary buildings (retrofit and new projects), which explains the BIPV Spanish market bias to façade glazing solutions. Another additional factor has been that the requirements refer to the minimum PV installed power and not to the minimum contribution of PV energy, so vertical BIPV façades have competed equally with shading devices or roofs. Moreover, in the first CTE editions, BIPV was implicitly supported against BAPV: it was more permissive with solar irradiation losses if the modules were architectonically integrated, which made only BIPV and not BAPV permitted in vertical façades.

Before the CTE approval in 2006, the PV market had shown an increasing trend in installed power each year. The main reason was the feed-in tariff support system for PV generation. The Royal Decree 436/2004 defined a framework that established the legal and economic basis for the production of renewable energy, based on former RD 2818/1998 and RD 841/2002, and gave to the owner of the installation the option to trade with the electricity companies on its production.

During the '90s, the first BIPV projects developed mainly from the research area, progressing slowly into private homes and industrial buildings. Around 2004, domestic use of photovoltaic energy represented about 50% of the total market, followed by services; but BIPV installations were scarce. In 2008, the Royal Decree 1578/2008 reduced the feed-in-tariffs for big PV plants. The economic crisis and the drastic changes in the regulations and policies regarding renewable energies would weaken the photovoltaic sector, which would become damaged.

Among others, this crisis affected PV manufacturers, and, consequently, BIPV development coming from this sector. However, the little BIPV flame did not disappear and continued its activity. Some international actions influenced: the interest in promoting nearly zero-energy buildings and improving energy efficiency in buildings, the IEA-PVPS BIPV related Tasks (Task 7 at that time), the European funding programs and, of course, the CTE adoption. That framework served as a reference for those architects, building developers, and BIPV manufacturers who bet on BIPV. Thus, BIPV projects continued appearing during the following years.

Table 1: Comparative table of scopes and requirements related to PV in buildings in the different editions of the Spanish Technical Building Code (CTE).

CTE Edition	Scope	Requirement	BIPV/BAPV mandatory?
DB-HE 28/03/2006	New buildings and major retrofit actions • Hypermarkets (from 5000 m^2 constructed area).	Minimum installed power is a function of the type of building, its surface and the climatic region. In any case, the	**Yes,** BAPV or BIPV.

CTE Edition	Scope	Requirement	BIPV/BAPV mandatory?
	• Multi-store and leisure centres (from 3000 m^2). • Storage warehouses (from 10000 m^2). • Office buildings (from 4000 m^2). • Hotels and hostels (from 100 beds). • Hospitals and clinics (from 100 beds). • Exhibition pavilions (from 10000 m^2).	minimum power to install is 6.25 kW. For BAPV, maximum admissible losses: orientation and tilt 20%, shadows 15% and total 30%. For BIPV, maximum admissible losses: orientation and tilt 40%, shadows 20% and total 50%.	
DB-HE **12/09/2013**	New buildings and major retrofit actions, from 5000 m2 constructed area: hypermarkets, multi-store and leisure centres, storage and distribution warehouses, indoor sports facilities, hospitals, clinics and assisted residences, exhibition pavilions.	Minimum installed power is a function of building's constructed area and the climatic region. For BAPV, maximum admissible losses: orientation and tilt 20%, shadows 15% and total 30%. For BIPV, maximum admissible losses: orientation and tilt 40%, shadows 20% and total 50%.	**Yes,** BAPV or BIPV.
DB-HE 20/12/2019 (currently in force)	New buildings and major retrofit actions. All buildings' use, except private residential.	Minimum installed power of a renewable energy source for electric generation. Power is only a function of building's constructed area.	PV is **not mandatory** but renewable energy source for electric generation.

CTE Edition	Scope	Requirement	BIPV/BAPV mandatory?
	From 3000 m^2 constructed area.	Minimum installed power: 30 kW. Maximum installed power: 100 kW.	

3 STRUCTURAL ANALYSIS

The Spanish BIPV market can be segmented according to the use of the building, differentiating between two general groups: residential or tertiary. Regarding residential, there is a high percentage of household owners in Spain, which means that, in most cases, the potential BIPV user is the owner too. The distinction between single-family homes and communities of owners affects the decision capacity regarding BIPV. The residential single-family sub-segment, both in rural and urban areas, is strongly driven by the self-consumption of PV electricity, looking for a reduction of high electricity expenses. The Royal Decree 244/2019 (Government of Spain, 2019b) complements the regulation for renewable self-consumption and simplifies the economic compensation mechanism to reduce consumers' electricity bills, offsetting their surplus of self-produced but not consumed energy. Moreover, the Spanish government has approved subsidies for self-consumption (Government of Spain, 2021), making it even more profitable. So far, the easiest and cheapest solution is installing PV modules on the existing roofs, and many companies offer this type of turnkey PV roof solution. However, subsidies are higher if PV modules are installed in or on pergolas (addition of 500 euro/kW).

In blocks of flats, decision-making regarding self-consumption becomes more complicated to manage. A straightforward option is using PV to cover the energy needs of the shared areas of the building, such as lighting or the elevator. The collective self-consumption has high potential in Spain since the residents in flats are more than 65 %.

Although the growth of PV self-consumption installations in residential buildings is high, most cases are BAPV on roofs. It is easier to find BIPV in tertiary buildings, both in retrofit and new projects. The main reason is that since 2006, the scope of the Spanish CTE has been tertiary buildings. Most BIPV cases are rainscreens, awnings, skylights, and curtain walls.

In 2020, the total PV power installed in Spain was more than 3.4 GW, which was 2.4% of the global PV market (IEA, 2021); 596 MW corresponded to self-consumption, 19% residential and 81% commercial (UNEF, 2021), mainly in rooftop installations. There is no specific information about what part of that installed power corresponded to BIPV or how many BIPV new cases appeared last year.

This chapter focuses on the current status of the technological innovation system, considering these sections: technology, actors and networks, and institutions (Bergek et al., 2008).

3.1 Technology

The areas of knowledge included in the BIPV innovation system in Spain are:

Research, development, and innovation in materials and cells for BIPV: Thin-film materials, mainly amorphous silicon, semi-transparent electrodes, anti-reflecting coatings, module manufacturing, and system testing; the organisms and companies involved in those developments are research centres, university departments, and few companies related to BIPV modules and glass manufacture.

Manufacturing of BIPV modules: One consolidated company, Onyx Solar Energy, concentrates most BIPV manufacture; located in Avila (Spain) has a staff of 51 people (50 of them in Spain) and has developed 350 projects, 65 of them in Spain.

Building integration solutions: There are some façade-engineering companies and one BIPV engineering with relevant experience in BIPV; they are aware and informed about BIPV national, European, and related international standards (e.g., glazing requirements, fire safety); they are multinational or export their products and solutions.

Integral BIPV solutions: The company Onyx Solar offers complete service, from the consultancy and the design of the BIPV modules to the final installation of the BIPV system and their operation and maintenance. Most of their BIPV products are customized.

BIPV maintenance: In general, there is a lack of specific BIPV maintenance companies; there is significant activity in regular PV maintenance.

BIPV consultancies/business development and innovation support: Renewable energy consultancies have started to include PV in buildings, although they are not usually skilled in BIPV solutions (few exceptions).

Glass manufacturing: Glass manufacturers have collaborated with PV module and BIPV module manufacturers (low emissivity, high thermal insulation, coloured glass, anti-glare glass, etc.). Some companies are European subsidiaries, such as those of AGC or Saint-Gobain, or Spanish companies, such as Vidursolar or Mascarell.

Project development and financing: Companies offering turn-key PV self-consumption solutions do not usually include BIPV as an option; building companies and the BIPV sector are starting to collaborate to find financial support in the framework of national or European projects; the Technical Platforms (construction and photovoltaic) have started collaborating for that purpose.

3.2 Actors and networks

This section describes the current actors and networks in the value chain. They classify into 15 groups listed below (see Figure 3):

3.2.1 Actors

- **PV and BIPV manufacturers.** Eventual BIPV manufacturing comes from PV companies. There is one relevant BIPV manufacturer.
- **PV installers and engineering.** Few consulted PV installers have some experience in BIPV, although they do have in BAPV. Most of them are members of the PV Industry association UNEF; some expressed some experience in BIPV.
- **Mounting and fixation of PV systems manufacturers**. The Spanish manufacturers of supporting and mounting structures and sun trackers for PV plants are relevant in the market although there are not specifically BIPV structures.
- **Construction products manufacturers.** More than 600 companies of building products in Spain scattered throughout Spain; few of them have developed some innovative BIPV products (prototypes).
- **Construction companies.** More than 500 construction companies in Spain, although with experience in BIPV, a few façade-builders.
- **PV project developers.** Although PV projects development is mainly limited to PV plants or BAPV (self-consumption on roofs), there are a few developers with some experience in BIPV.
- **Technical consultants.** Some renewable energy consultants have experience in BIPV.
- **Research and academia sector**. Several Spanish Universities include research groups that have participated in projects or actions related to BIPV. At least the below-listed universities in the last years (with related masters, projects, and publications). In some of the Polytechnic Universities, the Technical Colleges of Architecture have also participated in these BIPV activities, e.g. Escuela Técnica Superior de Arquitectura de Madrid (ETSIM) and Escuela Técnica Superior de Arquitectura del Vallès (ETSAV).
    - Universidad Politécnica de Madrid (UPM).
    - Universidad de Málaga (UMA).
    - Universidad Politécnica de Cataluña (UPC).
    - Universidad Politécnica de Valencia (UPV).
    - Universidad de Valladolid (UVA).
    - Universidad Internacional de Andalucía (UNIA).
    - Universidad de Vigo (UVigo).

  Also, there are some research and technological centres, such as CIEMAT, CENER, TECNALIA, and IREC, that have participated in BIPV research activities. There are more than 100 related publications in peer-reviewed journals, and related Thesis, Master Thesis, and Bachelor's Degree Final Projects.

- **Educational and dissemination sector.** The educational and dissemination activity in PV and BIPV includes courses and workshops that have been organized by the technological platforms (FOTOPLAT, PTEC), the photovoltaic industry association (UNEF), the official professional associations of architects and architectural technicians, some municipalities, and regional governments, private technological and research centres, some private (TECNALIA), other public (CIEMAT, CENER) or public-private (IREC).
  Since some years ago, in Spain there are two certificates of Higher Education (General National Vocational Qualifications) related to renewable energies and energy efficiency in

buildings: since 2011, 'Senior Technician in Renewable Energies (2000 hours) [9]. These Professional Courses are taught in 50 High Technical Schools in Spain, respectively. Although there is no specific BIPV subject, the following one is related: 'Management of the assembly of photovoltaic solar installations', which includes 'The assembly of isolated photovoltaic solar installations: Architectural and urban integration. Aesthetics and technique'.

- **Architects.** Several Spanish architects with expertise in BIPV work in BIPV companies, architecture offices, façade engineering companies, or as university professors. However, they are not numerous.
- **Promoters.** The main business of promoters related to renewable energies is the development, financing, construction, management, and operation of photovoltaic plants and photovoltaic self-consumption systems in buildings. In general, there is no direct connection with BIPV.
- **Property owners.** Companies and citizens are increasing their interest in BIPV. Real cases correspond to commercial and industrial buildings, public educational buildings (schools, institutes, universities) and, to a lesser extent, particular residential houses. No information about property owning organisations and BIPV, just BAPV.
- **Users and consumers.** The Spanish users and consumers feel especially attracted by the profitability of PV self-consumption, not especially interested in BIPV.
- **Policy-makers**
    - Ministry of Transport, Mobility and Urban Agenda (responsible for the Technical Building Code, and the Long-term strategy for energy rehabilitation in the building sector in Spain).
    - Ministry of Science and Innovation (MCI) (see next section about 'Networks').
    - Ministry for the Ecological Transition and the Demographic Challenge (MITECO) (responsible for the Integrated National Energy and Climate Plan (PNIEC) 2021-2030, Recovery, Transformation and Resilience Plan).
    - AENOR and UNE (Spanish certification and standardization associations, respectively). The IEC TC82 and CENELEC CLC TC82 Spanish mirror committee is AEN/CTN206/SC82 (Secretariat: UNEF, presidency: CIEMAT); it is an active group of 29 vocals representative from industry, universities, technological centres, and research centres (public and private).
- **NGOs, associations, and organizations.** The PV industry association UNEF (www.unef.es) and the PV technological platform FOTOPLAT (www.fotoplat.org) have both BIPV activity groups, following up the international activities (Task 15) and coordinating initiatives from the PV sector side to improve the PV role in the BTC and trying to boost the relationship with the construction sector. The consumer and user associations in Spain have not yet considered BIPV a topic, while they have dedicated some of their market analysis to PV self-consumption.
- **Public and private financial institutions**

    Public institutions have financed different research development and innovation BIPV projects, in the framework of different calls addressed to renewable energies/efficiency in buildings/new materials and technologies:

    - The Institute for Energy Diversification and Saving (IDAE, https://www.idae.es).

