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Building Integrated Photovoltaics:

A practical handbook for solar buildings' stakeholders

Status Report
2020

Report by

SUPSI – Swiss BIPV Competence Centre
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The Swiss BIPV Competence Centre of SUPSI was created in 2005 within the Institute for Applied Sustainability to the Built Environment (ISAAC).
It aims to combine the competences of the department of Architecture of the University of Applied Sciences and Arts of Southern Switzerland (SUPSI) with those of ISAAC, offering a new multidisciplinary approach to support the transfer of photovoltaics in the built environment.
Applied research, technological development, validation and testing in collaboration with industries and real players at national, European and international level, training and professional advice are the main activities. The website www.solarchitecture.ch, that is replacing the previous www.bipv.ch website, supported by the Swiss Federal Office of Energy and Energie Schweiz, is the new communication platform to promote the construction of solar buildings by shifting the attention from technology to architecture with real showcases and stories.

Becquerel Institute
Philippe Macé, Elina Bosch.

The Becquerel Institute is a privately-owned Belgian company founded in 2014, providing a hybrid service of high-quality consultancy and not-for-profit research focused on the role of solar PV and its ecosystem in the energy revolution.
This spans through neighbouring fields such as the building and transportation sectors, as well as electricity storage, "green" hydrogen production and more. The Becquerel Institute provides research, strategic advisory services and due diligence to private companies as well as to public and institutional organizations. Its internal team of researchers and consultants provides advisory excellence thanks to its extensive experience in the PV and energy sectors, completed by partners and external consultants from around the globe. Together, they empower companies and organisations to embrace the energy revolution.

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Preface

The built environment remains a strategic research and innovation domain in view of a full decarbonization of our economy. As set in the European Green Deal, one of the two pillars of this transition towards decarbonization is the on-site production of electricity via sustainable, renewable energy technologies, covering buildings' energy needs but also providing services to the grid. The exploitation of building skin surfaces represents a huge potential in turning the built environment into a decentralized renewable energy producer, by saving lands and landscape areas, as well as advancing towards a refurbished and improved building stock in the EU. Today, BIPV has achieved a high level of technical maturity and the market perspective looks promising. Supported by increasing technological developments, by digitization and process innovations, such systems are ready to explore the next frontier: to be fully integrated in the construction market and to help make cities healthier and powered by on-site solar renewables. Building integrated photovoltaics (BIPV) also offers a key opportunity for PV market development and the establishment of a competitive value chain in Europe[1].
Existing BIPV products offer to architects, building owners, façade makers and real estate developers a diversified range of products which can be manufactured and customized like any conventional building envelope solution.

However, the BIPV market has not reached relevant development and continues to occupy a niche of both PV and building markets. In addition, the combination of building and solar industry processes requires the involvement of several stakeholders that have to be carefully coordinated, which remains challenging in such a multidisciplinary field. Its hybrid nature, methods and logics, if not streamlined and optimized within a virtuous cycle in the supply chain, could lead to a fragmentation of the sector. This could discourage many building investors, planners or industries from investing in solar buildings or, in any case, generate a "fear of surcharge", which would eventually compromise decision making. Even though the most evident BIPV barriers are clear and many issues have been solved during the last years, one of the main challenge today is to widely demonstrate BIPV in real buildings with a turnkey solution and an efficient process able to ensure performance, reliability, durability and replicability in a cost competitive way.

The BIPV Status Report 2020 aims to provide a practical handbook to all stakeholders of the BIPV development process, providing insights to each of these actors, although they approach the topic of BIPV from different perspectives. This handbook highlights the main steps of BIPV's evolution, the key challenges of the sector, as well as the necessary interdisciplinary of the activities across the whole BIPV project development process. The status of BIPV in Europe, relying on an extensive database of BIPV case studies and on an analysis of past and future market trends, is presented over the critical reflection on the main traits of its evolution along last decades. The case studies analysed, the database of products and the results from our applied research fully oriented to practice and to the real market, offer to architects inputs for new projects and references to quantify BIPV costs and advantages. This can eventually help them to reach new customers. Moreover, the practicality of this booklet and its infographics make it a potential tool for public authorities and educational istitutions to promote BIPV and, in general, the sustainability of buildings. The economic calculation and the cost competitiveness analysis can support investors, building managers and real estate developers in taking the most economically convenient decisions. The crucial question of cost competitiveness is illustrated with data coming from the real market and built examples and is representative of the common EU building typologies and building envelope solutions.

The BIPV Status Report 2020 is structured around three chapters. Nonetheless, they should not be seen as separate entities, but rather as parts of a unique, integrated process:

- Evolution of BIPV in 40 years: architecture, technology & costs;
- BIPV products and market overview;
- Competitiveness and cost-effectiveness of BIPV in Europe.

The BIPV Status Report 2020 ends with real case studies summarizing the key points discussed in the previous sections. Three BIPV buildings realized in Europe in different climate conditions are selected and analysed from an architectonic, energetic and economic perspective to highlight that the real breakthrough is in the opportunity of a real and widespread take up.

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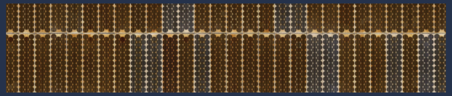
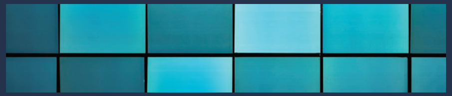


1 Evolution of BIPV in 40 years: architecture, technology & costs



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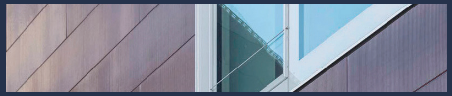
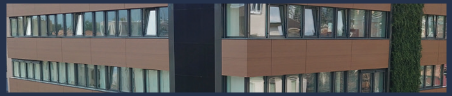
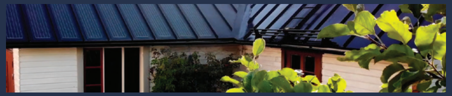


2 BIPV products and market overview



4 Residential and administrative building, Lugano

5 Multifamily house, Zurich



6 Single family house, Knivsta

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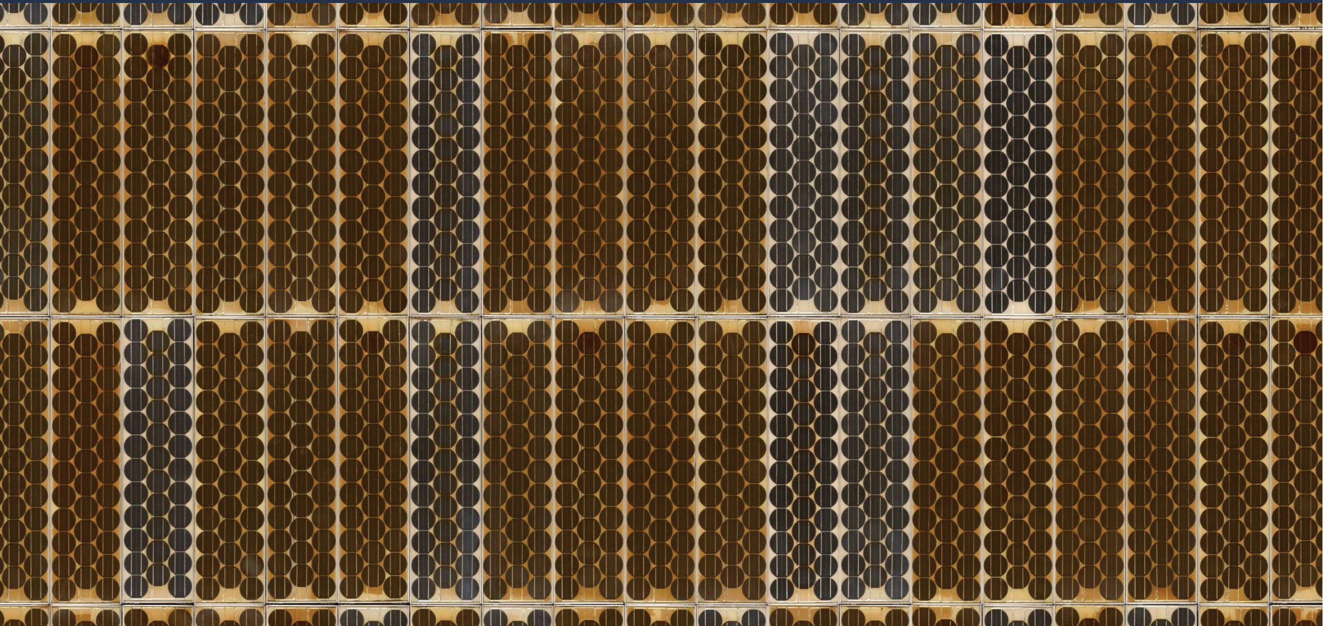
Evolution of BIPV in 40 years: architecture, technology & costs



«The sun never knew how great it was until it hit the side of a building.»
L. I. Kahn

Louis Kahn, one of the most influential architects of the twentieth century, stated the connection between light and architecture. The light is the "giver of all presences"[1] and the maker of material with the power to shape the architecture. The meaning of a space in architecture is demonstrated only if it embraces the natural light coming from a natural environment. A strong link, that turns into a mutual addiction, is created between the interior and the exterior space. The light, that is the energy, does not penetrate only through windows. A photovoltaic (PV) module is another mean able to create a permanent bond between the interior and the exterior environment, by capturing and converting the solar light into a form of energy that can be used to power the everyday life.

The relation between building and environmental resources has always been part of the architectural art: in vernacular architecture, namely "architecture without architects", some of the most evolved solutions of bioclimatic and sustainable design are still recognizable today. For years, since the first pioneering applications in the 80's, the use of PV systems has been merely considered as a solution to generate electricity. A technological mean that, even if applied onto buildings, was mainly conceived as a standardized accessory to produce energy without a specific own language, thus conflicting with the most common architecture design criteria. The architectural sphere was not able to consider solar systems beyond their technical role, while the BIPV industry did not find sufficient market potential within the architectural sector. In the last years, the idea of photovoltaic as mean of energy production has been completed by the idea to consider solar elements as integrated part of buildings and real construction materials. This metamorphosis accomplished in just over 40 years. Since the first application of building integrated photovoltaics (BIPV) was experimented by Thomas Herzog, in 1982, the idea of integration as well as the aesthetic principles, the technology and the social habits have gradually changed. Solar innovation is no longer limited by technical aspects and things that "just work" do not bring satisfaction anymore. Moreover, creativity and design philosophies, quality of daily life, languages of architecture, processes and approaches in construction are changing under the sustainable (r)evolution driven by solar energy. The transfer of PV to buildings, including roofs, façades, and accessory systems, is a tangible "cause" of innovation in contemporary architecture and PV today, as the most promising way to make building skins active. It is much more than a technical possibility: it is a new fundamental in building aesthetics, ethics, and technology.

The purpose of this chapter is to examine and find some key points, trends and breakthroughs defining the evolving path of technological innovation linked to PV transfer to buildings, with an insight into the centrality of the letter "I" of the acronym BIPV, recognized as its basic facet. This challenge intends to encompass the main traits of the innovation process, where the "I" is understood in its duplicity of "Integration" and "Innovation", from building conceptualization to product and process levels. Within the following chapters, an attempt to describe the evolutionary process is reported along with the main milestones that permitted a synthesis between technics and architecture within the BIPV sector.
Starting from some experiences of pioneering and visionary architects and industries, the analysis will be based on the large database of case studies collected by SUPSI in the last 15 years through the platform bipv.ch[2] and the website solarchitecture.ch[3], along with the most recent cases analysed in the projects "BIPV-BOOST"[4] and "BIPV Meets History"[5], totalling 94 representative BIPV installations realised in Europe, during the 40 years of existence of solar building systems.
The BIPV case studies are grouped in four characterizing clusters, identified on the base of the historical milestones reached during the evolutionary development of BIPV installations:

- (BI)PV as experimentation;
- Architecture of standard PV;
- Energy integration: BIPV as a building's skin material;
- BIPV in dialogue with history.

"**(BI)PV as experimentation**" is represented by case studies realised from the early 1980s up to the end of the 2000s. In this category, BIPV solutions are concepts represented by isolated projects, often experiments conducted by visionary and innovative researchers and architects.

Fig. 1 TISO-10-kW plant, installed in Lugano (Switzerland) in 1982, is the first grid-connected PV plant in Europe. Credits: SUPSI.

Then, the period that corresponds to the boom of standard PV systems and the rise and decline of massive subsidies for solar systems is represented by the group "**Architecture of standard PV**". These solutions are usually realized within the first decade of 2000s where solar buildings are covered with standard PV modules and often designed to maximize energy production and economic benefits as typically expressed by European south-oriented solar roofs.

"**Energy integration: BIPV as a building's skin material**" represents the third group, denoted by BIPV samples realized during the last years, up to now, after the peak of financial support schemes. Today, building applications and BIPV products are more and more considered as construction elements, aiming to be aesthetically pleasant, multi-functional and cost-effective.

The last group, "**BIPV in dialogue with history**", presents how solar can also overcome some typical limitations on historical buildings, by reporting examples from the '90s up to now. We included this chapter within the evolutionary process since historical buildings are often considered as a side and independent category with its own regulations and principles, where the technological integration is always debated and discussed. This last section provides the best practices, demonstrating a specific connotation of technology in renovation approaches which incorporates an "aesthetic intentionality" in respect of the existing values.

For each case study, both energetic and architectonic data are collected. Here are the definitions of the main concepts used:

Technological system:
It is meant as the technological unit and/or technical section that assembles a main part of the building skin (e.g. a façade or roof system) by satisfying all the technological requirements and features needed for such a building envelope part.

Building typology:
It is a set of buildings with similarities in function, dimension and distribution.

Nearly-Zero Energy Building (nZEB):
It is a building that has a very high energy performance, i.e. limited primary energy needs. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

Nominal power:
It is the power capacity of a PV system, measured under standard testing conditions [kWp].

Final yield:
It represents the ratio between the energy produced by the PV system during a period and the nominal power, for a certain time period, typically one year [kWh/kWp]. It is function of the solar irradiation reaching the surface of the PV modules and the performances of the PV system.

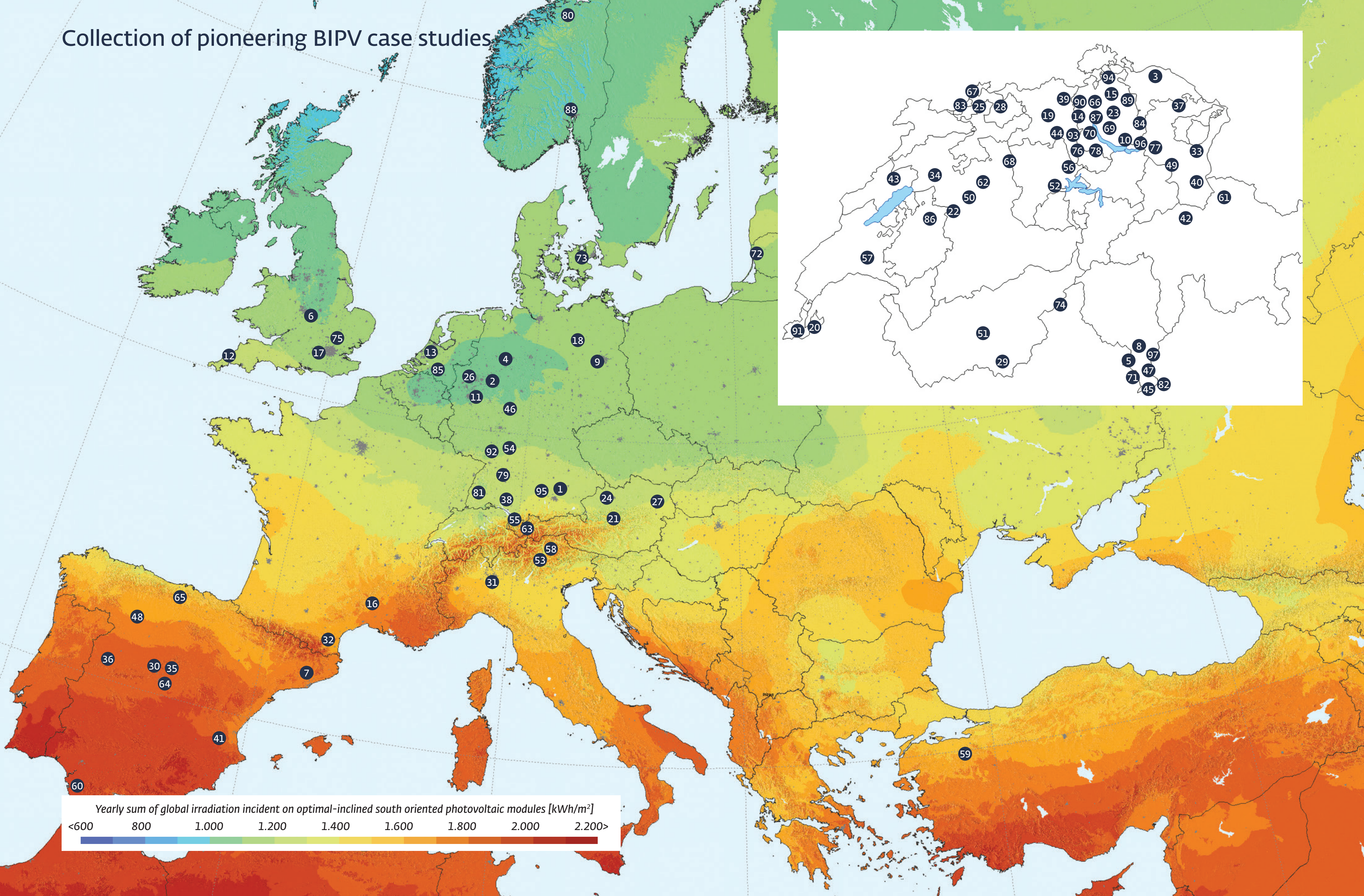
Solar Ratio:
Ratio between the surface occupied by the PV system and the surface of the building component on which the system is installed. For instance, the PV surface installed on the south façade divided by the total surface of the south façade.

System power density:
It is the ratio between the nominal power of a PV system and the surface that it occupies [Wp/m²]. It is usually expressed in %.

Within the next pages a collection of 97 BIPV case studies is shown. These case studies are placed on a map of Europe that shows the yearly sum of global irradiation incident on optimally-inclined south oriented photovoltaic modules in kWh/m^2 based on the research of Šúri M. et Al.[6]. The solutions collected are BIPV buildings with a relevant architectonic value and does not represent an exhaustive database of the BIPV solutions realized in Europe. Within the pages 14-15 the list of 97 BIPV buildings is further analysed by year of completion and technological system.

Fig. 2 BIPV facade of the Grosspeter Tower, Switzerland. Credits: NICE Solar Energy.

Collection of pioneering BIPV case studies



Project		ID	Year	Technological system
Wohnanlage Richter		1	1982	Curtain wall
Schüco International		2	1993	Curtain wall
St. Jakobus Katolische Kirche	●	3	1993	Discontinuous roof
E.F.I.		4	1994	Skylight
FEAT building		5	1997	External integrated device
BP solar showcase		6	1998	Discontinuous roof
Pompeu Fabra library		7	1998	Curtain wall
UBS building		8	1998	Rainscreen
Reichstag building	●	9	1998	Skylight
High school in Stadelhofen		10	1999	Discontinuous roof
Mont Cenis Academy		11	1999	Curtain wall, Skylight
Eden project		12	2000	Discontinuous roof
Fire Station in Houten		13	2000	Curtain wall
Dock-E Zurich International Airport		14	2001	Discontinuous roof
Sunny Woods		15	2001	Discontinuous roof
Tourism office	●	16	2001	Curtain wall
Bedzed		17	2002	Curtain wall
Lerther Railway station		18	2002	Skylight
House in Dintikon		19	2003	Discontinuous roof
STMicroelectronics Headquarters		20	2003	Skylight
Schiestlhaus		21	2005	Rainscreen
Lauper pilot installation		22	2007	Discontinuous roof
Marchè International		23	2007	Discontinuous roof
Active Energy Tower Fronius		24	2007	Curtain wall
Novartis Campus Gehry Building		25	2008	Skylight
Riedel Recycling		26	2008	Rainscreen
ENERGYbase office		27	2008	External integrated device
MFH Feldbergsrtasse	●	28	2009	Discontinuous roof
Monte Rosa Hut		29	2009	Curtain wall
The Black Box		30	2009	Rainscreen
3M Italia Headquarters		31	2010	Discontinuous roof
El Centre del Mon		32	2010	External integrated device
Heizplan Solar Park		33	2010	Discontinuous roof, Rainscreen
Positive energy house		34	2010	Discontinuous roof
San Anton market	●	35	2010	Skylight
Historic Mercado Bejar	●	36	2011	Skylight
Hofberg 6/7		37	2011	Discontinuous roof, Rainscreen
Stadtwerke Konstanz		38	2011	Curtain wall
Umwelt Arena		39	2011	Rainscreen
Werkhof Mels		40	2011	External integrated device
Alzira Town Hall	●	41	2011	Skylight
Casa Solara		42	2012	Rainscreen
Hotel des Associations	●	43	2012	Discontinuous roof
MFH Kettner	●	44	2012	Discontinuous roof
Plus Energy MFH		45	2012	Ext. int. device, Rainscreen
+E Kita Marburg		46	2013	Curtain wall
Castello di Doragno	●	47	2013	Discontinuous roof
Edificio Lucia		48	2013	Skylight
Flumroc Headquarter		49	2013	Rainscreen
Hutterli Rothlisberger		50	2013	Discontinuous roof
New Tracuit Hut		51	2013	Rainscreen
Schlossgut Meggenhorn	●	52	2013	Discontinuous roof
Quartiere le Albere		53	2013	External integrated device
WetterOnline BIPV design façade		54	2013	Rainscreen
Omicron Headquarters CI-façade		55	2014	Rainscreen
MFH Stalder-Luzern	●	56	2014	Discontinuous roof
Swisstech Convention Centre		57	2014	External integrated device
Cantina di Colterenzio		58	2014	Skylight
Bursagaz/Sunvital		59	2015	Curtain wall
Conil Town Hall	●	60	2015	Skylight
DWHG Doppelkindergarten	●	61	2015	Discontinuous roof
Glaserhaus	●	62	2015	Discontinuous roof
House on the mountain		63	2015	Discontinuous roof
ING Building		64	2015	Skylight
Marques de Valdecilla		65	2015	Curtain wall
Mehrfamillenhaus		66	2015	Discontinuous roof, Rainscreen
Solar Silo	●	67	2015	Discontinuous roof, Rainscreen
MFH Chruezmatte	●	68	2016	Discontinuous roof, Rainscreen
MFH in Brütten		69	2016	Discontinuous roof, Rainscreen
MFH Hofwiesenstrasse		70	2016	Rainscreen
Villa Carlotta	●	71	2016	Discontinuous roof
Glassbel Office		72	2016	Curtain wall
Copenhagen International School		73	2017	Rainscreen
Football Stadium Lipo Park		74	2017	Discontinuous roof
London Castle Lane		75	2017	Rainscreen
MFH in Zwirnerstrasse		76	2017	Rainscreen
St. Otmarsberg Solar Abbey		77	2017	Discontinuous roof, Rainscreen
Wohnhaus Solaris		78	2017	Discontinuous roof
ZSW Stuttgart		79	2017	Rainscreen
KIWI Dalgård supermarket		80	2017	Rainscreen
Freiburg Town Hall		81	2017	External integrated device
MFH in Vacallo		82	2017	Discontinuous roof, Rainscreen
Grosspeter Tower		83	2017	Discontinuous roof
St. Franziskus Church	●	84	2018	Rainscreen
Workshop Waalwijk		85	2018	Discontinuous roof
Rural House Galley	●	86	2018	Discontinuous roof
University of Zurich		87	2018	Rainscreen
Spar Supermarkt		88	2018	Rainscreen
MFH Zurich-Oerlikon		89	2018	Rainscreen
Coop Letzipark		90	2018	Rainscreen
Vacheron manufactory		91	2018	Discontinuous roof
Lindy Insulated BIPV façade & roof		92	2018	Curtain wall, skylight
MFH Seewadelstrasse		93	2019	Rainscreen
Wattbuck Tower		94	2019	Rainscreen
Audi Brand Experience Center		95	2019	Curtain wall
Männedorf		96	2020	Rainscreen
CP Pregassona		97	2021	Rainscreen