- The Centre for Technological and Industrial Development (CDTI, https://www.cdti.es).

Some public institutions provide support and advice to entrepreneurs; they may help in the business development plan and the financing needed. Support is mainly subsidies:

- Enisa is a public company dedicated to the financing of viable and innovative business projects of Spanish SMEs through loans.
- Neotec is an initiative promoted by the CDTI (Centre for Industrial Technological Development), which aims to support and create new technology-based companies (intensive technical and scientific knowledge use).

- **Public and private banking**
  Official Credit Institute (ICO), the European Investment Bank (EIB), and public banks offer financial support for SMEs with preferential loan lines at low-interest rates. Some private banks have specific financing plans for entrepreneurs. There is also collaboration between public institutions and private banks for financing actions such as the building stock renovation (e.g., BBVA bank).

- **Venture capital companies**
  Venture capital companies, managed by different financial institutions, have been investing in the PV sector for years by acquiring and promoting PV plants and, more recently, investing in the self-consumption business. There is no known BIPV support.

- **Start-ups, incubators, and accelerators**
  As an example, Repsol Foundation offers an accelerator program ("the Entrepreneurs Fund") to support start-ups that are offering innovative solutions in the fields of low-emissions technologies, the circular economy, and the digitalization of the energy industry.

- **Business angels**
  There is a network of private investors that provide capital for creating companies, generally in exchange for shareholding. An increasing number of angel investors are organized into networks, groups, or angel clubs to share efforts and pool their investment capital. No examples of actions on BIPV.

- **Mutual guarantee companies**
  Mutual guarantee companies have played a role in developing some business initiatives related to BIPV (e.g., Onyx Solar first steps). There is an official list of these non-profit financial institutions, which usually have a regional scope. The purpose is to ensure access to credit for small and medium-sized enterprises and improve, in general, their financing conditions through the provision of guarantees to banks.

3.2.2 Networks

In 2020 the Spanish Ministry for the Ecological Transition and the Demographic Challenge communicated to the European Commission the Integrated National Energy and Climate Plan 2021-2030 (PNIEC), following Article 3 of Regulation (EU) 2018/1999 of the European

Parliament and of the Council on the governance of the Energy Union and Climate Action. The PNIEC document was published in March 2021.

The PNIEC 2021-2030 targets reaching 42% of renewables on the final use of energy in 2030 and the decarbonisation of the economy in 2050. The Plan foresees by 2030 a total installed capacity in the electricity sector of 161 GW, of which 39 GW will be solar photovoltaic. These goals might be increased in the following years according to recently presented REPowerEU Plan (https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131). The Institute for the Diversification and Saving of Energy (IDAE) is the agency attached to this Ministry which has among its functions the financing of projects and the development and management of public aid programs that affect the main energy-consuming sectors. Financing resources managed by the IDAE come mainly from ERDF Funds, the National Energy Efficiency Fund, General State Budgets, and the Institute's own financing.

On the other hand, the Ministry of Science and Innovation (MCI) is responsible for the policies related to scientific research, technological development, and innovation. The Centre for the Development of Industrial Technology (CDTI) is a Public Business Entity answering to that Ministry and which fosters technological development and innovation of Spanish companies. It is the entity that channels the funding applications for national and international R&D&I projects of Spanish companies, and supports the Technological Platforms, such as FOTOPLAT (Photovoltaic Technological Platform) or PTEC (Construction Technological Platform).

There are also several public and private research and technological organisations, such as the Centre for Energy, Environmental and Technological Research (CIEMAT), which participate in the implementation of those national programs, in collaboration with the industry.

Many of the public or private financing is a result of networking. An example of collaboration between public institutions and private banks is the BBVA bank financing the energy rehabilitation of neighbourhood communities promoted by the Institute for the Diversification and Saving of Energy (IDAE) to support the energy transition of buildings throughout Spain. Many companies are offering turnkey self-consumption solutions to communities of owners after solving the administrative procedures, about 30 interactions (emails, calls, messages) between future users and the companies that offer the service. Many of these companies are start-ups that have sprung up over the past two years. However, their business aims at self-consumption PV, not necessarily linked to BIPV.

Apart from the national networks, the research, development and innovation actions of industry, research centres and universities have benefited from the European supporting programs, some of them directly or indirectly related to BIPV. Currently, there are 23 ongoing BIPV related projects funded by the EU with Spanish participation, and Spain is coordinating eight of them.

Other international organisms that have a relevant impact on the Spanish institutions are:

- IEA-PVPS: Currently, Task 15 with the Spanish participation in all Task 15 subtasks, and management (co-leading subtask C).

- Standardization technical committees IEC-TC82 and CENELEC CLC TC82, with Spanish BIPV experts in the development of BIPV standards (CIEMAT, TECNALIA, CENER) and in the Spanish standardization mirror committee.

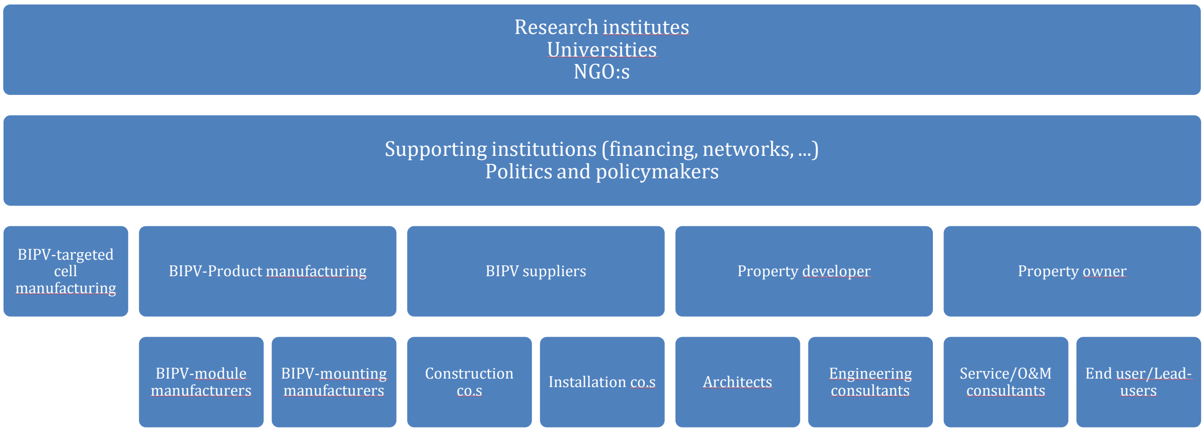

Figure 3 Value chain for BIPV, after (van Noord et al., TBP).

3.3 Institutions

In social science, the term 'institution' refers to the social systems or structures which organize the primary social practices, roles, and relationships; in other words, the established ways of society's behaviour. In the present analysis, institutions divide into soft and hard. The soft ones include society awareness, perception, and practices, while the hard ones include support programs, regulations, codes, and standards.

3.3.1 Soft institutions

- **Climate emergency awareness** is a driving force for the Spanish societal support of renewable energies in general and photovoltaic energy in particular. According to the recently published climate survey by the European Investment Bank (2021-2022 edition), 81% of the Spanish population is in favour of stricter government measures in people's behaviour to deal with the climate emergency, an increase of more than 2 %-points compared to last year and 11 %-points above the European Union average. Awareness of climate change (private and public authorities) is also increasing, which intensifies photovoltaics acceptance and support by society in general.
- National, regional, and local public procurements align with the European Directives. New building developments are starting to include BIPV instead of BAPV, although, in general, BIPV is not significant in the final decision. Project developers still do not see BIPV's benefits against BAPV, so self-consumption projects do not contemplate BIPV but **BAPV, which is well established** and could represent an obstructive force.
- The **environmental and visual impact of PV plants** is becoming an issue. The PV association UNEF has reacted and established good practices guidelines to reduce this

negative impact; there are also some initiatives by the Ministry. Indirectly, this context is favourable for distributed PV and, consequently, for BIPV.

- **Aesthetics requirement** is also driving BIPV forward. The building owners, architects, and the public in general appreciate aesthetic buildings and, usually, find BIPV more attractive than BAPV.
- The **construction sector** is still quite **conservative** about sustainable practices in general. However, the recent *renovation wave* of buildings is pushing them to look for new solutions that boost the energy efficiency in buildings.
- An increasing number of companies consider that having BIPV in their buildings is positive for their corporate image.

3.3.2 Hard institutions

- The government support programs align with the **European Directives, which do not specifically talk about BIPV**. Although there are sound national support programs for renewable energies and the improvement of energy efficiency in buildings (energy retrofit actions), BIPV does not play a role. Moreover, **BIPV modules are not considered as building products**, so they are not eligible costs in the retrofit projects.
- There is **no specific attention to BIPV in public procurement regulations**. Thus, BIPV competes with BAPV, which economically does not usually favour BIPV.
- Most **codes and standards** related to PV are similar to the European standards, since Spain is a CENELEC member. There are additional electrical regulations that affect the PV systems' reliability and safety. The low Voltage Electrotechnical Regulation has been recently updated and harmonized with the IEC and CENELEC standards.
- **European standards EN 50583**, parts 1 and 2, are also Spanish standards (Norma Española UNE-ENE 50583). However, since these are not European Harmonized Standards, and they are not mentioned in the Technical Building Code, their **fulfilment is not compulsory**. Spain has actively participated in the development of EN 50583 and IEC 63092. However, since IEC 63092 is not a European standard, it is not adopted as a Spanish standard either.
- The building requirements included in the **Technical Building Code** align with the national and European regulations. Fire safety in buildings is also included in the Technical Building Code, although there are no specific requirements for PV installations in buildings.
- Since June 2013, the **energy certificate** is mandatory for owners when making a sale or rental operation. The selling or leasing party must provide the energy label of the property. However, the energy certificate only affects the thermal insulation of the house (mainly windows and awnings), the facades' and floors' state, and water and cooling installations. The energy certificate does not consider BIPV.

4 PHASE OF DEVELOPMENT AND TARGET DEFINITION

In Spain, BIPV technology is mainly in the niche-market phase, although there are already commercial products that may be already competitive with other construction products. This occurs with BIPV elements for ventilated façades, curtain walls, and skylights, mainly for the tertiary segment.

At the same time, there is still room for new concepts, prototypes, and models. The proof is the various current projects where new designs, products, solutions, and models are being developed (see Annex I).

Figure 4 shows the different product types identified and their estimated development phases. There is research on new materials for BIPV, and on a variety of BIPV products available in the market or under development. The products were identified from a few companies (design and manufacture), while predevelopment prototypes and research projects come from R&D centres and universities. As shown, there are different solutions for roofs, balconies, parapets, and shading devices that are in the demonstration phase, while glazing solutions for skylights, curtain walls, rainscreens, and shading devices are in the niche-market phase.

The main reasons why most market-developed products are BIPV glazing are that the technical building code has only addressed tertiary buildings and has required some installed power instead of some energy contribution. Moreover, according to the CTE, PV façades had to be BIPV and not BAPV if they showed irradiation losses of more than 40%, which occurs in most locations in Spain. This particular context has promoted BIPV glazing in commercial and office buildings, as elements of curtain walls and ventilated façades (rainscreens), and in skylights and shading devices. It is still difficult to establish a target year to see the commercial growth of the Spanish BIPV market. However, the recently started supporting programs for the energy rehabilitation of buildings could significantly help in accelerating this pathway.

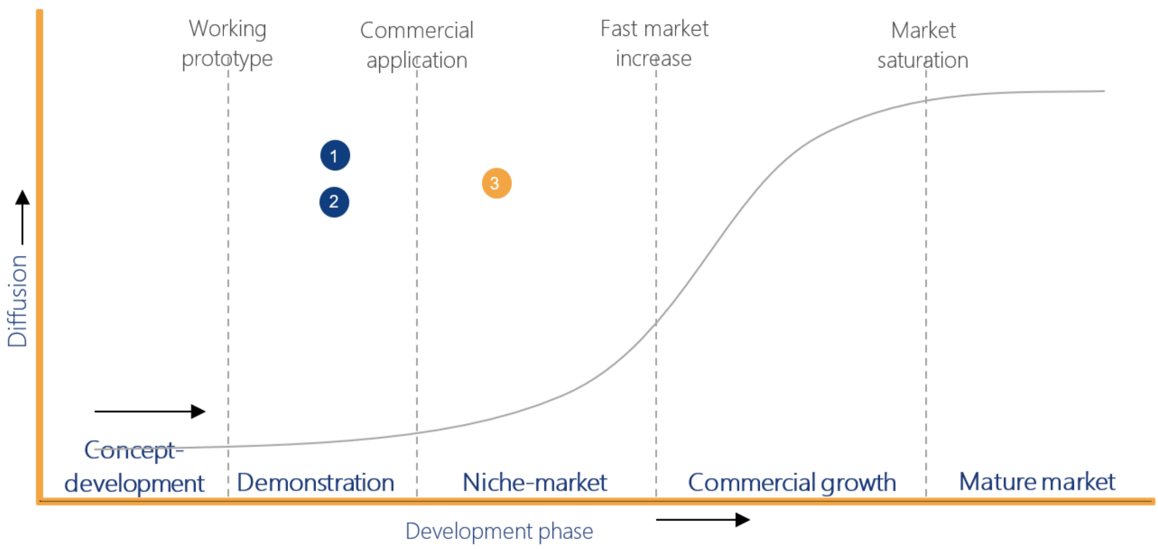

Figure 4. Development phases for BIPV in Spain. Blue circles indicate non façade BIPV solutions, and orange circles façade-integrated solutions. Numbers in circles: 1. Different solutions for roofs, balconies, plinths, parapets, parking canopies, pergolas; 2. Roof tiles by construction sector manufacturers; 3: Glazing solutions (semitransparent or not) for curtain walls, rainscreens, skylights and shading devices.

5 FUNCTIONAL ANALYSIS

Functions represent the core of the innovation system; in this chapter, we describe and assess them to identify what needs further development. We have adopted the eight functions and the function analysis proposed in STA (van Noord et al., TBP), which included the description, the assessment focus, and the key indicators for each function. We consulted different databases of publications, projects, and patents; however, the largest source of information for this study has been the responses to a survey sent to the different actors involved in BIPV technology, and six detailed interviews conducted with experts in the field. After its analysis, we have assessed each function as absent, weak, moderate, strong, or excellent. The values that quantify this assessment are 1, 2, 3, 4, and 5, respectively.

We identified 15 subgroups in the Spanish BIPV value chain and 117 relevant companies. Table 2 indicates the number of companies in each group. As shown, most identified companies belong to the photovoltaic, construction, or architectural sectors. The surveys were sent directly or through national networks (associations, platforms, social networks). Additionally, six full interviews were done. Figure 5 shows the geographical distribution of the companies. Annex II includes the full list of them.

Table 2 Number of companies contacted in each group for the survey, from most to least. The table includes the BIPV users or potential users.

Group	Number of companies
PV suppliers and installers	23
Technical consultants	19
Construction companies	12
Construction products manufacturers	9
Architects	9
Research and academia sector	8
NGOs, associations and organizations	7
PV and BIPV manufacturers	6
Policy makers	4
Educational and dissemination sector	3
Mounting and fixation of PV systems manufacturers	2
Public and private financial institutions	2
Property owners	2
Promoters	2
End users	9
TOTAL	117

5.1 Knowledge development

In Spain, the **scientific knowledge** regarding BIPV has been developed mainly by research centres and universities, usually supported by funding programs (National or European). There are around 52 related publications in peer-reviewed journals (see Annex III). Papers refer to new materials and product development, BIPV system's electrical design, simulation and forecasting, description of demonstration projects, characterization and modelling of BIPV elements, or theoretical studies about the physical behaviour of BIPV elements (thermal, solar, optical).

Most BIPV **technological knowledge** has been conducted by the industry in collaboration with technological and research centres. Annex I shows the relevant participation of Spain in BIPV related projects co-financed by the EU, both ongoing or ending 2020 at the latest, with participation in 21 projects and coordination of 9 of them. In the patent database Espacenet (Espacenet – patent search), there are 26 Spanish granted related patents about BIPV and 16 BIPV granted utility models. We also found other nine BIPV patent applications that were not granted or deemed to be withdrawn. The results are obtained with a combined search in Espacenet and a subsequently filtering. The final results are displayed in Annex IV.

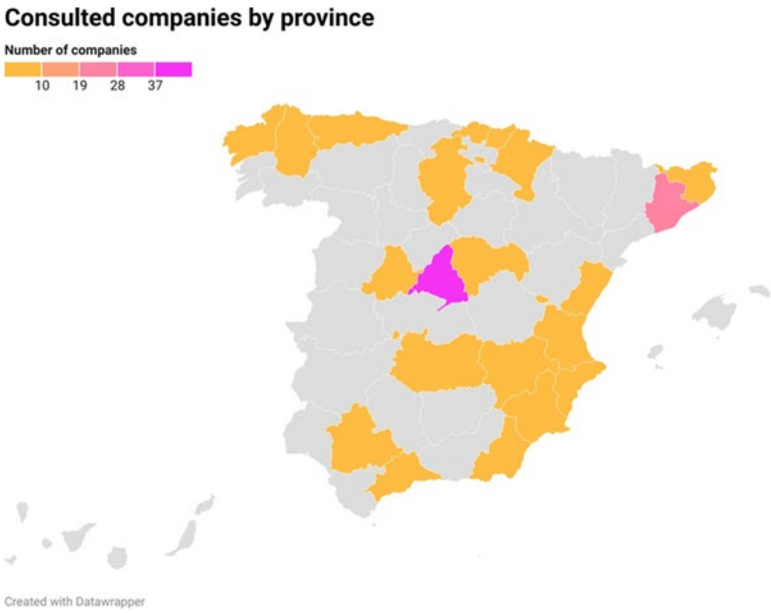

Figure 5. Map with the location of all the consulted companies (García, 2021).

However, technological knowledge is not so widely published. BIPV production and market knowledge are scarce. Knowledge has sufficient quality, but it is mainly limited to the scientific field. This could indicate that the innovation system needs more technological, production, and market knowledge.

From the analysis of the architects' responses to the survey, 40% against 20% think they have quite a knowledge about BIPV and consider that BIPV is not complicated to implement in the design phase of the building compared to conventional construction elements. The rest (40%) condition their answer to the type of project and claim the need for complete digitization of databases and specific calculation tools/software for BIPV calculations. In general, architects demand more information about the available BIPV products.

Other stakeholders also agree that there is a need for of more consultants and experts that advise on the subject, and think that the available BIPV practical knowledge is insufficient.

Summary. Knowledge development has sufficient quality, but it is quite limited to the scientific field. Technological knowledge is not so developed, and especially in BIPV roofing when compared to BIPV façade solutions. This indicates that the innovation system needs more technological, production and market knowledge. Function fulfilment score: 3.5. Moderate-Strong.

5.2 Knowledge dissemination

Regarding theoretical knowledge diffusion, the first publications of BIPV in Spain (dissemination articles, books, and chapters of books) appeared between the end of the 20th century and the beginning of the 21st century. Then, they became relatively more numerous since the publication in 2006 of the first edition of the Technical Building Code, which attracted the interest of architects in photovoltaics. Some examples of magazines where some BIPV articles have been published are: a) in the field of energy, renewable energies and photovoltaics: *PV magazine, Era Solar, El periódico de la Energía, Solar News, Revista Energías Renovables, Técnica Industrial, Energética21*; b) in the field of construction and architecture: *Ecoconstruccion, Construible, Cercha*.

BIPV started to be commonplace in every PV conference or PV fair in Spain, often organised by the sectorial association UNEF and the PV technical platform FOTOPLAT, where workshops or sessions devoted to BIPV were included in the agendas. However, the majority of these BIPV diffusion activities have been addressed to the PV sector and not to the construction one. Currently, a collaboration between FOTOPLAT and PTEC is foreseen for BIPV dissemination in the construction sector.

Examples of Spanish conferences, congresses, or other events in which BIPV has been included in some sessions are:

- Foro Solar-UNEF (https://unef.es/foro-solar/viii-foro-solar/).
- FOTOPLAT periodic webinars (https://fotoplat.org/2020/11/serie-de-webinars-tecnicos/).
- Congreso Ibérico de Energía Solar (http://www.cies-congreso.org/67569/detail/xviii-congreso-iberico-y-xiv-congreso-iberoamericano-de-energia-solar.html).
- GENERA, Feria Internacional de Energía y Medioambiente (https://www.ifema/genera/).
- Congreso de edificios de energía casi nula (https://www.congreso-edificios-energia-casi-nula.es/).
- Smart City Expo World Congress (https://www.smartcityexpo.com/).
- Webinars organized by different magazines (e.g., Ecoconstruccion, a magazine for architects and construction technicians).

Regarding practical diffusion, some demonstration projects cofounded by the EU or national programs have developed different BIPV projects, usually as new buildings but also as retrofit case studies. A key demonstration event was the Solar Decathlon Europe celebration in 2010 in Madrid, with several Spanish Universities participating. Some years before, in the USA second edition, held in 2005, a non-American university, the Polytechnic University of Madrid (UPM), participated for the first time, coming in 9th place. After that, the building is at the UPM for demonstration and educational purposes. In USA 2007 edition, UPM gained 5th place.

The survey and the interviews show that, in general, there is low knowledge exchange among the relevant actors of the value chain (Researcher, 19-04-2021; CEO, 16-06-2021), especially between the BIPV and the construction sectors. Although most survey participants agree that cooperation between the different stakeholders is necessary to successfully develop a BIPV project (Production Manager, 10-06-2021; CEO, 16-06-2021; Project Manager, 15-06-2021), some of them claim that there are still architects that do not see the need to work with a multidisciplinary team from the starting of the project. However, the perception is that the situation has improved in the last few years.

More BIPV training courses specifically addressed to architects is another common idea (Research Director, 10-05-2021; Production Manager, 10-06-2021). Also, enhancing the connection between the different actors by promoting related conferences, workshops, and other activities that make them meet and collaborate (Projects Engineer 20-05-2021; CEO, 16-06- 2021; CEO, 21-06-2021). “The BIPV sector should be better organized and coordinated with the construction sector.” (Business Manager, 22-06-2021).

Potential end-users consider that there is not enough diffusion of BIPV knowledge too. Most know very little or nothing about the topic and some suggest using social media to spread information and organizing more webinars and workshops.

A policymaker suggests CERVERA network (https://evolutioneurope.eu/blog-es/red-cervera-estimulo-necesario-centros-tecnologicos/) for supporting the exchange of knowledge for all technologies and sectors, including BIPV.

From an international point of view, there is good communication with companies, institutions, and actors from other countries; some companies have been working on many projects out of Spain, even with most of their turnover coming from abroad. Some interviewees think that BIPV in Spain is less developed than in other countries despite the high solar resource and the many buildings that are suitable for BIPV (CEO 16-06-2021).

Summary. Knowledge dissemination exists, but it is insufficient, especially between the photovoltaic and the construction sectors. Architects are demanding more information from manufacturers and suppliers. However, while the examples of commercial buildings have served to disseminate knowledge of photovoltaic facades (construction sector magazines, congresses), BIPV roofing knowledge exchange has been very scarce. Function fulfillment score: 2. Weak.

5.3 Entrepreneurship

Traditionally, the construction sector in Spain has been very conservative regarding innovation (Project Manager, 14-06-2021; CEO, 16-06-2021), and now it is seen as key sector for BIPV development. Most interviewees consider that BIPV development came from the photovoltaic sector, although current BIPV product innovation comes from a few specialized BIPV firms, and from other types of companies (e.g., natural lighting, building materials).