● Historic buildings

(BI)PV as experimentation

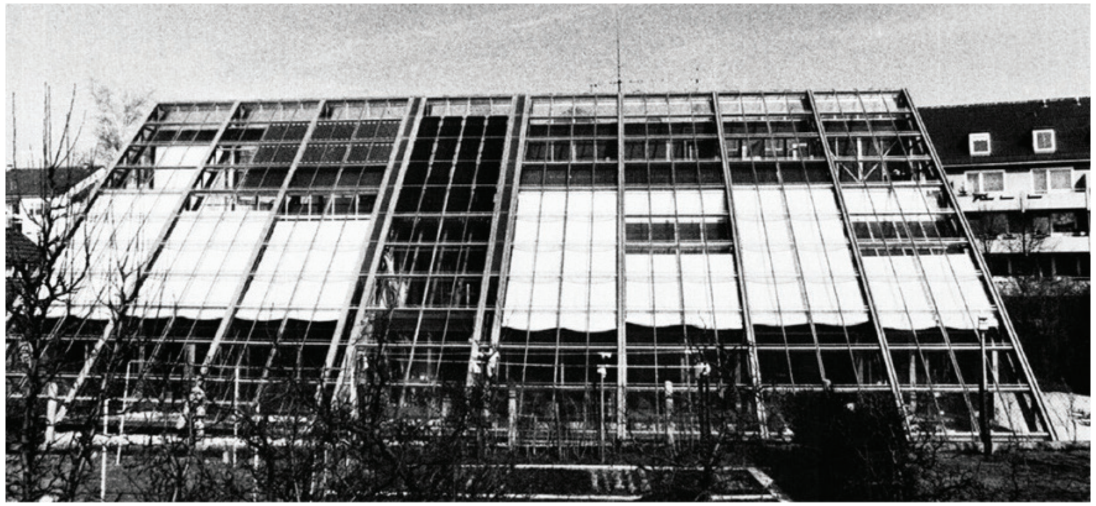
Keywords
prototype buildings, experimentation,
pioneering design, design as research.

The first PV solutions for buildings began appearing in the 1970s but it is only from the 1980s that photovoltaic solutions' add-ons to roofs began being demonstrated. These PV systems were on grid-connected buildings in areas with centralized power stations[7].

In 1973, SOLAR ONE, the first house equipped to directly convert sunlight into both heat and electricity for domestic use, was realized. Built at the University of Delaware with support from the Delmarva Power and Light Co., SOLAR ONE was designed as an experimental structure to accumulate data from its solar harvesting system. The house showed the practical potential of thin-film and passive solar technologies, producing both electricity and heat, by representing "the most technologically advanced solar house in existence."[8]

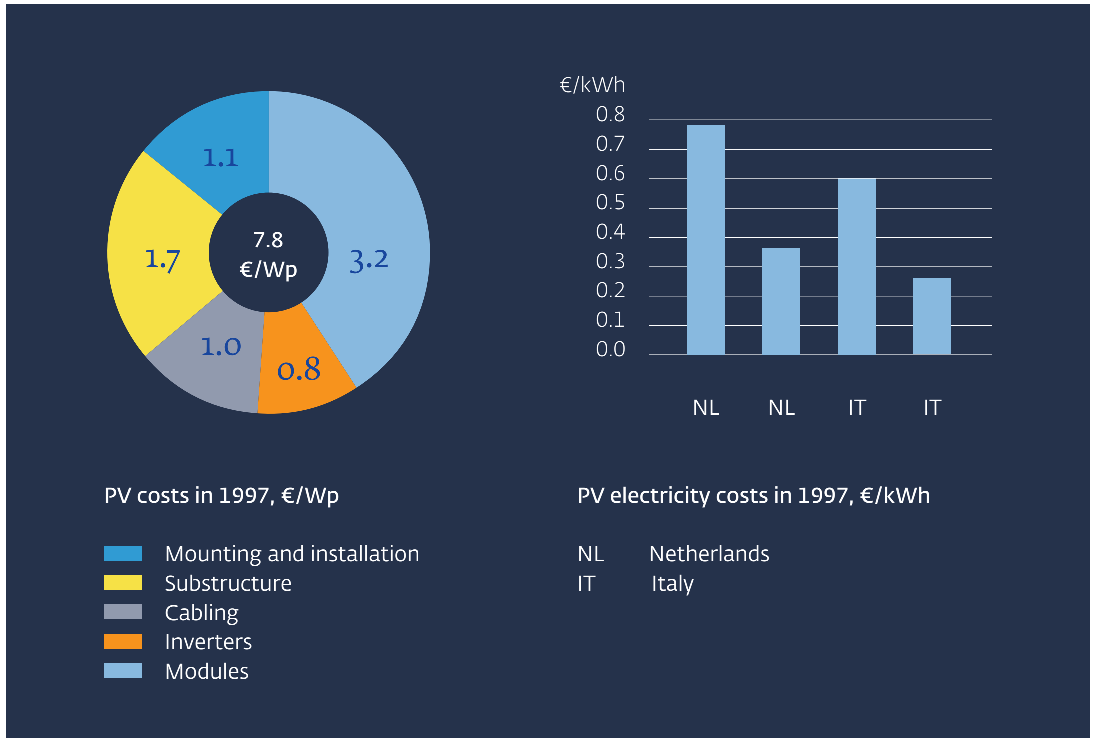
In the case of the Wohnanlage Richter, a solar-centric area of urban development was designed in 1982 by Thomas Herzog and Bernard Schilling in a village close to Munich (*Fig.3, Fig.4*). The contractor entrusted the architects with the project of a prototypical building that should be glazed, light, transparent and should provide the possibility of installing solar technology. The building itself is a wooden skeleton within which are lined up individual housing units. The outer, southern glass slope consists of a slightly modified greenhouse construction with aluminium profiles and toughened safety glass. The inner glass slope is made of double-pane insulating glass. In the context of a European research project, the Institute for Solar Energy Systems of the Fraunhofer Institute, located in Freiburg, installed on the upper part of the outer glass slope approximately 60 m² of solar cells developed by different German manufacturers. These solar surfaces are part of the first integrated solar installation with crystalline solar cells on a glazed building skin. Electricity was used in the house itself, stored in batteries or fed back to the local grid[9].

Fig. 3, Fig. 4 Wohnanlage Richter, Germany. Credits: Bund Deutscher Architekten and e-periodica.ch.



It is only from the 1990s that the first PV systems to be integrated in the building envelope became commercially available. From the early years of this decade, the US Department of Energy demonstrated its commitment to bring together PV and building products' manufacturers in a coordinated effort to develop new BIPV materials, including PV roofing shingles, façade glazing and curtain wall. Since the early 1990s, the Photovoltaics: Building Opportunities in the United States (PV: BONUS) program was developed.
Even though the potential of BIPV systems was recognized around the world, a cost reduction was still necessary in order to enable a large scale adoption. Indeed, while a standard PV module cost in 2019 0,29 $/Wp, 1990 it was still priced at 5 $/Wp, and in 2000 at 3,5 $/Wp[10][11]. To achieve this cost reduction, Schoen et Al. suggested, as early as 1994, to develop new building products, optimize integration concepts and develop standardized products[12]. Challenges that still today represent some of the key research and innovation topics in the BIPV sector to advance towards an improved market competitiveness.
On *Fig.5*, left, the cost breakdown of a BIPV system installed in the late 1990s is shown. Even though cost estimates vary from country to country, this is an informative example. The incidence of the BIPV modules on the total BIPV system cost is about 40%. On the right, the resulting PV electricity cost for different countries and assumptions (optimistic and pessimistic) is presented. Within the following chapters, an accurate definition of PV electricity cost, defined as "levelized cost of electricity", will be given.
Researchers also determined that the cost competitiveness of such system would be reached when the PV electricity costs would reach 0,05 to 0,1 $/kWh, depending on the country. This analysis shows that before 1997, both in Italy and in The Netherlands, a reduction of the LCOE by a factor 3 to 10, depending on the case, was required to reach cost competitiveness.

Fig. 5 Cost breakdown of a BIPV system (left) and PV electricity costs (right). Source: Building with Photovoltaics — The Challenge For Task VII Of The IEA PV Power Systems Program. Schoen, T., et al. Vienna: Proceedings of the EC Photovoltaic Energy Conference, 1997.



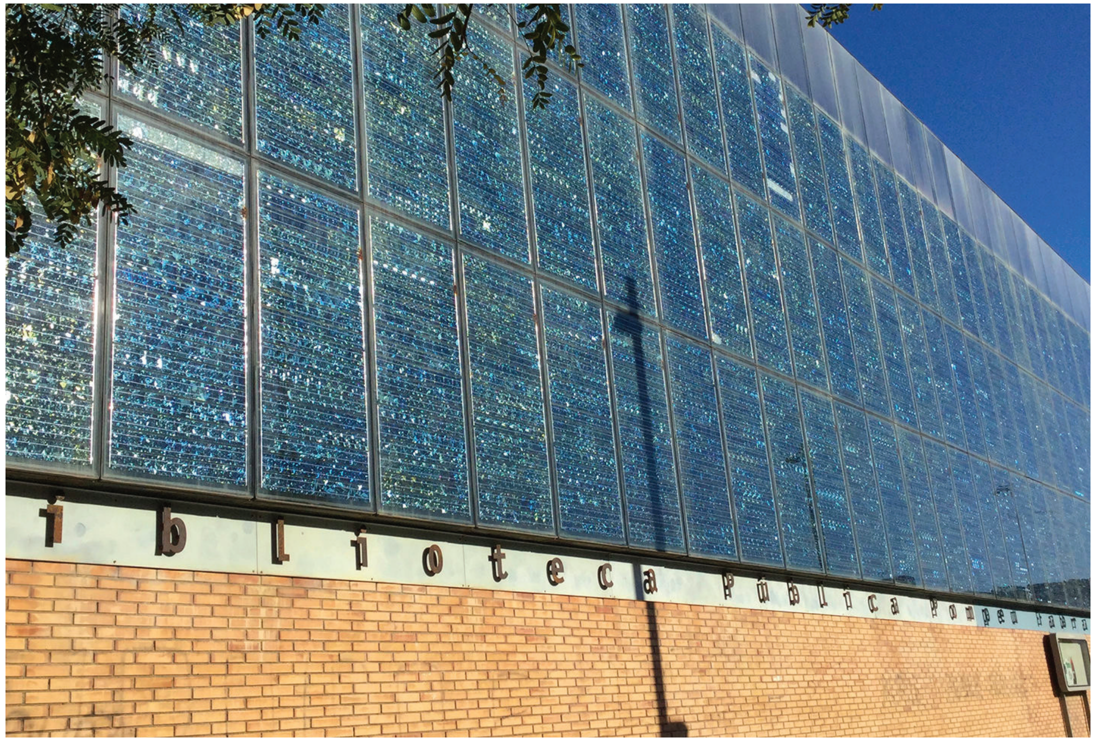


Fig. 6 Public library Pompeu Fabra, Matarò, Spain. Source: Roberts, Simon and Guariento, Nicolò. Building Integrated Photovoltaics: A Handbook. Basel: Birkhäuser, 2009.