However, there is one outstanding BIPV company in Spain, Onyx Solar, which is the main actor in most BIPV industry innovations. One of the two co-founders of this company explained in an interview (https://hemeroteca.innovaspain.com/detalle_noticia.php?id=1119) that in 2009 they emerged as a start-up founded by two persons who believed in the growth possibilities of incipient BIPV. They opted for technologically advanced and competitive products, which provide high-added value to the customer. This company makes individualized proposals for each project. It has a multidisciplinary team of physicists, engineers, and architects who carry out complete bioclimatic engineering studies for each proposal, offering the solution that best suits the project, and taking into account factors such as location, photovoltaic technology, client's objectives, transparency degree, or colours. Semitransparent customized BIPV amorphous silicon modules have been one of their key products, although 80% of their current production (m^2) is crystalline silicon, with outstanding projects with this technology (Chief of Technology, 26-05-2021; R&D Technician, 26-05-2021, Marketing Director, 27-05-2021). They offer other BIPV products and solutions for skylights, facades, roofs, and floors (e.g., the patented BIPV walkable floor).

Examples of companies (some of them start-ups) that offer solutions and sell imported products are BIREN (CEO, 21-06-2021) or Nest City Labs (International Project Manager, 03-06-2021)). Other companies, such as La Escandella (Marketing Director, 03-06-2021), which manufactures ceramic tiles, import BIPV tiles for their clients. Consultancies such as Magna Research Buildings (Associate Partner, 27- 05-2021) offer "solar active glass" solutions in collaboration with various suppliers and engineering. Another example is the natural light and photovoltaic solar energy company Lledó Energía, which offers consulting, advisory services, complete project design, and supplies the BIPV products to the engineering or architecture office ("coloured façade elements" from a Swiss manufacturer).

Although quite limited, the construction sector has started to develop BIPV products. A good example is the ceramic tile manufacturer Tejas Borja, who has recently developed different types of BIPV flat ceramic tiles (monocrystalline or CIGS), some with large dimensions (457 mm x 1.268 mm). It is also important to mention the innovation activity in BIPV of the private technological research centre TECNALIA, which developed some BIPV products and solutions for BIPV facades, some of them patented (Project Manager, 14- 06-2021; Researcher, 14-06-2021).

The type of projects that attract new actors is related to PV self-consumption in residential and commercial applications (Technical Manager, 24-05- 2021; Project Manager, 26-05-2021). Most interviewed architects and engineers consider that although pilot projects help, now it is time for **real BIPV projects**. Preferably, those private or public projects that demonstrate the technical and financial viability of the investments.

An architect suggested comparing data in two similar buildings except for the BIPV solution. Some companies and research centres support increasing the number of real projects that share monitored data together with continued testing data (Technical Evaluator of R&D, 24-06-2021; CEO, 16-06-2021). About who should start or execute these projects, both private and public appear in the answers, although more the public sector. In general, commercial and public buildings are the most suitable for implementing BIPV in Spain (Architect, 24-05-2021; R&D Manager, 04-06-2021). BIPV residential buildings are expected to increase, although they have a more complex execution because of regulations and legislation (Project Manager, 15-06-2021). Regarding whether new or retrofit are preferred, some suggest that renovation offers more benefits for the inclusion of BIPV (CEO, 16-06-2021). Most interviewees think it is easier to design BIPV in new buildings than in retrofit ones (Industrial Engineer, 09-06-2021; R&D Manager 04-06-2021), but the renovation wave is seen as a good opportunity for BIPV retrofit projects.

Regarding the compatibility of BIPV products with construction needs, many of the developed BIPV products fit well with other types of construction elements, and there is some experience of using Building Information Modelling (BIM) tools for BIPV projects. However, there are still some demands on the suitability of the BIPV properties, for example, regarding transparency (Anonymous actor from construction sector, 16-06-2021). Proper marketing of BIPV products would help (Anonymous actor from construction sector, 09-06-2021).

Summary. There is a slow growth coming from the construction sector. One BIPV manufacturer in Spain stands out with high investment in R&D&I. There is a need of pilot projects. Function fulfilment score: 2.5. Moderate-weak.

5.4 Resources

Using BIPV today is still translated into higher investment, which explains the higher percentage of BAPV and PV plants financed by the banks (Manager, 28-06-2021; Researcher, 28-05-2021) compared to the BIPV ones. Moreover, there is a lack of specific financing for BIPV (CEO, 23-06-2021, Researcher, 19-04-2021). However, a new surge of subsidies for the renovation of the Building Park and PV self-consumption is happening in Spain, which can lead to new opportunities for BIPV. R&D&I BIPV projects can benefit from financial support from the national and regional support programs. Concerning research funding in BIPV, international outweighs national (Assistant Professor, 21-05-2021; Researcher, 28-05-2021).

Some public institutions provide support and advice to entrepreneurs; they may help in the business development plan and the financing needed. Regarding public and private banking, Official Credit Institute (ICO), the European Investment Bank (EIB), private and public banks offer financial support for SMEs with preferential loan lines at low-interest rates). However, to the authors' knowledge, there are no venture capital companies, start-up incubators or accelerators, or business angels supporting BIPV initiatives. However, there is some reported experience of mutual guarantee companies that helped medium-sized enterprises to ensure their access to credit (e.g., Onyx Solar, 2010).

There are still not sufficient experts in BIPV (Researcher, 19-04-2021). It is necessary to increase and improve the BIPV training knowledge in current engineering and architectural degrees (Anonymous actor from construction sector, 16-06-2021), and to further invest resources in BIPV R&D projects (Architect, 24-06-2021).

Regarding the BIPV infrastructure in Spain, there are several indicators of enough development to guarantee the further promotion of the BIPV market growth. However, research centres and test facilities could be reinforced and expanded (Programs Manager, 16-06-2021).

Summary. Although there are funds for PV R&D&I, they are not specific to BIPV. There are not enough BIPV qualified technicians. Function fulfilment score: 2.5. Weak-moderate.

5.5 Development of social capital

Although there is good communication among known stakeholders, it is not so when addressing new actors or companies, with or without experience in BIPV projects (CEO, 21-06-2021). In general, there is mutual trust and good communication between those familiarized with BIPV and reluctance between those who are not (Commercial Manager, 22-06-2021). But lack of communication and understanding between those who work with BIPV was also found (CEO, 16-06-2021; CEO, 21-06-2021), identified as one of the main barriers that hamper the further BIPV development in the Spanish market.

Communication among sectors is challenging (R&D Manager, 04-06-2021, Project Manager, 15-06-2021). However, while almost all architects declared that the communication between BIPV actors is good, researchers are aware of the need for better communication between different actors. BIPV in Spain suffers from distrust and lack of diffusion between actors (Researcher, 19-04-2021).

Summary. Trust and communication only occur between known agents, and it is insufficient between the construction and photovoltaic sectors. Function fulfilment score: 2. Weak.

5.6 Legitimation

Social acceptance is key to BIPV development. Most of the interviewed architects, consultants, and promoters find resistance to the inclusion of BIPV technologies. Cost is the main barrier (Researcher, 14-06-2021; R&D Manager, 14-06-2021; CEO, 16-04-2021), but not only because it is considered high, but also because there is some uncertainty about the final cost of BIPV in the project.

Another cause of resistance to including BIPV is the administrative bureaucracy. However, self-consumption steps are not different when considering BIPV or BAPV. They involve local, regional and national regulations. Recently, UNEF succeeded in eliminating the planning permission in most Autonomous Communities (regions) of Spain and is convincing the municipalities for eliminating administrative barriers. Also, self-consumption subsidies have been approved in most Autonomous Communities of Spain.

In general, BIPV solutions do not extend the duration of the project in a relevant way. This is because the projects have their bottlenecks around administrative deadlines for the planning permission (Managing partner, 02-06-2021). However, BIPV could extend the time of these projects in the preliminary design phases, especially if there is a lack of BIPV skilled technicians (Architect, 02-06-2021; Architect, 26-05-2021) and because of the administrative requirements associated with the PV installation. In many cases, delay can occur in the design phase, since it involves the supervision of a multidisciplinary team. If not well designed, BIPV can create further bottlenecks when technical issues appear in the final project due to e.g. not optimal electrical designs.

If the BIPV typology has standard sizes and characteristics, execution times can become shorter. The manufacture of customized photovoltaic glass is a bottleneck that sometimes delays the deadlines more than desired. In addition, everything that involves the breakage of a glass (in transport, assembly, storage, or in the factory) produces delays and disorganization.

Some actors suggest that BIPV manufacturers contribute positively to BIPV legitimation by publishing their best practices and projects (Manager, 22-06-2021; Manager, 26-05-2021), while many others claim that project information be shared and publicly accessible (Project Engineer, 29-05-2021; Photovoltaics Engineer, 08-06-2021; Energy Consultant, 25-06-2021; Manager, 28-06-2021).

Another aspect that BIPV offers is the use of urban space instead of natural land. Many potential users showed concern for the emerging tendency of installing large solar plants in Spain because of the direct impact on nature and land use, and they support BIPV and PV self-consumption to be further developed in cities and urban spaces to restrain those impacts.

Not explicitly mentioning BIPV in the Technical Building Code creates an uncertain situation for customers and suppliers and could hinders the acceptance for BIPV. The survey participants claimed to update the CTE to include PV and BIPV (Production Manager, 10-06-2021; Project Manager, 15-06-2021).

According to a national policy-maker, the regulatory barriers, where appropriate, are mainly derived from the use of innovative construction solutions without having a National Technical Approval (DIT) or Document of Adequacy to Use (DAU), technical evaluation of the suitability of innovative products issued by the Spanish Construction Sciences Institute (IETcc).

Spain has an important implication in the PV-related National and European Standards, necessary for the BIPV development. The only Spanish standard that refers to BIPV is UNE-EN 50583, the Spanish translation of the EN 50583; it defines BIPV modules and systems, classifies them, and refers to other Spanish (European) standards relating to glazing, construction elements, or electrical safety. The survey participants agree that this standard adds value to the development of BIPV but needs some improvement: "This standard should be enhanced and complemented with new ones so that BIPV products are more defined in terms of safety, quality, or technical characteristics, thus improving their guarantee (CEO, 16-05-2021)".

Summary. Good perception of BIPV, but cost and administrative barriers increase the resistance to including BIPV. The CTE does not contribute to BIPV acceptance. Function fulfilment score: 3. Moderate.

5.7 Guidance of the search

In Spain, there are national policies that promote using renewable energies in buildings and nZEB, but BIPV is not considered a specific solution (Policy Maker, 24-06-2021). However, BIPV is seen as a relevant solution to achieve the set decarbonisation objectives (Policy Maker, 24-06-2021; Policy Maker, 16-06-2021).

The emerging boost of renovation and PV self-consumption will bring opportunities to BIPV (Researcher, 19-04-2021); however, because of the lack of knowledge of BIPV in Spain, these innovative solutions could be overlooked and not used (Project Engineer, 19-05-2021; Manager, 26-05-2021).

The interviewed policy-makers in Spain consider that the ongoing support for the energy rehabilitation of buildings in Europe and Spain provides good opportunities for BIPV; BIPV is an innovative technological solution to implement in building renovations. However, it is necessary to improve the information policies and the education programs to train the construction sector and bring them to market and the financial incentives for owners to include BIPV. They also think BIPV commercial products and systems in the market, in comparison to ad-hoc solutions, should increase to improve user confidence.

Guidance is more directed towards BAPV in tertiary buildings than prompting BIPV against BAPV as the CTE did some years ago (CTE 2006). According to a national policy-maker, the main regulatory barriers to the use of innovative construction solutions occur if the product has not the National Technical Approval (DIT) or the Document of Adequacy to Use (DAU), which are technical evaluation certificates of the suitability of innovative products issued by the Spanish Construction Sciences Institute (IETcc).

Summary. The general framework is favourable to BIPV development (self-consumption, energy rehabilitation of buildings), but there is no specific regulatory or financial support addressed to BIPV. Majority of products are BIPV glazing products. Function fulfilment score: 2.5. Moderate-weak.

5.8 Market formation

The BIPV market leans on the current Spain support schemes for renewable energies and energy efficiency in buildings, although those support schemes do not directly address BIPV. So far, the BIPV market is still a niche market in Spain. However, according to some stakeholders, there are growth expectations (Consultant Manager, 28-06-2021; Commercial Manager, 22-06-2021), although the market formation by entrepreneurs is still not playing a role in raising user awareness. The potential users are not yet sufficiently motivated.

The market size may significantly increase if it addresses building retrofit actions. Residential buildings are a targeted market for BIPV not yet exploited. Prices should reduce first (CEO, 16-06-2021). The main barriers to the development of the BIPV market are BIPV prices, the lack of regulations and policies regarding BIPV, and the lack of BIPV knowledge. Additionally, some participants suggest that BIPV module efficiency should increase.

The proposed solutions should focus on prices that are more competitive for BIPV and strengthening the communication and trust between all the stakeholders of the value chain (CEO, 18-05-2021). Also important is to include new experts and relevant actors in this value chain, which means further training and education (Commercial Manager, 22-06-2021). The entrepreneurial actors should implement more BIPV projects in the institutional building sector to help disseminate BIPV to the public (Project Engineer, 26-05-2021).

Some interviewees think that BIPV products are well standardized and designed but consider that the complete digitization of BIPV products, improved design and computing software, and adequate regulations are still necessary (Architect 24-06-2021). The sustainable certification for buildings is another opportunity for BIPV (Project Engineer, 26-05-2021).

Despite the success of the PV industry and PV market in Spain, BIPV has not been brought the attention of policymakers because (or consequently) no multinationals were involved. However, the Spanish Onyx Solar is probably the largest BIPV company in Europe. To its success could have contributed being a BIPV company that manufactures customized 'photovoltaic glass', gets involved in the design and execution of the projects (includes architects and engineers in its staff), has invested in R & D and has good connections with the construction sector and a good international and national business portfolio.

Summary. Products are in pre-development, development or take-off (BIPV glazing applications). BIPV is still a niche market although with a good future perspective. Not clear policy support for the industry. Function fulfilment score: 2.5. Moderate - weak.

5.9 Summary of the functional analysis

The functional analysis has shown that BIPV knowledge development in Spain has sufficient quality, although it is mainly limited to the scientific field. That means that the innovation system needs more technological and market knowledge. Even though most of the interviewed architects said they have sufficient knowledge or some knowledge to implement BIPV, they claim more knowledge from BIPV manufacturers and suppliers. In general, knowledge dissemination is especially low between PV and construction sectors.

Regarding the market, entrepreneurial experimentation increases slowly. It is necessary that companies' competency increases. There are public funds for PV, but they are not specific for BIPV, so BIPV is directly competing with BAPV, usually with lower costs. Moreover, trust and good communication are limited to the known stakeholders, so initiatives are necessary to improve this market driver; maybe the PV should first meet the construction sector. However, there is good acceptance and perception of BIPV from all stakeholders, although they are aware of two main barriers that increase the customers' resistance to include BIPV: the cost and the regulations.

Regarding the future, the general framework is favourable to BIPV development, despite no specific attention paid to it; BIPV is not explicitly included in any regulation (e.g., the Technical Building Code or financial incentives and subsidies), but can benefit from the support addressed to PV or retrofit actions, if it can compete with BAPV. As a general conclusion, the BIPV market in Spain is still a niche market, slowly growing but with good future perception. The market size may significantly increase in the next years if addressed to building retrofit actions.

Figure 6 summarizes the fulfilment assessment of the TIS functions and Table 3 shows the main results. The final numerical assessments were established after a Marking Workshop celebrated in November 2022 within the Task 15 STA, where we shared our functional analysis results and received the STA experts' feedback.

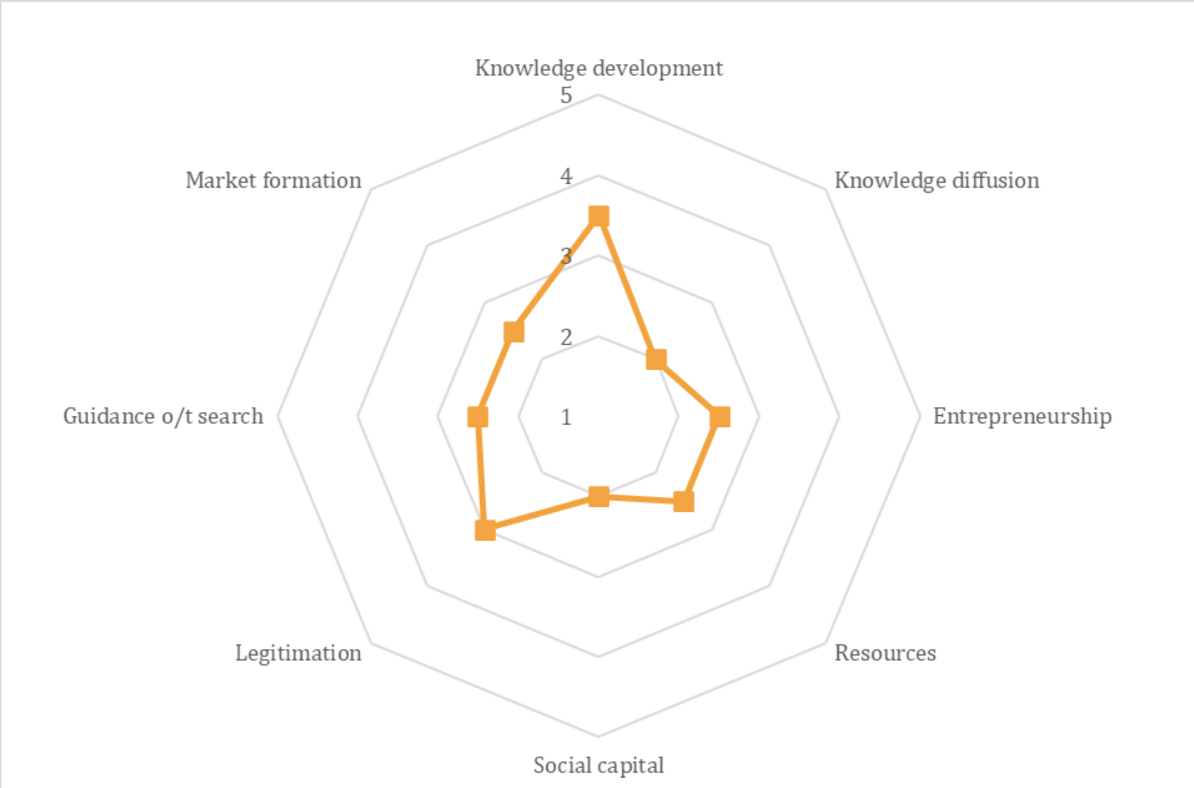

Figure 6 Results of the fulfilment assessment of the TIS functions. Numbers indicate the degree of fulfilment: 1 – absent; 2 – weak; 3 – moderate; 4 – strong; 5 – excellent.

Table 3 Summary of the results of the functional analysis

Functions	Strenghts/Opportunities	Weaknesses	Assessment
F1. Knowledge development	• Scientific knowledge is relevant: 50 BIPV publications in peer reviewed journals. • 19 European projects (ongoing or finished in 2020) with Spanish participation; 9 of them coordinated by Spain. • 26 Spanish patents related to	• Low number of technological development publications. • Few current BIPV national projects. • Weak technological, production and market knowledge. • 40% of the architects claim the need for complete digitization of databases and specific calculation tools/software for BIPV calculations.	**Moderate to strong** Knowledge development has sufficient quality, but it is quite limited to the scientific field. The innovation system needs more technological, production and market knowledge.

Functions	Strenghts/Opportunities	Weaknesses	Assessment
	BIPV (and 16 utility models).		
F2. Knowledge dissemination	• Several dissemination events in PV sector fairs, and energy-related magazines. • Some dissemination papers and webinars by architecture and construction magazines.	• 60% of the architects and building engineers do not have sufficient knowledge. • Not sufficient knowledge exchange between BIPV manufacturers and/or suppliers and architects. • Few dissemination activities addressed to architects and especially to the construction industry. • Bad connection between the technical platforms of different sectors. • Not much feedback from the architects.	**Weak** Although most of the architects interviewed have sufficient or some knowledge to implement BIPV, they claim more knowledge from the manufacturers and suppliers. Knowledge dissemination is especially low between PV and construction sectors.
F3. Entrepreneurial experimentation	• Some construction companies are starting to develop BIPV solutions. • Some new small companies interested in BIPV (consultancies, designers). • Half of the BIPV patents are developed by or with the industry.	• Low number of BIPV companies. • Low number of pilot or demo installations. • Low variety of products. • No specific solutions for rehabilitation with BIPV.	**Moderate to weak** Entrepreneurial experimentation is growing, but slowly.
F4. Resource mobilisation	• There are national and regional funds for R&D&I projects (research and technological centres and	• There are no specific funds for BIPV, which has to compete in costs with BAPV.	**Weak** Trust and good communication are limited to the known stakeholders.

Functions	Strenghts/Opportunities	Weaknesses	Assessment
	industry), and BIPV projects can benefit from them. • Self-consumption is becoming profit business for many companies (especially growing in the residential sector). • Subsidies for self-consumption have been recently approved and favour PV in/on pergolas. • Good network infrastructure (grid line capability).	• Lack of BIPV competency. • Few BIPV specialized testing labs (construction testing labs are not adapted to BIPV)	Communication initiatives are necessary (PV should meet construction).
F5. Social capital development	• Good communication among already known stakeholders.	• Distrust among not known stakeholders. • Low interaction between PV sector and construction sector.	**Weak** Trust and good communication are limited to the known stakeholders. Communication initiatives are necessary (PV should meet construction).
F6. Legitimation	• Architects' perception of BIPV is good in general. • Good acceptance from the public. • BIPV uses urban space, and not additional land (no impact on nature). • Recently, UNEF succeeded in eliminating the planning	• Most architects, consultants and promoters find some resistance to the inclusion of BIPV technologies (main reasons: costs, real final cost uncertainty, administrative barriers). • In many BIPV projects, delay can occur in the design phase.	**Moderate** Although there is good acceptance and perception of BIPV, there are two main barriers (cost and administrative burden) that increase customer resistance to include BIPV.

Functions	Strenghts/Opportunities	Weaknesses	Assessment
	permission in most Spanish regions. • The standard UNE- EN 50583 adds value to the development of BIPV. Good representation of Spain in the development of national and European standards.	• Low number of published real practices. • Standard UNE- EN 50583 still needs to be further upgraded.	
F7. Guidance of the search	• There are national policies that promote the integration of renewable energy in buildings and nZEB. • BIPV is considered a relevant solution in order to achieve the set objectives. • The emerging boost of renovation and PV self-consumption is expected to bring opportunities to BIPV. • Ongoing support for the energy rehabilitation of buildings in Europe and Spain provides good opportunities for BIPV. • CTE now includes the requirement of production of electricity with	• Difficult to obtain the required information from laws and regulations. • BIPV is not considered specifically as a solution for nZEB. • BIPV does not appear in the Technical Building Code (CTE). • Low Information on BIPV technology, education and training of the construction sector • No financial incentives for owners to include BIPV. • Lack of specific funds for BIPV.	**Moderate to weak** Although general framework is favourable to BIPV development, no specific attention is paid to it. BIPV is not explicitly mentioned in any regulation document.

Functions	Strenghts/Opportunities	Weaknesses	Assessment
	renewable energy (RE) sources.		
F8. Market formation	• BIPV market in Spain is growing, although it is still a niche market. • There is a sound Spanish BIPV company, Onyx Solar (globally 350 projects and staff 51 p.; in Spain, 65 BIPV projects and staff 50 p.) • There is a big potential for BIPV in retrofit actions. • There are good expectations for all the interviewees. • BIPV is seen as an innovative and attractive solution.	• BIPV market is still small. • BIPV market formation lays on the Spanish government's current support schemes for renewable energies and energy efficiency in buildings (where BIPV modules are not eligible costs). • Market formation by entrepreneurs is not still playing a key role in raising user awareness. • Potential users are not yet sufficiently motivated.	**Moderate to weak** Market is slowly growing but with good future perception. The market size may increase significantly if addressed to building retrofit actions.