In the mid '90s, the city of Matarò in Spain decided to join the Aalborg Charter[13]. The building of the public library Pompeu Fabra was included within this program (*Fig.6*). This project aimed to show the potential of the European photovoltaic industry and to find the optimal equilibrium between aesthetic, comfort, energy balance and economic aspects. The integration of PV to the building of the library consisted in the installation of a semi-transparent double skin façade as well as of a monocrystalline silicon-based and thin film-based roof skylight. The library represents one of the first cases of completely integrated PV systems into buildings. As the Nottingham University Jubilee Campus, the German Reichstag and other PV buildings of the '90s, the project was subsidized by public programs, often promoted by the European Commission or governments' budgets. For instance, the Pompeu Fabra library was part of the Joule II program[14].

One of the challenging aspects of the BIPV buildings designed and developed during the '90s was the requirement to achieve innovative and outstanding designs while using experimental procedures and materials. Nonetheless, they eventually allowed to demonstrate that BIPV systems are not only meant to produce energy, but that they are multifunctional construction materials and also part of the building skin's technological units.

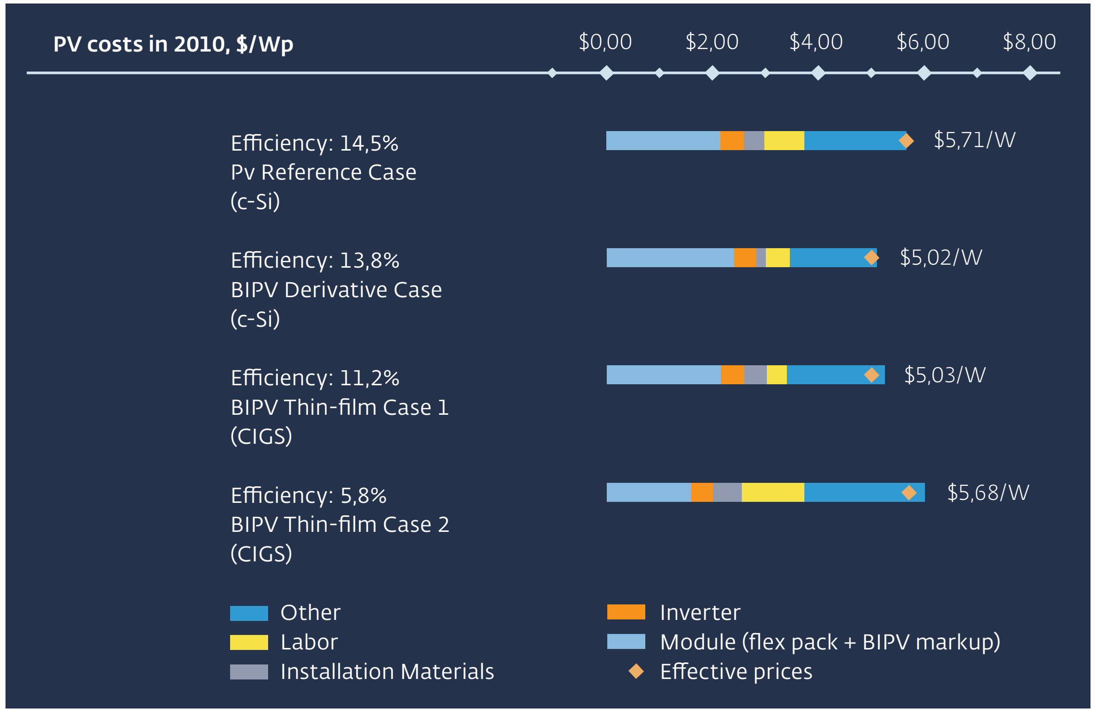
Architecture of standard PV

Keywords:
market potential, niche sector, cost reduction, subsidies, PV design, normative.

Elements of Architecture, from Koolhaas's exhibition at the 2014 Venice Architecture Biennale, focused on the fragments of the rich and complex architectural collage. Window, façade, balcony, corridor, fireplace, stair, escalator, elevator: the micro-narratives of the building's details is no single history, but rather the web of origins, contaminations, similarities, and differences in architectural evolution, including the influence of technological advances, climatic adaptation, political calculation, economic contexts, regulatory requirements, and new digital opportunities[15]. Looking through the microscope at the fundamentals of our buildings, revealing the design techniques used, history of construction arranged around functional building elements such as standardized elements. Of all building materials in the world, brick is one of the most enduring, showing resilience and remaining one of the backbones of the sector since its first use as building material till contemporary architecture, sometimes considered limiting, but actually full of spectacular potentials.

In the early 2000s, the solar industry demonstrated that solar PV technology could be efficiently deployed, at various scales, with several installations around the world. The interest towards zero energy buildings increased, proved by the constitution of the Passive House Institute in 1996[16] and the Minergie Association in 1994[17]. Solar architects were awarded winning solar prizes with buildings like the MFH Sunny Woods (winner of the Swiss Solar Prize 2002 and the European Solar Prize 2002) and BedZED where the potential of BIPV was widely expressed and recognized (winner of the Housing Design Award for sustainability in 2001). However, despite the efforts to enlarge the market spread of BIPV systems, by the end of 2009, solar systems that are partially or fully integrated to the building skin accounted for about 1% of the installed capacity of distributed PV systems worldwide[18].

Fig. 7 Comparison of residential rooftop prices for a rack-mounted the PV Reference Case and three BIPV cases. Source: James, Ted, et al. Building-Integrated Photovoltaics (BIPV) in the Residential Sector: An Analysis of Installed Rooftop System Prices. s.l.: National Renewable Energy Laboratory (NREL), 2011.



As during the previous decade, the upfront investment costs of BIPV systems were one of the major impediments to wider market penetration and were still too high to be competitive with standard construction materials. In 2003, the average cost of a conventional PV system was appointed at 8,75 $/Wp [10]. The *Fig.7* shows a comparison of US residential rooftop prices for a rack-mounted PV reference case and three BIPV cases in 2010 This comparison demonstrates that BIPV systems could be comparable with BAPV solutions from an economic perspective. The listed "effective prices" account for cost offsets due to an assumption that the BIPV cases replace traditional building materials. In this example, they replace asphalt shingles. BIPV had the potential to achieve system prices that are about 10% lower than rack-mounted PV system prices, as shown. The labour costs and in general the costs related to the installation phase are the main drivers of the cost reduction of the BIPV systems. This analysis showed, in 2011 already, that the BIPV systems had the potential to reduce the installed system prices of comparable rack-mounted PV in residential rooftop markets. The calculation is explained in detail by James et Al.[18].

On the basis of the results of the article "Method for the cost evaluation of BIPV façades and multilevel cost analysis of six Swiss case studies"[19], in Switzerland, two high quality BIPV façades realized in 2012 and in 2014, had a cost between 710 €/m^2 and 1.060 €/m^2, including PV modules, suspension system, substructure and electrical installations.

In order to speed up the diffusion of such systems, around the end of the 2000s, subsidies for solar systems were introduced by various local governments. In Germany, the Renewable Energy Sources Act came into effect in 2000 and similar regulatory frameworks have been adopted by many countries around the world. In Germany, it was amended several times and triggered an unprecedented boom in solar electricity production. Still today, although its importance has decreased, the success of PV installations is largely due to the creation of favourable political framework conditions[20]. In Italy, for example, the legal framework for the system known as "Conto Energia" was introduced starting from 2005. From 2007, with the introduction of the "2° Conto Energia", fully integrated PV systems received a subsidy of 0,44 to 0,49 €/kWh of energy produced[21]. Non-integrated PV systems received a subsidy of 0,36 to 0,4 €/kWh according to the nominal power installed. This was the only country in Europe, with France and Switzerland, to differentiate BIPV systems from other distributed systems.

Although the upfront investment costs of BIPV systems can highly impact the decision-making process, they are not the only criteria to be taken into account. It was recognized and discussed in multiple occasions that other benefits could be identified on the basis of direct and indirect economic impacts and qualitative value including environmental, energy and socio-economic aspects. Researchers of the International Energy Agency's Photovoltaic Power Systems Programme confirms that the major feature of BIPV is its multi-functionality, which results in a range of potential value perceptions and assessments[22]. One can also mention the aesthetical value. In this frame, partnerships among PV manufacturers, architects, and building-materials' suppliers have been developed with the objective to address barriers and bring new cost-competitive products and solutions on the market[4][23][24][25]. As a result, products we see on the market have more and more standardized designs that are intended to be easy to integrate with many common building materials. On the contrary, the first decade of 2000s is characterized by the use of standard PV modules as construction elements to reduce the costs of investment, a kind of technocratic "solar brick" aiming at maximizing the energy production and the revenues.

As the result of the application of standard PV modules on buildings, the question that architects, installers and experts of this sector asked themselves is: is it possible to use "conventional/standard" PV modules as BIPV skin?

A first aspect concerns the figurative character which, in general, can be read in PV systems' capability to express the linguistic morphology and rules governing the structure and composition of the architectural language. Basic aspects of language can be analysed both at the scale of the building's organism and of the constructive component. The tendencies in architectural linguistics, both in new buildings and refurbishments, looking at the semantic role of PV and to its expressiveness, can reach different grades, ranging from the mimicry, where its presence is not perceivable, up to the "showy" integration: PV so can be linguistically "subordinated", "integrated" or "dominant" to the perception of the envelope. Also, the "language inflection" at the elementary level of components such as module, cell or the photoactive material (colour, texture, semi-transparency, etc.), equivalent to the "word", affects the final result.

This question opens not only an architectural debate around the use of a standardized element as a fundamental of the language articulation and semantics, but also a practical topic regarding the product quality and reliability, certification and market introduction according to the EU normative framework for construction and PV products. According to the International Electrotechnical Commission Glossary a "conventional/standard" PV module can be defined as a PV module that has not been developed for any specific building skin system or application (IEC 60269-6, ed. 1.0-2010; IEC 60269-6, ed. 1.0 (2010-09); IEC 61727, ed. 2.0 (2004-12)). P. Bonomo et al. considered this question as a "misleading" question since the real topic is not necessary to force the adoption of a pre-defined element to serve as a functioning part of building skin but rather to engineer, develop, manufacture and qualify it according to the technical role within the building envelope, to the technological requirements and the legislative framework in force (building, European, national, etc.). The development of BIPV products playing a multifunctional role, involves the use of several materials that must coexist in the same united construction component. These elements, electrically active and non-active, once assembled, mutually induce and influence changes both in the energy performance and in the construction requirements, such as the energy yield, dissipation of heat, the mechanical and fire behaviour, etc. On this ground, many activities will be aimed at progressing on the research and development of new qualification procedures, as a support to other actions devoted to progress on standardization[26][27].

The MFH Alleestrasse in Switzerland (***Fig. 8***) is a building fully covered by standard PV modules. It was built in 2012 by the architects Viriden+Partner AG. The retrofitted building was covered with 295m² of standard c-Si PV modules integrated on the façade. The photovoltaic element is evident and emphasized. Additional 110m² of building applied PV (BAPV) was installed on the roof to reach a positive energy balance. It means that the building produces more energy than it consumes. The building received the Europäischer Solarpreis 2013 and the Norman Foster Solar Award PlusEnergieBauten Solarpreis 2013.

Mass customization is a revolutionary factor different from old industrial models that were mainly based on the standardization and serial production such as the "heavyweight prefabrication" of '70s. The opportunity to customize the basic architectural elements allows reaching a significant design flexibility that enables a high adaptability of PV to different contexts. The building process is today completely digitized, evolving from the Computer Aided Design (CAD) to Building Information Modelling (BIM) and Computer Aided Manufacturing (CAM), "file to factory" (F2F), etc., so that a tailored "design" and production is possible and affordable. For the first time, free-form 3D façades or envelopes can be created as an economical system solution with maximum design freedom, a high degree of planning reliability and cost certainty, as well as efficient fabrication and installation. On the other hand, the use of a "pure language" of PV characterizes other ways of design based on the use of conventional components (e.g. standard panels) that is an "architecture of standard". A lot of very nice examples shows this "epidermic" approach in design of PV: even though the building concept in terms of volumetric shape is not directly interested by PV integration, important reflections define the quality of the BIPV design such as the geometrical/dimensional coordination of modules within the surfaces, chromatic and material features of PV at cell/module scale, etc.