6 IDENTIFYING SYSTEM WEAKNESSES AND STRENGTHS

6.1 Actors' problems and opportunities

The main weakness of the actors involved in BIPV technology is the lack of specialized staff. The experience in the installation and maintenance of photovoltaic systems is indeed very good, and there are also good construction engineers, but BIPV experts are missing. On the other hand, the interest of architects in BIPV is increasing, especially among the new generations. It will be important to further develop specific courses on BIPV for engineers, architects, and construction technicians.

There is a need for more companies that experiment with BIPV-solutions: e.g., more companies from the construction industry, more entrepreneurial activity on retrofit and service of BIPV-installations, and more consultancies with experience in BIPV. Also, there is a lack of active customers leading the way, starting with public buildings.

6.2 Institutional problems and opportunities

Some soft institutions support BIPV because there is more and more concern about the environmental and visual impact of the energy sources. When compared with BAPV, the architectonic integration of BIPV results in it being more attractive for the users; however, BAPV is already part of the urban landscape and project developers and policy-makers still do not see BIPV as an added value against BAPV.

Regarding hard institutions, there are national and European support programs for renewable energies and the improvement of energy efficiency in buildings (energy retrofit actions), but not addressed to BIPV. BIPV modules are still not considered building products in the financing of retrofit projects, so they are not eligible costs.

Moreover, BIPV standards and certifications are not compulsory, and the Technical Building Code does not mention BIPV anymore. Including the BIPV solutions and referring to the EN 50583 in the code can be a way to reinforce institutional support. Anyway, standard EN 50583, now under revision, needs to be better adapted to the BIPV special features to facilitate its implementation.

6.3 Interaction problems and opportunities

The analysis shows that one of the challenges is to solve the lack of interaction and good relationship between the involved agents. Not only between the photovoltaic and construction sectors, but also among equals. There is little dissemination of knowledge and little practical demonstration and examples. The photovoltaic sector must make an effort to understand what the needs of the construction sector are and, at the same time, for the construction sector to lose its fear in integrating photovoltaic in its products and solutions. The two have succeeded separately, but there are new opportunities if they work together.

6.4 Infrastructural problems and opportunities

While the physical infrastructure would easily withstand a high growth of the BIPV in Spain, the financial infrastructure is very focused on large photovoltaic plants. Specific incentives and support should be created for the development of BIPV. A simple way to promote BIPV is to include it in the energy rehabilitation of the building envelopes to increase the thermal insulation of buildings, encouraging the inclusion of BIPV modules in the place of the usual elements of ventilated facades, for example.

More BIPV training courses specifically addressed to construction professionals and more frequent BIPV meetings and workshops among the different actors during sectorial conferences and forums will result in boosting innovation and market development opportunities of BIPV.

7 RECOMMENDATIONS

The analysis of the structure of the TIS shows that a series of changes are needed to boost BIPV in Spain. In particular, the technical building code should include BIPV as a solution to combine renewable electricity production and energy efficiency improvement in buildings. It is important for construction technicians that this document explicitly refers to BIPV (this is extensive to other possible renewable energy solutions). The latest draft of the technical building code has been in the process of public information, which means that it has been receiving correction suggestions from individuals and organizations. Those have included giving photovoltaics a leading role in building electrification with renewables and including BIPV solutions in the document. The latest version after the closing of allegations is to be published.

Also, it would be convenient to promote BIPV from the institutions, with incentives for its development and installation. It would be interesting if public buildings served as an example for society by implementing BIPV on their facades and roofs. It would be good to show how BIPV provides efficient solutions for the rehabilitation of buildings.

Communication between the photovoltaic and construction sectors should be promoted through direct meetings and invitations to congresses and forums. It would be good if the support for BIPV projects encouraged the interaction of agents from the different sectors in the project.

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ANNEX I: SPAIN PARTICIPATION IN RECENT BIPV EUROPEAN PROJECTS

Recent BIPV related research, development and innovation projects co-financed by the EU (ongoing or ending 2020), with Spanish participation (those coordinated by Spain are shaded in light brown).

oPEN Lab: Open innovation living labs for Positive Energy Neighbourhoods.
4RinEU: Robust and Reliable technology concepts and business models for triggering deep Renovation of Residential buildings in EU.
APOLO: SmArt Designed Full Printed Flexible RObust Efficient Organic HaLide PerOvskite solar cells.
Be-Smart: BE-Smart: Innovative Building Envelope for Sustainable, Modular, Aesthetic, Reliable and efficient construction.
BIPVBOOST: Bringing down costs of BIPV multifunctional solutions and processes along the value chain, enabling widespread nZEBs implementation.
BRESAER: Breakthrough solutions for adaptable envelopes for building refurbishment.
CUSTOM-ART: Disruptive kesterites-based thin film technologies customised for challenging architectural and active urban furniture applications.
EnergyMatching Adaptable and adaptive RES envelope solutions to maximise energy harvesting and optimize EU building and district load matching
HEART: Holistic Energy and Architectural Retrofit Toolkit
IDEAS:Novel building Integration Designs for increased Efficiencies in Advanced Climatically Tunable Renewable Energy Systems.
InDeWaG: Industrial Development of Water Flow Glazing Systems.
IRIS: Integrated and Replicable Solutions for Co-Creation in Sustainable Cities.
MAESTRO: MAking pErovskiteS TRuly explOitable.
PVadapt: Prefabrication, Recyclability and Modularity for cost reductions in Smart BIPV systems.
PVSITES: Building-integrated photovoltaic technologies and systems for large-scale market deployment.
SENSATE: Low dimensional semiconductors for optically tuneable solar harvesters.
SERENDI-PV: Smooth, REliable aNd Dispatchable Integration of PV in EU Grids.
SolarSharc: SOLARSHARC - A durable self-clean coating for solar panels to improve PV energy generation efficiency.
Solar-Win: Next generation transparent solar windows based on customised integrated photovoltaics.
SUSNASOL: Designing of Environmentally Friendly Colloidal Nanocrystals for Sustainable Solar Cell Manufacturing.
Tech4Win: Disruptive sustainable TECHnologies FOR next generation pvWINdows.

ANNEX II: LIST OF PARTICIPANTS IN THE SURVEY AND INTERVIEWS

Architects (architecture studios) (9):
100x100Madera, Arquitectura invisible, ATANGA, Castaño y asociados, elii [oficina de arquitectura], Estudio Ataria, Luengo arquitectos, Urban Espora SL, Picharchitects.

NGOs, associations and organizations (7):
Formación, Energía y Edificación, FOTOPLAT, Green Building Council España (GBCe), Sunthalpy Engineering, UNEF, AUNAFORUM, Aiguasol.

Construction and engineering companies (12):
ARUP España, BREEAM® España, COMSA Corporación (TFM Barcelona), Eiffage Energía, Entera Energia y Construcción, EOS energy, Green Building Management, Grupo Sitecno, Impermungi, Inbisa Construcción, JG Ingenieros SA, SANJOSE constructora.

Technical consultants (19):
Sustainable Innovations Europe (SIE), Aaag Seros Training S.L., Acciona, BIPV Solutions, CEEIM Centro Europeo de Empresas e Innovación de Murcia, Cefiner, Consultores de Energía Fotovoltaica SL, Dlazen, Eficiona, Emaverick Technologies, Gravity Energía, Green Living Projects, Magic Block Engineers, MAGNA Energy Buildings, Nest City Lab, OTEM2000, Zero Consulting, SENSEDI, R2M Solution Spain.

PV and BIPV manufacturers (6):
Onyx Solar, Atersa, Longi, Solar Innova, Vidurglass, Sitecno Solar.

Mounting and fixation of PV systems manufacturers (2):
Alusin Solar, Mondragon Assembly Supports.

Construction products manufacturers (9):
AGC Glass Europe - Active Glass AIRCLOS, Alium Technologies, COSENTINO, DANOSA, Denvelops, La Escandella, Soprema Iberia, Technal Spain.

Project developers, PV (BIPV) suppliers and installers (22):
Abasol, Azimut360, BIREN, communityCFV, Cleanergetic, Ecogal, Ecooo, EDP Renovables, Enertis, Fototronica Ingenieros, HelioEsfera, H-SOLAR, Lledó Energía, MASPV Energy, Nousol Nuevas Energías, One Solar, Quetzal Ingeniería, SJ12 Enginyers, SolarServicios, SvR Ingenieros, Techsolar, Xunzel.

Public and private financial institutions (2):
Suma Capital, Triodos Bank.

Policy makers (4):
CDTI (Ministry of Science and Innovation), IDAE (Institute for Energy Diversification and Saving, MITECO), Malaga Municipality.

Property owners (2):
Professional association of San Anton Market merchants, particular owner.

Educational and dissemination sector (3):
PV Magazine, Ecoconstrucción, secondary school teacher.

Research and academia sector (8):
CENER, CIEMAT, Universidad Politécnica de Madrid (UPM), Universitat Politecnica de Catalunya - CISOL (Centre d'Investigació Solar), TECNALIA, FENERCOM (Energy Foundation of the Community of Madrid), ISFOC, ITeC - Instituto Catalán de Tecnología de la Construcción.

ANNEX III: BIPV PUBLICATIONS WITH SPANISH AUTHORSHIP

Source: Web of Science WOS (www.clarivate.com/products/web-of-science). Publications until March 2022.

Authors	Article Title	Source Title	DOI	Publication Year	Times
Daniel Valencia-Caballero, Ya-Brigitte Assoa, Werther Cambarau, Didier Therme, Asier Sanz, Françoise Burgun, Iván Flores-Abascal, Eduardo Román-Medina	Performance analysis of a novel building integrated low concentration photovoltaic skylight with seasonal solar control	Journal of Building Engineering	10.1016/j.jobe.2022.104687	2022	0
N. Martín-Chivelet, K. Kapsis, H.R. Wilson, V. Delisle, R. Yang, L. Olivieri, J. Polo, J. Eisenlohr, B. Roy, L. Maturi, G. Otnes, M. Dallapiccola, P. Wijeratne	Building-Integrated Photovoltaic (BIPV) products and systems: A review of energy-related behaviour	Energy and Buildings	10.1016/j.enbuild.2022.111998	2022	0
Martín-Chivelet N, Polo J, Sanz-Saiz C, Núñez LM, Alonso-Abella M, Cuenca J,	Assessment of PV module temperature models for Building-Integrated Photovoltaics (BIPV)	Sustainability	10.3390/su14031500	2022	0
Polo Lopez, Cristina S.; Lucchi, Elena; Leonardi, Eleonora; Durante, Antonello; Schmidt, Anne; Curtis, Roger	Risk-Benefit Assessment Scheme for Renewable Solar Solutions in Traditional and Historic Buildings	Sustainability	10.3390/su13095246	2021	7
Polo Lopez, Cristina S.; Troia, Floriana; Nocera, Francesco	Photovoltaic BIPV Systems and Architectural Heritage: New Balance between Conservation and Transformation. An Assessment Method for Heritage Values Compatibility and Energy Benefits of Interventions	Sustainability	10.3390/su13095107	2021	1
Polo, Jesus; Martin-Chivelet, Nuria; Alonso-Abella, Miguel; Alonso-Garcia, Carmen	Photovoltaic generation on vertical facades in urban context from open satellite-derived solar resource data	Solar Energy	10.1016/j.solener.2021.07.011	2021	0
Polo, Jesus; Martin-Chivelet, Nuria; Sanz-Saiz, Carlos; Alonso-Montesinos, Joaquin; Lopez, Gabriel; Alonso-Abella, Miguel; Battles, Francisco J.; Marzo, Aitor; Hanrieder, Natalie	Modeling soiling losses for rooftop PV systems in suburban areas with nearby forest in Madrid	Renewable Energy	10.1016/j.renene.2021.06.085	2021	1
Lopez-Garcia, Alex J.; Bauer, Andreas; Fonoll Rubio, Robert; Payno, David; Jehl Li-Kao, Zacharie; Kazim, Samrana; Hariskos, Dimitrios; Izquierdo-Roca, Victor; Saucedo, Edgardo; Perez-Rodriguez, Alejandro	UV-Selective Optically Transparent Zn(O,S)-Based Solar Cells	Solar Rrl	10.1002/solr.202000470	2020	1