Fig. 8 MFH Alleestrasse, Romanshorn, Switzerland. Credits: Viridén + Partners.

Energy integration: BIPV as building's skin material

Keywords:
customized products, architectonic integration,
extra cost analysis, BIPV definition,
construction material.

Thanks to industrial developments, during the first decade of the 2000s, a wide range of solar products for the building sector became available at attractive prices. However, the market of BIPV solutions, especially those integrated to buildings with a high aesthetic impact, did not reach the forecasted development and continues to occupy a niche of the PV market. Standard PV products are not often considered by architects and other stakeholders as valid substitutes of traditional cladding solutions since they are only occasionally customizable in colour, shape and size and can barely be integrated in projects with a high architectonic language.

The BIPV products developed today inverted the trend and made a breakthrough approach available: PV can become a conventional construction element. A solar cladding looks like a traditional non photovoltaic cladding and a solar tile looks like a traditional tile. The industry already makes plenty of products for building applications available, combining many aspects: good aesthetics, multi-functionality, cost-effectiveness, mass customization and other paradigms are ensuring a growing penetration of the technology. Beyond functional and construction aspects, BIPV is, without any doubt, one of the new fundamentals of contemporary architecture. As Sergio Los described in the '60s, "The houses covered with solar collectors, with morphologies adapted to the geometry of the radiation emitted by the sun, are a way of designing a monumental plant ...The House becomes a solar collector... a new international "bioclimatic" style emerges offering anywhere objects built according to a specific geographical area" [Cit. Sergio Los].

The innovation process linked to the transfer of PV to the buildings' skin, as typical in the history of building technologies, is about finding balance between new and tradition. Generally, the replacement of a conventional system by a new one, points out the permanence of characteristics linked to the existing practice. This is the example of many PV systems, from the simplest ones (e.g. roof tiles, metal sheets, membranes) to the most complex ones (e.g. curtain wall, façade cladding), where the fil rouge is the effort of re-adaptation of PV to a pre-existing building technological unit or component. As a result, the technological concept of the building component does not strongly evolve because of the introduction of PV, but adapts or is optimized, from a functional point of view, to the production of energy (with the integration of cells, cabling, etc.). Furthermore, some PV systems on the market show a forced permanence of the past archetypes that, in some cases, become a mimicry of repertoire techniques that is scenography. This kind of parody in some cases has become an approach to search the respect and the acceptability of using this technology, through its cosmetic. In this perspective, e.g. some solar tiles, trying to simulate brick roof tiles, lose all contacts with the original non PV components. It is interesting to observe that the tendency to dissimulation or mimicry is one of the main focus of product innovation in recent research activities, through for instance glass treatments (printing, sand blasting, etc.), coloured filters and layers interposed between the module's layering, or till to examples of "invisible PV". In this heterogeneous approach, between memory and invention, the "innovation in architecture" cannot be reduced to the implementation of a new product or component but rather has to be related in approaches and paradigms that today describe an upsurge of tradition in the architectural designs and concepts.

Because of these research trends, a PV module integrated in a building could be easily mixed up with a standard construction material. Special treatments, colours or patterns applied to glass allow to mask solar cells and to mimic solar products with similar products commonly used in construction, without significant loss of electrical performance (Copenhagen International School ***Fig. 9***, Wohnhaus Solaris, etc). The innovation in these examples does not only lie with the component itself, but also with the fact that the architectural language of the building becomes a clear manifesto of technological innovation. The morphogenesis of building organism, the border between energy and spatial conception, the linguistic morphology, the rules governing the structure of the language and the building image towards the city show a change: solar becomes architecture.

Fig. 9 Copenhagen International School, Copenhagen, Denmark. Credits: C.F. Moller Architects.

The MFH in Brütten was built in 2016 by the architect René Schmid. The façades are fully covered with customized, opaque and affordable PV modules. The PV modules can hardly be distinguished, but the roof is covered with high efficiency PV modules. A part of the electricity produced is stored in batteries and the remaining part is used to power a heat pump. The MFH in Brütten is the first example of autarkical building, with a cost of the BIPV façade that was about 550 €/m^2[28].

Even though BIPV systems have been on the market for many years, architects, installers and experts of the building sector often do not have the competence to evaluate the costs necessary to realize a BIPV system. This uncertainty can, and often does, lead to a further increase of construction costs, due to the misperceived risk and a wrong timing evaluation. The paper "Method for the cost evaluation of BIPV façades and multilevel cost analysis of six Swiss case studies" offers a cost comparison of BIPV façades in Switzerland[19]. Six case studies realized between 2012 and 2019 are analysed. The average price per square meter of the BIPV cladding is about 375 €/m^2 (only BIPV modules are considered including assembly and logistic). A further analysis at the European level, was conducted in BIPVBOOST project[29]. Here emerged that the total material end user costs for a single-family house rooftop application is about 260 €/m^2 (excluding VAT), while a façade application about 680 €/m^2 (other interesting analysis are shown within this study). Within different projects emerged that the average price of BIPV modules can be significantly higher than the average market price of standard PV modules that, according with 2012-2019: EU spot market price by technology, "www.pvXchange.com", during the year 2016-2019 saw the average price decrease from 0,51 €/Wp to 0,25 €/Wp (converted from US dollars at the first available exchange rate of January 2016 and 2019 respectively). Since BIPV solutions are treated as standard construction elements, the method of extra cost made inroads into a realistic and appropriate cost evaluation of solar systems integrated in buildings. The extra cost of a BIPV solution is defined as the difference between the BIPV solution and a competing conventional building envelope solution. It is quantified by summing the cost of making the cladding "active" and the associated accessories such as cabling, inverters and/or optimizers. More details about the extra cost will be explained within the next chapters.

The 2010s have seen a wide development of BIPV systems both from a technological and aesthetical perspective. Many trends define today's routes to innovation, as both products and processes are interconnected. Glass treatments that hide the solar cells – coloured films or structured glazing, for example – are one path. But integration today means something more than pure cosmetics. In the future, the industry of BIPV must move to a mass-market, cost-effective approach, with a clear focus on ordinary built stock. This involves innovation at different levels – not just with product aesthetics, but also in terms of flexibility and automation in manufacturing, creating multifunctional products for the building skin, process management based on digitization, advanced performance assessments, and procedures that support the market to ensure quality, safety and reliability[30](*Fig. 10*).

"Good architecture always begins with an efficient construction. No buildings, no architecture. The construction incorporates the material and its use according to its properties[...]. I think we can create a contemporary architecture with all materials - only if that is used properly in accordance with its properties [...]. The architecture cannot exist without the landscape, the climate, the soil, the habits and customs. This is the reason why we sometimes see old buildings that seem contemporary and, for the same reason, we construct contemporary buildings that could be built in the past [...]. But I cannot ignore a sentimental factor that we have to reveal to our building, otherwise we would be lazy and inhuman [...], then we'll choose our material not only according to the standard and economy or pure science, but with the spirit of an emotional freedom and an artistic imagination. Consequently, the architecture arises beyond the pure purposes, above the achievements and results of logic and cold calculation."[31]

Fig. 10 Freiburg Town Hall, Freiburg, Germany. Credits: ingenhoven architects.

Sponsored content

Centro Polifunzionale Pregassona

The largest BIPV facade in Ticino (CH) is on its way

Completion year	2020-2021
Planning & Installation	Alsolis SA
Building typology	Medical (SIA380/1)
Category	New building
Installed PV power	173 kWp
Energy production	76.500 kWh/yr

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In the year 2017 the City of Lugano, Switzerland, began the construction of a new Multi-Functional Centre (MFC) in Pregassona that will host a medical residence for elderly people and other services. The original project provided for rainscreen facades covered by a light colour fibrecement cladding.

In the year 2019, the City Council decided to replace the planned cladding of the facades, from fibrecement slabs to integrated photovoltaic modules, preserving the same colour earlier planned.

The new solar façade has a surface of about 1.678 m^2 and a nominal power of 173 kWp with a calculated energy production of about 76.500 kWh/yr. The glass/glass photovoltaic modules are covered with a coating that makes invisible the underlying photovoltaic cells. The aesthetic value of the modules, the customization rate, the resistance and the possibility to produce clean energy, convinced the client to choose for a photovoltaic solution.

The MFC-Pregassona is the public building in Ticino, Switzerland, with the largest facade-integrated photovoltaic installation. In addition, the MFC-Pregassona will become an experimental building that permits the City of Lugano to collect data regarding the technical and economic competitiveness of BIPV building facades.

The BIPV façades and the electrical connections have been realized by Alsolis SA, local company that is operational within the PV and BIPV sector since the year 2007. Alsolis SA dealt with a feasibility study simulating the energy performance, the efficiency and a preliminary cost analysis involving specialists of the building process, including Ecolite AG for the load-bearing structures, Sunage SA for the photovoltaic modules and SUPSI for the energetic simulations and the tests of the modules.

Once selected the best technical-architectonic solutions together with the client, Alsolis SA begun the executive planning, the installation and the tests on the solar system. The BIPV facades and the modules are constantly monitored to measure the power and the energy output, the temperature of the air and the temperature of the photovoltaic modules.

The planning team faced with different challenges, including the achievement of a minimum nominal power of 120 W/m^2 with light colour photovoltaic modules, the configuration of the technical details between the substructure of the façade and the intrados of the windows, the improvement of the electric system with optimizators, the coordination of the construction site and the assembly of the modules considering the size of the photovoltaic modules, up to 3m^2 per module.

BIPV in dialogue with history

Keywords:
market potential demonstrated, niche sector,
cost reduction, subsidies, emphasize PV design,
normative awareness.

The group "**BIPV in dialogue with history**" is a collection of the historical buildings on which a BIPV system was installed, from the '90s up to now. This permits to analyse a category of buildings that many architects are afraid to approach considering the high restrictions associated with these contexts.

Improving energy efficiency in historic heritage, certainly preserving the value and the historical characters, is a topic of great importance within the challenge of renovation and functional upgrading. The necessity to moderate the use of energy is unquestionable and renovation measures in construction to advance towards climate-neutral energy generation are supported by all countries[32][33][34]. These measures also affect our monuments and historical buildings, as investigated in numerous ongoing research projects (e.g. ATLAS[35], BIPVmeetsHistory[5], ERDF European Transnational Cooperation Programmes) and the activities of the International Energy Agency, IEA EBC Annex 76 / IEA-SHC Task 59[36]. The main aim is to find conservation-compatible energy retrofit approaches and technologies (including RES and solar energies) for historic – not necessarily protected – buildings with an existing low level of energy efficiency and energy comfort. Buildings worth to be preserved that are more than 50 years old and require urgent energy retrofit measures, constitute a considerable part of the total building stock. In Europe, historic buildings built before 1945 represent 30-40% of the total building stock[37] and about 64% of buildings in Switzerland were built before 1980 with a very low energy renewal rate[38]. At the same time, less than 10% of the European building stock has a special value as a material testimony to our past and as a cultural asset: they are listed or protected in inventories. That being said, in most cases, energy improvements are possible in historical buildings. However, in order for this to succeed without losing substance and historical significance, a dedicated engagement with the task is required.

In many cases of "historical" perimeters where the monumental value is objectively limited, there is the possibility and the need to intervene in improving the energy performances of the buildings, often outdated, potentially unhealthy and unsafe, as well as ecologically very impacting. In the current technological framework for BIPV, increasingly oriented towards the "mass customization" of the building industry, the study of ways to integrate technology in sensitive areas may take advantage of an innovative "craft dimension" of technology which, more and more adaptable to the design paradigm of the "micro-intervention" and "controlled transformation", makes available new scenarios of "compatibility", compliant with the degree of "transformability" of these places[39].

New approaches to solar design show that it is possible to achieve optimal use of solar energy - thermal and photovoltaic - while preserving the heritage and architectural quality of the site, based on a careful and in-depth review of the area of study and its solar potential (i.e. constraints, cultural heritage buildings, solar technologies, strategies, economic tools or funding schemes to support spatial planning). In ***Fig. 11***, the mediaeval castle Doragno, retrofitted in 2013 by the architects deltaZERO, with the integration of a rooftop BIPV system is shown.

Once recognized a "controlled improvement" as the intervention approach, instead of an undifferentiated performance retrofit, the design process consists of a gradual deepening of knowledge, that starts from the critical reading of typological structures and of constructive, material, spatial, environmental and functional correlation in the considered heritage. After defining the degree of "transformability" (namely, the vocation to be transformed) a comparative assessment between values and needs allow defining the sustainable forms of compatible interventions.

Fig. 11 Doragno Castle, Rovio, Switzerland. Credits: Luciano Carugo.

Realized examples as best practices cases studies (e.g. Swiss or European Solar Prizes) demonstrated the coexistence and the feasibility in the use of these solar technologies to reach the energy efficiency goals of existing buildings and in particular of historical buildings. Twenty-four buildings across Europe renovated in the last decade have been analysed in order to point out the main aspects of solar products so far used in historic buildings. Examples studied show a wide range of applications, from cold roof (67%), skylight (17%), cold façade (12%) and curtain wall (4%) depending mainly on the building uses, public (administrative) or private (residential).

Old buildings in Europe were largely built as steep-roofed houses until the 20th century. Pitched roofs are initially defined by their shape and contours, but also by the construction, by the nature of the surfaces (e.g. opaque slate or tiles in shades of natural red and brown). Examples of good integration of BIPV (cold roof) solar solutions are widespread, and show that from their early years, solar technologies have been well integrated using specific connecting elements or materials and non-active PV solutions, even in any complex roof typology and in some cases, together with solar thermal solutions. In these buildings, mainly private residential buildings, the installed surface and capacity are generally greater because it usually involves complete roof renovation's interventions. Only in some cases, usually due to a higher level of protection and to favour the intact perception of the original building, a part of the roof has been maintained and preserved. It allows reducing the visual impact of the solar system from the public spaces, which generally leads to a higher level of appreciation and acceptance.

A perfect example of this is the residential building Hutterli Röthlisberger, a protected object of cantonal importance, with a well-integrated photovoltaic system and solar thermal collectors integrated under the natural slate panels. The listed, neo-baroque house of the Hutterli Röthlisberger family in Bern / BE from 1898 was extensively renovated and refurbished. Thanks to the energy revamping of the renovation, the total energy requirement fell by 76% from 46.900 kWh annually to 11.100 kWh per year, saving 10,6 tons of carbon dioxide per year. Due to the high level of protection, solar panels are hidden on the sloping roof of the natural slate roofing. On the upper roof area, a BIPV system with an electrical output of 2,7 kWp delivers around 3.200 kWh/y of electricity. The energy renovation strategy combines solar photovoltaic with solar thermal production which equals around 10.000 kWh/y. It is either brought directly to the hot water balloon for domestic water heating, or used for the heat pump in combination with geothermal probes. This challenging energy revamping of a more than 100-year-old listed building was awarded with the Swiss Solar Prize in 2014 and has been worthy of the seal of approval from the Minergie association as showcase ultra-low-energy building.

Fig. 12 *Solar Silo building, Basel, Switzerland. Credits: SUPSI-BFE, Caspar Martig.*

On the other hand, skylights and curtain walls are in most cases used in public buildings to cover surfaces with semi-transparent BIPV solutions equipped with crystalline and amorphous silicon technologies, which can in some cases contribute to improving comfort through their passive properties, both in summer (shading) and winter (solar gains). In these cases, the covered surface, the installed power and the final yield of the system are usually lower than opaque technological systems. Several examples are shown in different countries across Europe (e.g. Tourism office Alès in France and Bejar or San Anton Market in Spain).

Technological advances of recent years in the BIPV industry led to adapt technical solutions with the objective to improve future integration in historic buildings. Although solar installations can be difficult to reconcile with building regulations, space planning, urban heritage conservation and budgets, more and more new solar products are currently available on the market that would facilitate the integration of these technological systems. BIPV products with new formats, textures and colours, which allows a better integration without interfering with the appearance, the historical value and structural substance of these historical buildings, of monuments tied to preservation, or of urban and rural landscapes. Good evidence are the terracotta solar tiles developed for historical contexts (e.g. Rural House Galley) or the invisible and coloured solar BIPV modules used in the industrial and administrative building of the Solar Silo in Basel.

The coal silo "Kohlesilo" of the Sulzer and Burckhardt machine factory in Basel has been modernized and was completely converted into a multi-purpose building (***Fig.*** *12*). Innovative coloured customized photovoltaic modules are used, creating a particular visual design to be integrated in the ventilated roof and façade envelope of an industrial refurbished historical building. Green, golden, orange, blue and grey PV modules with monocrystalline silicon solar cells (Kromatix SwissINSO technology) and some standard PV modules in black were used. The 159 m^2 BIPV system is fully integrated and generates 16.400 kWh of solar electricity annually. As part of a research project, this best practice building investigates new approaches for BIPV integration as cladding innovative materials and new energy storage strategies. The electricity produced is stored in "2nd Life" batteries to be used later by the residents of the area. As "Gundeldinger Feld" ensemble is under heritage protection, the remodelled building was required to match the style and colour scheme of the site and all the old industrial area has been reconverted in a new model energy district. The project is part of the "2000 Watt society - pilot region Basel". Solar Silo project that was rewarded in the "renovation" category with the 2015 Swiss Solar Prize.

"There are always problems which we must not neglect; for example, energy, resources, costs, social aspects. You should always be careful about all these aspects. For me, architecture is a global issue. There is no ecological architecture, intelligent architecture, sustainable architecture. There is only good architecture..."
Souto de Moura

Analysis of the case studies

Within this section the aim is to analyse the best practices realized during 40 years of the BIPV history. The timeline at page 34 and 35, shows the most representative events and case studies that influenced the BIPV evolution.

The 97 case studies collected and analysed are grouped by:

- Technological system (opaque and semi-transparent building envelope);
- Characterizing clusters ((BI)PV as experimentation; Architecture of standard PV; Energy integration: BIPV as a building's skin material; BIPV in dialogue with history);
- Values (nominal power, final yield, solar ratio and efficiency).

Nominal power

High values of nominal power emerged during the period of the "boom" of the photovoltaic. This is explained by the "feed-in tariff" policy to encourage the solar installations. Nowadays, the building envelope of administrative and industrial typologies is often exploited for small installations of experimental solar modules, new technologies and semi-transparent solutions. BIPV systems are used to increase the value and the image of administrative buildings. In addition, today, it is common to cover the whole building envelope with solar solutions regardless the orientation, preferring a homogeneous architectonic language to the maximization of the energy production. This concept is represented by the high installed photovoltaic nominal power of cold façades. For historical building, BIPV used as cladding material (cold façade) in the analysed cases is mostly used in private buildings were high level of appreciation of BIPV are reached where acceptability of flagship or showcases pilot project to demonstrate the innovation of solar technologies are important.

Final yield

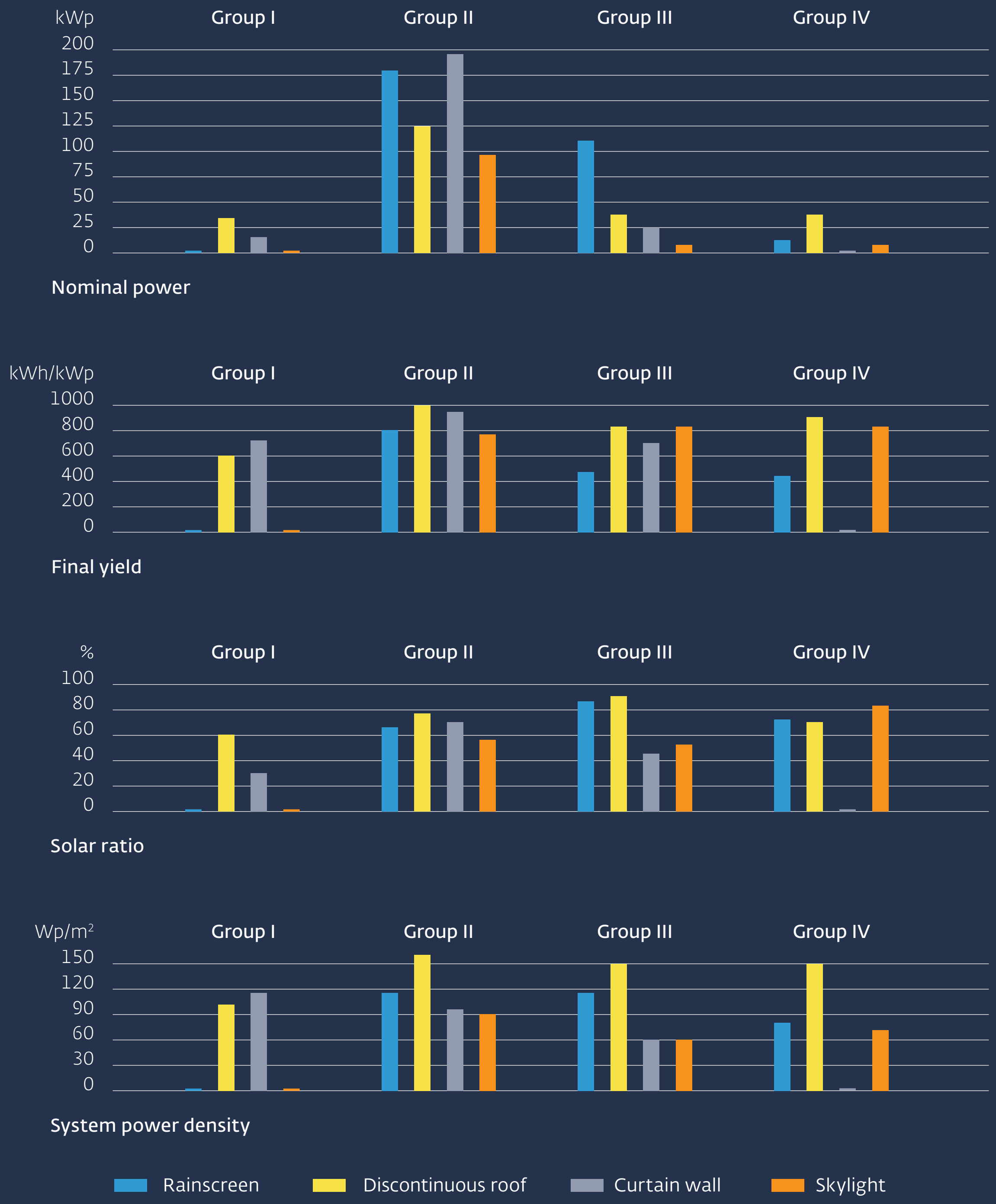
High values of final yield mean that photovoltaic solutions are oriented and tilted to maximize the energy production on a yearly basis. This usually happens for roof solutions both opaque and semi-transparent. The shape and the tilt of the roof offer an optimal surface to optimize the design of solar systems. It explains the high values for residential and industrial building typologies, where the roof represents the most common application area for solar systems. Today, it is common to have solar solutions integrated to the building envelope rather than applied on it, preferring an architectonic language homogeneous instead of high solar irradiation. For this reason, the final yield of BIPV solutions can be lower than that of BAPV solutions. Nevertheless, from the analysed case studies, it seems that solutions are still often installed with the objective to maximize the energy production.

Solar ratio

The shape of a traditional roof often permits to fully cover its available surface maximizing the energy production. This is visible within the first three groups. For semi-transparent solutions, including transparent façades and skylights, the architectonic component is often partially covered by PV, this justifies the low value of solar ratio for these categories. The solar ratio value for opaque solutions (rainscreen systems and discontinuous roofs) is increased during the last years from an average value of 65% during the period "Architecture of standard PV" up to 90% in the period "Energy integration: BIPV as building's skin material". It shows that a high ratio of the building envelope is covered by solar integrated solutions. Semi-transparent solutions, often integrated in administrative and industrial buildings, still cover a small portion of the building skin.