Menendez, M. F.; Martinez, A.; Sanchez, P.; Gomez, D.; Andres, L. J.; Haponow, L.; Bristow, N.; Kettle, J.; Korochkina, T.; Gethin, D. T.	Development of intermediate layer systems for direct deposition of thin film solar cells onto low cost steel substrates	Solar Energy	10.1016/j.solener.2020.08.046	2020	1
Toledo, Carlos; Gracia Amillo, Ana Maria; Bardizza, Giorgio; Abad, Jose; Urbina, Antonio	Evaluation of Solar Radiation Transposition Models for Passive Energy Management and Building Integrated Photovoltaics	Energies	10.3390/en13030702	2020	9
Toledo, Carlos; Lopez-Vicente, Rodolfo; Abad, Jose; Urbina, Antonio	Thermal performance of PV modules as building elements: Analysis under real operating conditions of different technologies	Energy And Buildings	10.1016/j.enbuild.2020.110087	2020	9
Diez-Mediavilla, M.; Rodriguez-Amigo, M. C.; Dieste-Velasco, M. I.; Garcia-Calderon, T.; Alonso-Tristan, C.	The PV potential of vertical facades: A classic approach using experimental data from Burgos, Spain	Solar Energy	10.1016/j.solener.2018.11.021	2019	10
Rico, Elena; Huerta, Irene; del Cano, Teodosio; Villada, Loreto; Gallego, Angel; Velasco, Vicente; Zubillaga, Oihana; Vega de Seoane, Jose Maria; Arrizabalaga, Igor; Yurrita, Naiara; Aizpurua, Jon; Imbuluzketa, Gorka; Cano, Francisco J.	PVCOM Project: Manufacture of PV Modules Encapsulated in Composite Materials for Integration in Urban Environments	Smart Cities	10.1007/978-3-030-12804-3_4	2019	0 (3)
Sanchez-Palencia, P.; Martin-Chivelet, N.; Chenlo, F.	Modeling temperature and thermal transmittance of building integrated photovoltaic modules	Solar Energy	10.1016/j.solener.2019.03.096	2019	17
Toledo, Carlos; Serrano-Lujan, Lucia; Abad, Jose; Lampitelli, Antonio; Urbina, Antonio	Measurement of Thermal and Electrical Parameters in Photovoltaic Systems for Predictive and Cross-Correlated Monitorization	Energies	10.3390/en12040668	2019	7
Zambrano-Asanza, Sergio; Zalamea-Leon, Esteban F.; Barragan-Escandon, Edgar A.; Parra-Gonzalez, Alejandro	Urban photovoltaic potential estimation based on architectural conditions, production-demand matching, storage and the incorporation of new eco-efficient loads	Renewable Energy	10.1016/j.renene.2019.03.105	2019	5
Alarcon-Castro, J.; Garcia-Alvarado, R.; Sanchez-Friera, P.; Zapico-Ania, A.	Evaluation of Photovoltaic Windows with Luminescent Solar Concentrators for Zero-energy Buildings in Santiago de Chile	Informes de La Construccion	10.3989/id.58081	2018	2
Cronemberger, Joara; Caamano-Martin, Estefania	Shadowing Windows with BIPV Blinds: Delicate Balance for Office Buildings in Low Latitudes	Smart And Healthy Within The Two-Degree Limit (Plea 2018), Vol 1		2018	0

Freitas, Sara; Santos, Teresa; Brito, Miguel C.	Impact of large scale PV deployment in the sizing of urban distribution transformers	Renewable Energy	10.1016/j.renene.2017.10.096	2018	21
Fuentes, M.; Vivar, M.; de la Casa, J.; Aguilera, J.	An experimental comparison between commercial hybrid PV-T and simple PV systems intended for BIPV	Renewable & Sustainable Energy Reviews	10.1016/j.rser.2018.05.021	2018	25
Lopez, Cristina S. Polo; Frontini, Francesco	Dialogue between Research Solar Practices and Training Activities: Interactive Webinar by Integration of ICT in Education	Proc. ISES Eurosun 2018 Conference - 12th Int. Conf. Solar Energy for Buildings and Industry	10.18086/eurosun2018.07.02	2018	0
Martin-Chivelet, Nuria; Carlos Gutierrez, Juan; Alonso-Abella, Miguel; Chenlo, Faustino; Cuenca, Jose	Building Retrofit with Photovoltaics: Construction and Performance of a BIPV Ventilated Facade	Energies	10.3390/en11071719	2018	11
Martin-Chivelet, Nuria; Guillen, Cecilia; Francisco Trigo, Juan; Herrero, Jose; Jose Perez, Juan; Chenlo, Faustino	Comparative Performance of Semi-Transparent PV Modules and Electrochromic Windows for Improving Energy Efficiency in Buildings	Energies	10.3390/en11061526	2018	11
Robledo, Carla B.; Oldenbroek, Vincent; Abbruzzese, Francesca; van Wijk, Ad J. M.	Integrating a hydrogen fuel cell electric vehicle with vehicle-to-grid technology, photovoltaic power and a residential building	Applied Energy	10.1016/j.apenergy.2018.02.038	2018	84
Sanchez-Pantoja, Nuria; Vidal, Rosario; Carmen Pastor, M.	Aesthetic impact of solar energy systems	Renewable & Sustainable Energy Reviews	10.1016/j.rser.2018.09.021	2018	25
Sorgato, M. J.; Schneider, K.; Ruther, R.	Technical and economic evaluation of thin-film CdTe building-integrated photovoltaics (BIPV) replacing fa ade and rooftop materials in office buildings in a warm and sunny climate	Renewable Energy	10.1016/j.renene.2017.10.091	2018	49
Zalamea-León, Esteban Felipe; García-Alvarado, Rodrigo Hernán	Integración de captación activa y pasiva en viviendas unifamiliares de emprendimientos inmobiliarios	Ambiente Construído	10.1590/s1678-86212018000100231	2018	1
Almeida, Marcelo Pinho; Munoz, Mikel; de la Parra, Inigo; Perpinan, Oscar	Comparative study of PV power forecast using parametric and nonparametric PV models)	Solar Energy	10.1016/j.solener.2017.07.032	2017	23
Baenas, T.; Machado, M.	On the analytical calculation of the solar heat gain coefficient of a BIPV module	Energy And Buildings	10.1016/j.enbuild.2017.06.039	2017	12

Banguero, Edison; Julian Aristizabal, Andres; Murillo, William	A Verification Study for Grid-Connected 20 kW Solar PV System Operating in Choco, Colombia	Proc. Int. Conf. Power and Energy Systems Engineering	10.1016/j.egypro.2017.11.019	2017	11
Fernando Mulcue-Nieto, Luis; Mora-Lopez, Llanos	A novel methodology for the pre-classification of façades usable for the decision of installation of integrated PV in buildings: The case for equatorial countries	Energy	10.1016/j.energy.2017.11.150	2017	5
Fuentes, Manuel; Fraile-Ardanuy, Jesus; Risco-Martin, Jose L.; Moya, Jose M.	Feasibility Study of a Building-Integrated PV Manager to Power a Last-Mile Electric Vehicle Sharing System	International Journal of Photoenergy	10.1155/2017/8679183	2017	7
Martin-Chivelet, Nuria; Montero-Gomez, David	Optimizing photovoltaic self-consumption in office buildings	Energy and Buildings	10.1016/j.enbuild.2017.05.073	2017	24
Ramirez-Iniguez, Roberto; Desiga-Gusi, Jose; Freier, Daria; Abu-Bakar, Siti Hawa; Muhammad-Sukki, Firdaus	Experimental evaluation of a solar window incorporating rotationally asymmetrical compound parabolic concentrators (RACPC)	Proc. Snec 11th Intl. PV Power Generation Conference & Exhibition	10.1016/j.egypro.2017.09.402	2017	3
Aguacil, S.; Lufkin, S.; Rey, E.	Towards integrated design strategies for implementing BIPV systems into urban renewal processes: first case study in Neuchatel (Switzerland)	Expanding Boundaries: Systems Thinking In The Built Environment		2016	1
Pinto, Julian T. M.; Amaral, Karen J.; Janissek, Paulo R.	Deployment of photovoltaics in Brazil: Scenarios, perspectives and policies for low-income housing	Solar Energy	10.1016/j.solener.2016.03.048	2016	35
Tablada, Abel; Zhao, Xi	Sunlight availability and potential food and energy self-sufficiency in tropical generic residential districts	Solar Energy	10.1016/j.solener.2016.10.041	2016	7
Fernando Mulcue-Nieto, Luis; Mora-Lopez, Llanos	Methodology to establish the permitted maximum losses due to shading and orientation in photovoltaic applications in buildings	Applied Energy	10.1016/j.apenergy.2014.09.088	2015	18
Martinez-Rubio, A.; Sanz-Adan, F.; Santamaria, J.	Optimal design of photovoltaic energy collectors with mutual shading for pre-existing building roofs	Renewable Energy	10.1016/j.renene.2015.01.043	2015	17
Moralejo-Vazquez, F. J.; Martin-Chivelet, N.; Olivieri, L.; Caamano-Martin, E.	Luminous and solar characterization of PV modules for building integration	Energy and Buildings	10.1016/j.enbuild.2015.06.067	2015	13

Olivieri, L.; Frontini, F.; Polo-Lopez, C.; Pahud, D.; Caamano-Martin, E.	G-value indoor characterization of semi-transparent photovoltaic elements for building integration: New equipment and methodology	Energy And Buildings	10.1016/j.enbuild.2015.04.056	2015	8
Pacheco-Torres, Rosalia; Lopez-Alonso, Monica; Martinez, German; Ordonez, Javier	Efficient design of residential buildings geometry to optimize photovoltaic energy generation and energy demand in a warm Mediterranean climate	Energy Efficiency	10.1007/s12053-014-9275-5	2015	6
Sanchez, Esteban; Izard, Javier	Performance of photovoltaics in non-optimal orientations: An experimental study	Energy And Buildings	10.1016/j.enbuild.2014.11.035	2015	31
Cronemberger, Joara; Almagro Corpas, Monica; Ceron, Isabel; Caamano-Martin, Estefania; Vega Sanchez, Sergio	BIPV technology application: Highlighting advances, tendencies and solutions through Solar Decathlon Europe houses	Energy and Buildings	10.1016/j.enbuild.2014.03.079	2014	35
Fernando Mulcue-Nieto, Luis; Mora-Lopez, Llanos	A new model to predict the energy generated by a photovoltaic system connected to the grid in low latitude countries	Solar Energy	10.1016/j.solener.2014.04.030	2014	26
Jose Garcia-Ballesteros, Juan; Lauzurica, Sara; Morales, Miguel; del Cano, Teodosio; Valencia, Daniel; Casado, Leonardo; Lorenzo Balenzategui, Jose; Molpeceres, Carlos	Silicon PV module customization using laser technology for new BIPV applications	Laser Processing And Fabrication For Solar, Displays, And Optoelectronic Devices	10.1117/12.2064084	2014	0
Lopez, Cristina S. Polo; Frontini, Francesco; Friesen, Gabi; Friesen, Thomas	Experimental testing under real conditions of different solar building skins when using multifunctional BIPV systems	Proceedings Of The 2nd International Conference On Solar Heating And Cooling For Buildings And Industry (Shc 2013)	10.1016/j.egypro.2014.02.159	2014	4
Lopez, Cristina S. Polo; Sangiorgi, Marco	Comparison assessment of BIPV facade semi-transparent modules: further insights on human comfort conditions	Proceedings Of The 2nd International Conference On Solar Heating And Cooling For Buildings And	10.1016/j.egypro.2014.02.160	2014	13

		Industry (Shc 2013)			
Masa-Bote, Daniel; Caamano-Martin, Estefania	Methodology for estimating building integrated photovoltaics electricity production under shadowing conditions and case study	Renewable & Sustainable Energy Reviews	10.1016/j.rser.2013.12.019	2014	25
Mundo-Hernandez, Julia; Alonso, Benito de Celis; Hernandez-Alvarez, Julia; de Celis-Carrillo, Benito	An overview of solar photovoltaic energy in Mexico and Germany	Renewable & Sustainable Energy Reviews	10.1016/j.rser.2013.12.029	2014	36
Olivieri, L.; Caamano-Martin, E.; Moralejo-Vazquez, F. J.; Martin-Chivelet, N.; Olivieri, F.; Neila-Gonzalez, F. J.	Energy saving potential of semi-transparent photovoltaic elements for building integration	Energy	10.1016/j.energy.2014.08.054	2014	55
Olivieri, L.; Caamano-Martin, E.; Olivieri, F.; Neila, J.	Integral energy performance characterization of semi-transparent photovoltaic elements for building integration under real operation conditions	Energy And Buildings	10.1016/j.enbuild.2013.09.035	2014	52
Ramirez-Iniguez, Roberto; Muhammad-Sukki, Firdaus; Abu-Bakar, Siti Rawa; McMeekin, Scott G.; Stewart, Brian G.; Sarmah, Nabin; Mallick, Tapas Kumar; Munir, Abu Bakar; Yasin, Siti Rajar Mohd; Rahim, Ruzairi Abdul	Rotationally Asymmetric Optical Concentrators for Solar PV and BIPV Systems	2013 IEEE 4th Intl. Conf. on Photonics		2013	4
Cronemberger, Joara; Caamano-Martin, Estefania; Vega Sanchez, Sergio	Assessing the solar irradiation potential for solar photovoltaic applications in buildings at low latitudes - Making the case for Brazil	Energy and Buildings	10.1016/j.enbuild.2012.08.044	2012	30

*January 2022 (WOS)

ANNEX IV: LIST OF BIPV SPANISH PATENTS

List of identified Spanish patents (26) and utility models (16) about BIPV. Also are included at the end the BIPV applications that are in process or were deemed to be withdrawn (9). Source: Database Espacenet (combined search) and further filtering.

Title	Inventors	Applicants	Publication reference
Granted Patents			
Solar roof or solar facade construction	Grosse Bernd L [ES]	Grosse Bernd L [ES]	EP2408018B1
Facade system comprising sun tracking slats	Lleo Fernandez Blanca [ES]	Blanca Lleo Asoc. SL [ES]	ES2322748B1
Mobile and autonomous facade system with folding solar panel for the optimal use of natural light	Grande Nuñez Carlos Garcia Santos Alfonso	Univ. Politécnica Madrid [ES]	ES2708399B2
Multifunctional element for producing photoelectric energy	Aceves Torrents Oscar [ES]	Teulades i Facanes Multifuncionals [ES]	ES2105947B1
Solar tiles	Moreno Sanchez Oscar [ES]	Moreno Sanchez Oscar [ES]	ES2390992B1
Solar collector support for roofs and method	Cano Ordoñez Anibal [ES]	Uralita Tejados S A [ES]	ES2330501B1
Modular system of solar holographic concentration integrated in urban and road elements	Rodriguez San Segundo Hugo Jose [ES] Calo Lopez Antonio [ES] Villamarin Villegas Ayalid Mirlydeth [VE] Perez Lopez Francisco Javier [ES]	Inst Holográfico Terrasun SL [ES]	ES2563680B1
Procedure to carry out the coverage of facades and the ecoenergetic coverage of buildings	Gual I Campabadal Josep Maria [ES] Gual I Campabadal Josep Maria	Europ SA [ES]	ES2335169B1
Modular wavy solar panel imitating the placed tile	Madrigal Ballester Guillermo [ES]	Madrigal Ballester Guillermo [ES]	ES2611707B1

Photovoltaic units and structures	Pérez Lepe Antonio [ES] Izquierdo Rodríguez María Ángeles [ES] Hernández Rueda Silvia [ES] Prieto Acedo Óscar [ES] Del Cano Teodosio [ES] Casado Leonardo [ES] Beltrán Álvaro [ES] Valencia Daniel [ES] López González Eduardo [ES]	Repsol SA [ES] Onyx Solar Energy SL [ES]	EP2866268B1
Building envelope element having a first glass layer and a second photovoltaic layer	Beltran Albarran Alvaro [ES] Del Caño Gonzalez Teodosio [ES]	Onyx Solar Energy SL [ES]	ES2462865B1 (US2015288322A1)
Panel, assembly of panels and associated roofing	Chabas Eric [Fr] Masure David [Fr]	Arcelormittal Investigacion y Desarrollo Sl [ES] Arcelormittal [Lu]	EP2724088B1
Solar tracker for thermal and photovoltaic panels with forced air system, applicable to buildings	Manuel Lahuerta Romeo [ES]	Manuel Lahuerta Romeo [ES]	ES2304211B1 (CN101303152A CN101303152B)
Support structure for photovoltaic solar panels and method	Vazquez-Illa Navarro Jose Ignacio [ES]	Proyectos y Estudios Termales SL [ES] Integraciones Solares en Poliéster SL [ES]	ES2396254B1
Marquee-one-axis solar tracker (Machine-translation by Google Translate, not legally binding)	Pacheco Ortiz Francisco Felix Pacheco Ortiz Francisco Félix	Galio Tecn Energéticas SL [ES]	ES2446690B1
Blind (Venetian blind, slatted shutter) which generates photovoltaic energy	Ferreiro Garcia Ramon [ES]	Univ de A Coruña [ES]	ES2121545B1
Modular system for fixing solar panels to a roof including means for channelling water	Mitjavila Raymond	Producciones Mitjavila SA [ES]	ES2356763B1
Panel provided with a photovoltaic device	Vignal Renaud [FR] Geron Laurent [BE]	Arcelormittal Investigación Y Desarrollo SL [ES]	**EP3164938B1** (WO2016001695A1)
Walkable photovoltaic floor	Beltrán Albarran Alvaro Félix [ES] Del Cano Gonzalez Teodosio [ES] Valencia Caballero Daniel [ES] Jimenez Lopez Jose Maria [ES] Casado Delgado Leonardo [ES]	Onyx Solar Energy SL [ES]	ES2438441B1

Solar module	Hem-Jensen Ken [DK]	Balder Energy SLU [ES] Balder Energy SLU [ES]	EP3703945B1
Panel, panel assembly and associated roof	Chabas Eric [FR] Masure David [FR] Ninforge Dominique [BE]	Arcelormittal Investigacion y Desarrollo SL [ES]	**EP3074578B1** (WO2015079276A1)
Photovoltaic module for curtain walls and a curtain wall that includes such photovoltaic modules	Amundarain Suarez Aitor [ES] Chica Paez Jose Antonio [ES] Campos Dominguez Jose Maria [ES] Román Medina Eduardo [ES] Astudillo Larraz Julen [ES] Meno Iglesias Sandra [ES] Chica Páez José Antonio [ES] Campos Dominguez José María [ES] Román Medina Eduardo [ES]	Fundación Tecnalia Res & Innovation [ES] Fundación Tecnalia Res & Innovation [ES]	EP2660875B1
Photovoltaic lighting system for use in dome-shaped structure of building, has solar tracking tilting elements provided in closed state on dome-shaped structure during heavy wind, and solar radiation unit that illuminates tilting elements	Lloveras Macia Joaquim [ES] Pulgarin Fabre Albert [ES]	Univ Politecnica Catalunya [ES]	ES2274705B1
Slab for roof cover	Mendez Clemente José Alejandro [ES]	Mendez Clemente José Alejandro [ES]	ES2528066B1
Solar power generating coating provided on ceramic support has photovoltaic cells held between two encapsulating layers between support and protective layer	Alonso Reviejo Jesus [ES] Lucas Martin Fernando [ES]	Fritta SL [ES] Isofoton SA [ES]	**ES2153796A1**
Constructive element suitable for installation on roofs or similar	Galdon Mascarell Jordi [ES]	Cristalería Mascarell SL [ES]	ES2536572B1
Granted Utility Models			
Support for solar plates with fixing on a roof	Casanova Ramon-Borja Andres [ES]	Tejas y Ladrillos del Mediterráneo [ES]	ES1069461U ES1069461Y
Solar tile	Silvente Boluda José [ES]	Silvente Boluda José [ES]	ES1068696U ES1068696Y
Support for photovoltaic sheets	Vega Garcia Jeronimo [ES]	Vega Garcia Jerónimo [ES]	ES1069848U ES1069848Y

Cabinet for urban and port services with solar panels for distribution and electrical production, with sustainable design for installation in public and private places.	Moreno Oliver Daniel [ES]	Moreno Oliver Daniel [ES]	ES1248334U ES1248334Y
Bus stop shelter comprising means for recharging electric vehicles, internet services and dynamic advertising	Rojo Huerta Geraldo [ES]	Rojo Huerta Geraldo [ES]	ES1074348U ES1074348Y
Bioclimatic solar pergola	Martinez Monedero Miguel [ES]	Martinez Monedero Miguel [ES]	ES1078319U ES1078319Y
Drive system for single axis solar tracker integrated in canopy	Mestre Boix Lluis [ES]	Mestre Boix Lluis [ES]	ES1256959U ES1256959Y
Vertical sliding panels and facades of aluminium and self-cleaning glass, convertible into a balcony or door, with controlled ventilation and an articulated blocking system, powered by photovoltaic solar panels and the power grid	González Escobar Miguel [ES]	González Escobar Miguel [ES]	ES1233515U ES1233515Y
Support for photovoltaic laminates	Galan Martin Antonio [ES]	Galan Martin Antonio [ES]	ES1075233U ES1075233Y
Solar panel mounting structure	Mitjavila Raymond [FR]	Producciones Mitjavila SA [ES]	ES1071742U
Photovoltaic panel for covers and similar	Gual I Campabadal Josep Maria [ES]	Europ SA [ES]	ES1064533U ES1064533Y
Bioclimatic panel	Llano Eguiguren Julen [ES]	Onn Outside Mobiliario Urbano [ES]	ES1052514U ES1052514Y
Roof for buildings (cubierta para edificaciones)	Garrido Castello Jose Daniel [ES]	Garrido Castello Jose Daniel [ES]	ES1223214U ES1223214Y
Assembly and installation system of solar cells for the production of electrical energy in roofs and flat construction elements	Gonzalez Diaz Maria Jesus [ES]	Gonzalez Diaz Maria Jesus [ES]	ES2679294A1
Solar shutter	Reina Garcia Jose [ES]	Asturbath Reformas SL [ES]	ES1282489U ES1282489Y
Device for fixing supports of photovoltaic laminates to the roofs of buildings	Galán Martin Antonio [ES]	Galán Martin Antonio [ES]	ES1075756U ES1075756Y

Applications (withdrawn)			
Support device for a solar power generator assembly, solar power generator assembly comprising said device and installation method	Gonzalez Gonzalez Tamara [ES] Goncalves Ventura Paulo Jose [ES] Andreu Batalle Jordi [ES]	Solar Global SAT [ES]	US2011271997A1 EP2386807
Integrated electricity generation and smart lighting system	Gómez Pérez Carlos Eduardo [ES] Martín Higueras Felipe [ES]	Green Consultec Solar SL [ES]	WO2014131915A1
Solar collector module for roofs	Vicente Fernandez Matías [ES]	Vicente Fernández Matías [ES]	EP2541620A4
Photovoltaic solar tile	Palomares Millares Pascual [ES]	Ingeniería de Biocombustibles [ES] Palomares Millares Pascual [ES]	WO2007132027A1
Photovoltaic modules and their manufacturing method	Arrizabalaga Canellada Igor [ES] Cano Iranzo Francisco Jesús [ES] Garcia Arrieta Sonia [ES] Zubillaga Alcorta Oihana [ES] Machado García Maider [ES]	Fundación INASMET [ES]	EP2388830A1
Support frame for solar panels	Moreno Calderón Antonio [ES]	Aplisun Develop SL [ES]	EP1947402A1
Photovoltaic energy generator coating	Lucas Martin Fernando [ES] Alonso Reviejo Jesus [ES]	Fritta SL [ES] Isofoton SA [ES] Lucas Martin Fernando [ES] Alonso Reviejo Jesus [ES]	WO0115239A1
Photovoltaic solar roof	Ruiz Caballero Francisco [ES]	Ruiz Caballero Francisco [ES]	WO2009074167A1
Photovoltaic solar generator and method of installing it	Viscasillas Muret Josep [ES] Rubio Solis Oscar [ES] Fiera Sanchez Manel [ES]	Ecotecnia en Renovables SL [ES]	EP2138781A1

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