System power density

Good technical performances, even for transparent solutions, are shown within the characterizing clusters "Architecture of standard PV". It expresses a massive use of standard (or almost standard) PV solutions. Low customization, no colourful coatings and crystalline solar modules are exploited as BIPV. The efficiency of solar solutions integrated in façades remained the same as in the previous period but the installed solar modules are customized in size, shape and colour and in most cases the solar cells are not visible. This result highlights the development of the solar industry and technology during the last years.



Nominal power

Final yield

Solar ratio

System power density

Group I: (BI)PV as experimentation;
Group II: Architecture of standard PV;
Group III: Energy integration: BIPV as building's skin material;
Group IV: BIPV in dialogue with history.

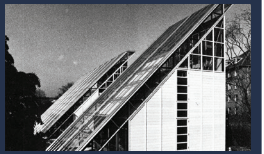
BIPV timeline

1970's

First PV solutions for buildings

Wohnanlage Richter (1)

Credits: BDA



1982

First integrated solar installation on a glass surface

1990's

BIPV systems commercially available, concept of multifunctional construction material

Pompeu Fabra Library (7)

Credits: Roberts S., Guariento N.

1998

Experimental semi-transparent curtain wall

1999

"Architects encounter several problems when designing PV buildings. One of the main problems is that PV systems do not correspond with building sizes. [...] the colours and sizes of PV panels are too limited." Task 7 IEA PVPS.

2000

Renewable Energy Sources Act, principles of feed-in-tariff

Tourism Office (16)

Credits: objectifgard.com

2001

Example of BIPV renovation of cultural heritage

BedZed (17)

Credits: ZEDFactory

2002

The first example of Plus Energy District

Monte Rosa Hut (29)

Credits: ETH Zurich

2009

A BIPV plant at 2,883 meters above the sea level

Market Bejar (36)

Credits: Onyx Solar

2011

Refurbishment: coloured and semi-transparent modules

Omicron Headquarters (55)

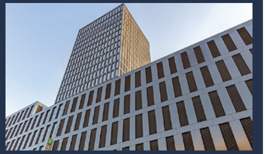
Credits: Sunovation

2014

BIPV façade and LED glass elements in CI colours

Grosspeter Tower (83)

Credits: NICE Solar Energy



2017

The solar skyscraper in Switzerland

2018

"Nobody can know that it is a solar-powered house."
Architect Erika Fries,
HUGGENBERGERFRIES Architects

Rural House Galley (86)

Credits: CSEM

2018

Coloured terracotta modules in a refurbishment

2018

BIPVBOOST.
Bringing down the cost of multifunctional building-integrated photovoltaic (BIPV) systems

Definition of BIPV.
IEA-PVPS T15-04
International definitions of "BIPV"

CP Pregassona (97)

Credits: Alsolis

2021

The largest BIPV façade in Ticino (CH)

EXPO 2020 - BIPV Canopy and e-Trees

2020, EXPO Dubai, UAE

BIPV Canopy and e-Trees

12,600 m², 5,080 pcs, 330 different sizes, 2.1 MWp nom. electrical power

The latest major BIPV project is the Sustainability Pavilion, which was built as part of the EXPO world exhibition in Dubai. Special attention was paid to the function of the pavilion, which should be completely self-sufficient even in the extreme climate region. The Net Zero Energy Building has a funnel-shaped transparent BIPV glass roof measuring around 9,000 m². In addition, 18 "solartrees" were equipped with approx. 220 m² of BIPV glass-glass modules each. In order to achieve the necessary high power density, individually customized trapezoidal glass-glass modules in different sizes were designed by module manufacturer SUNOVATION. The use of these specially shaped BIPV-modules enabled a complete and visually appealing coverage of the funnel-shaped roof with active PV modules. Due to this special roof shape, 330 different geometries were produced. Among others, large-format modules >3.5 m² were used.

2019, Russia

Exclusive BIPV Design Roof

6,000 m², 4,800 pcs, >300 different sizes, 1.2 MWp nom. electrical power

The architects of this one of a kind project in Russia planned a glazing with integrated photovoltaics that was not only supposed to generate energy, shading and shelter. It also had to represent a certain high end design. In close cooperation with the module manufacturer SUNOVATION, a special glass-glass module has been designed. Besides technical specifications, there was a strong focus on design requirements. By printing on different levels, the PV-cells of the transparent modules appear grey from the outside and white from the inside. In addition, the visible shape of the cells has been slightly changed into a look with soft edges from the inside. The realization of a huge number of unique sizes and geometries (> 300 variations) with partly exceptional shapes and cut PV-cells make this project special as well. The manufacturers ability to individualize at a very high level of customization allowed the manifold technical and visual requirements of architects and customers to be successfully implemented.

BIPV-Façade in corporate colours

2016, Athens, Greece

Walkable BIPV Roof, SNFCC

10,000 m², 5,700 pcs, 1.62 MWp nom. electrical power

The Stavros Niarchos Culture Center in the south of Athens is a major center for culture and education in Greece, housing the Greek National Opera and National Library. To achieve LEED Platinum certification, the entire roof was designed as a PV roof. For this purpose, SUNOVATION developed a statically reinforced, frameless photovoltaic roof element with a 3 ply glass composite. Static carrying capacity, accessibility, tare weight and high wind pressure had to be considered in particularly. As well as the static specifications, the specially manufactured glass modules also fulfil the design wishes of the architect, that planned a gapless roof surface with excellent aesthetics. The statically reinforced, frameless modules enable such an extensive installation with no gaps, creating the desired high quality surface optics. Installation, maintenance and cleaning activities can still be carried out easily thanks to the accessibility.

2014, Klaus, Austria

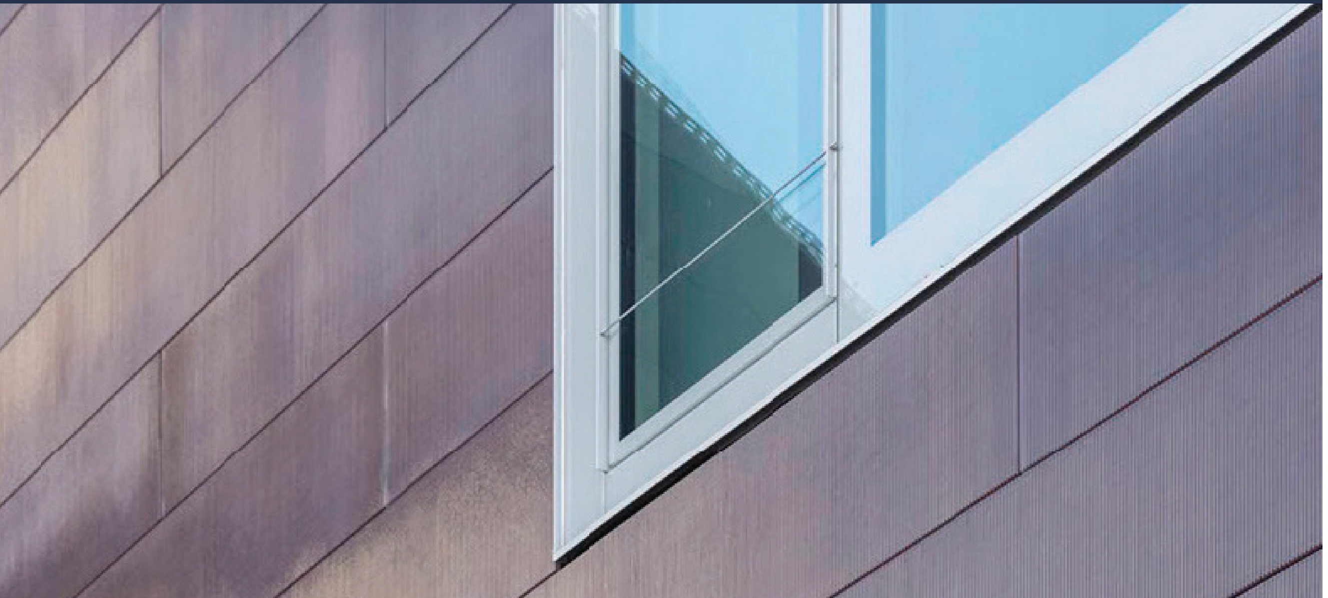
Building Envelope in CI-Colours

780 m², 600 pcs, 92 kWp nom. electrical power

The headquarters of a company with a multifunctional and sustainable BIPV façade in corporate colours. Module manufacturer SUNOVATION designed blue energy generating glass-glass modules and coloured LED glass elements matching the company colours. For the exclusive design, coloured solar cells were combined with special coloured glass, creating an architecturally sophisticated and homogenous coloured surface. The specific structure of the solar cells and its reflections create an interesting optical intensity, which gives this façade its vividness. A particular highlight is the specially programmed LED play of corporate colours. This sets the façade spectacularly in scene at night and reflects technical affinity and innovative strength of the company. The façade was designed as a curtain wall system with frameless glass-glass elements.

2

BIPV products and market overview



Existing and emerging BIPV product technologies

The external layer of the building skin, namely the cladding, is the shield against environmental conditions and the construction component that defines the architectonic language of a building. The need of introducing nearly Zero Energy Buildings (nZEB) in architecture induced designers and builders to investigate innovative technologies and products with increasingly high performance levels, including PV materials.
The following sections report an overview of the most common BIPV product technologies through the discussion of some key innovative features appeared in the last years, including the main cladding typology and the customization aspects such as the colour, the dimension and shape. In addition, a database of 68 BIPV products and mounting systems in Europe is shown with the goal to provide a perspective of what is really available on the market. This section provides architects, building owners and other stakeholders of the BIPV value chain with an overview of the possibility offered by the BIPV in architecture, showing several possibilities of integrated solar cladding module to be used as construction material.

Cladding archetype

The cladding characterizes the architectonic language of buildings and ensures protection. Today's architecture needs a large choice of different technical solutions to offer designers the possibility to customize the building envelope and adapt it to every surface. Since the building envelope cannot normally be produced in one piece, it is necessary to break it down into individual parts. When considering this system, the basic scientific terms resulting from literature can be broadened to five steps for the architect resulting in the following sequence: system, subsystem, component, element, material. In this framework, the options for developing BIPV building skins can be highly different in terms of functions, construction systems, materials, surface treatments and colours, shapes and performance. However, if we refer to the basic traits of BIPV which, differently from a conventional PV application, is firstly a construction product/system, we can ground the basic orientation of definitions in the building envelope. In general, the BIPV categorization can be referred to as a building-construction interpretation. **Technological units** are the classes of the main building skin sub-systems, identified by referring to the main technological alternatives to realize walls, façades and fenestrations as noticed in the technical literature. In **technological solutions**, the scale of building component/element is further included to translate these definitions into a real construction answer, by considering the context of materials, construction, jointing, sequence of manufacturing and installation, etc. Each technological solution of a component/element/system can be solved by implementing a technical alternative, depending on the specific project domain and context, by defining the final solution in terms of geometry, materials and performance on the basis of market availability and products readiness. For the **technical alternatives**, it is more problematic to establish a priori a limited number of categories, since many technical variables are implicated, ranging from material to aesthetical, functional and performance aspects. However, if we refer to the current technological readiness available on the market, we can adopt a classification including some technical key features that we establish as pertinent for the segmentation.

In this context, as it was mentioned within the report "Collection of building typologies and identification of possibilities with optimal market share" of the BIPV-BOOST project, **archetypal BIPV technical solutions** can be identified[1]. These aim at identifying some

Fig. 1 BIPV cladding in Wohnhaus Solaris, Zurich, Switzerland. Credits: hbf Architekten.

reference technical categories which represent an abstraction of the products portfolio typically available on the market. According to this analysis, three different typologies of BIPV products can be defined, by considering technological aspects such as the main material used as cladding outer layer, the transparency rate for the daylight penetration and the level of thermal protection of the building skin:

- Glazed semi-transparent BIPV solution with thermal properties;
- Opaque glazed BIPV solution without thermal protection;
- Opaque no glazed BIPV solution without thermal protection.

Glazed semi-transparent BIPV solutions with thermal properties

The research of transparency and de-materialisation of building can, in some cases, characterise the architectural scenario, especially for high-rise and administrative buildings, inducing designers to investigate innovative technologies and products with increasingly high technological performance levels. The high transparency rate guarantees brightness and diffusion of light inside the spaces. The thermal protection, necessary to guaranty the users' comfort and observe the normative framework, is ensured by typically using two or three laminated glass and I.G.U chamber units. In addition, the PV cells encapsulated between the glass panes soften the overheating effect during the summer by controlling the direct solar radiation through the shading of the building envelope. Curtain walls and skylights are the typical technological units for transparent surfaces to which glazed transparent BIPV solutions can be optimally integrated by adding multi-functionality to roofs and façades (*Fig. 2*).

The transparency rate is typically consistent with a low energy density (Wp/m^2) in the glass pane. Indeed, the nominal power per square meter of building skin is lower than opaque comparable solutions that typically results in lower active (PV) surface per square meter, due to the reduced number of solar cells and the spaces between them.

About 20% of the BIPV manufacturers included within the analysed database offer a glazed semi-transparent solution that is customizable in transparency, dimension, shape and colour. Thin-film semi-transparent elements (e.g. amorphous silicon, DSC semi-transparent glasses, etc.) are used differently to reach a homogeneous shading effect even though the market availability is a bit lower than crystalline silicon-based systems. The same product categories are available for accessories such as balconies, parapets, partitions, etc.

Opaque glazed BIPV solutions without thermal protection

Rainscreen façades and rooftop tiling solutions of buildings require opaque claddings that ensure the environmental protection, durability and good aesthetics (*Fig. 3*). These conventional surfaces of buildings represent an opportunity for an easy, cost-effective and easy-mounting integration for PV.

Considering the application, these products should be combined with a technical solution of the building skin which ensures additional layers of insulation and ventilation to guarantee the thermal protection and the ventilation of buildings, respectively. These BIPV claddings do not differ substantially from traditional opaque glazed elements. In most cases, to better allow the insertion of PV cells, the cladding solutions are realized with laminated glass-glass or tempered glass-glass panes.

Almost the totality of the opaque glazed BIPV products for façades included within the database analysed are customizable in shape, size and colour. The majority of the products for opaque applications available on the market are based on the crystalline silicon technology and on glass components as construction cladding support. Mounting systems are often simply adapted from conventional façade systems. The most advanced colouring technologies (see next sections) ensure a total coverage of the photovoltaic cells if desired as an alternative to the visible PV technology.

Opaque no glazed BIPV solutions without thermal protection

These solutions are a technological alternative where the PV active layer (typically in thin films such as CIS, CIGS, etc.) are encapsulated in metal and/or polymers which ensure also flexibility/bendability and lightness (*Fig. 4*). These products are versatile and adaptable to different applications such as curved surfaces. They are often combined with thermal protective materials to realize prefab components.

About 30% of the BIPV products included within the analysed database are opaque no glazed. About 70% of them are based on a polymer substrate.

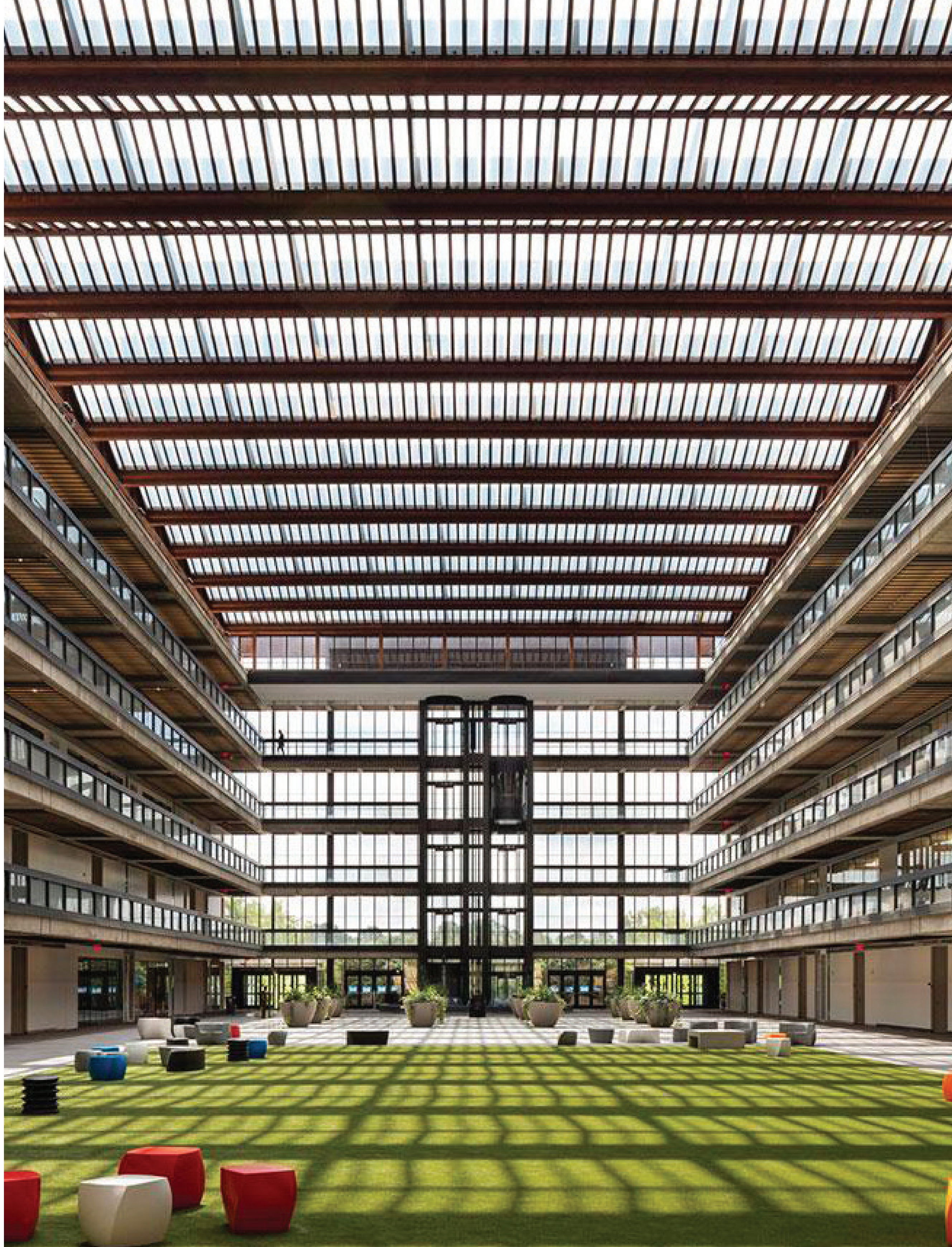


Fig. 2 BellWorks, skylight, USA. Credits: Onyx Solar.

Fig.3 +E Kita, Marburg, Germany. Credits: ErtexSolar.
Fig.4 Palema Sun Way, Sweden. Credits: Midsummer.

Beyond dark dresses: solar and colour

«Multicoloured is my favourite colour.»
W. Gropius

Why are architects, designers and scientists increasingly interested in materials? What are the materials of the future? The role of the white surface as an image of modernity and the importance of materiality in the perception of space was for instance immortalised by the modern movement related to the historiography of 20th century's architecture. The textures and reflections of materials are part of the materiality and space interpretation. The colouring, in this framework, represents one of the possible ways to customize architecture. Colour theory in Modern Architecture involved extended research in artistic, psychological and scientific aspects of colour. Associations between specific colours and forms represented also a further issue of respective interactions, in their interdependence with light, dark and contrast principles. During the last years the techniques to colour a PV element entered this debate in architecture. They have since been largely implemented and still represent today one of the most important metamorphosis of the BIPV industry towards designers and public acceptance, breaking the historic connection between the age of traditional PV integrated in buildings and the practice of BIPV as building component. Customized BIPV modules allow architects to reach new design opportunities using the aesthetic language of the photovoltaic elements. Today, several manufacturers offer coloured solutions and the implementation of coloured modules is growing fast, with multiple new techniques being investigated in laboratories and even entering the market. In such a way, for example, PV cells can be camouflaged behind coloured patterns that completely dissimulate the original materiality of the PV cells.
Here below is presented a short overview of the colouring possibilities available nowadays on the market. In particular, the advantages and disadvantages of each technique are underlined. This analysis is based on the Task 15 IEA-PVPS: Coloured BIPV. Market, Research and Development[2].

Products with coloured/patterned interlayers and/or special solar filters
Interlayers with colours/patterns: an interlayer with a certain colour/pattern can be laminated inside the module as an additional encapsulant sheet or the encapsulant/backsheet itself can be coloured resulting in quite an economical solution that does not require special treatment. Conventional film printing techniques from the graphics industry or semi-transparent

inks that allow light to pass through can be used. Due to these key advantages, this technique could reach a large market share in the foreseeable future.

Special solar filters: one of these techniques considers the application of an elective filter to the front of the glass cover. This filter reflects and diffuses solar radiation within the visible spectrum, providing a white appearance, while the infrared part is transmitted and converted into electricity. In this way, there is an efficiency reduction of about 40% in comparison to a comparable module without filter.

Products with coloured and/or semi-transparent PV-active layers (thin film, OPV)

Different technologies and different materials that can create coloured and/or semi-transparent photovoltaic solutions exist. For example, the semi-transparency of PV layers can be obtained for amorphous silicon PV modules (a-Si) thanks to laser treatment of the active layer that is partially removed in order to increase the light transparency (***Fig.5***).

For copper indium gallium selenide (CIGS) solar cells, transparency was experimented with partial removal of the semiconductor layer by both water-jet polishing and dry sand-blasting by using screen printing as a mask. Another opportunity is offered by PV modules based on organic PV cells (OPV) or dye-sensitized solar cells (DSSC) modules. Thanks to these new materials used to convert the solar light into electricity, it is possible to obtain modules in different colours and transparency. In the past two decades, the efficiency of dye-sensitized solar cells (DSSCs) has increased progressively (from 7% to 14%). At the same time, the efficiency of OPV solutions remains limited. But to become more competitive, various organic materials are being investigated to improve the cell efficiency, enhance the cell durability, and reduce the cost of production. More recently, another thin film technology has attracted a lot of attention thanks to its promising performances: perovskites. But no commercial product is yet available on the market. A possible application of coloured and/or semi-transparent PV-active layers can be seen in fully glazed buildings where the available surface to implement BIPV is very large, so there is no need for high power solutions. In order to reach both transparency and energy production, the efficiency of such solutions is often lower in comparison with opaque modules. For an amorphous silicon the efficiency is about 5-10% according to the visual light transparency. Other solutions can be offered by organic PV cells (OPV), CdTe, CIGS.

Fig.5 Bejar Market, Salamanca, Spain. Credits: Onyx Solar.

Fig.6 Car park, Lindköping, Sweden. Credits: Soltech Energy.
Fig.7 Next page. Wohnhaus Solaris, Zurich, Switzerland. Credits: hbf Architekten.

Products with coloured polymer films (encapsulant, backsheet)

Amorphous silicon technology can be combined with coloured polyvinyl butyral (PVB) as the back encapsulant to obtain PV coloured glass with various degrees of transparency. There are examples of skylights, façades, canopies, flooring and walkways with these products. Coloured encapsulants are also used in combination with thin film technologies. As the photovoltaic thin film is sputtered onto the front glass cover during production, the energy output is not affected by the coloured encapsulant behind it (***Fig.6***).

Products with coated, printed, specially finished or coloured front glass covers

In this case, a surface treatment is applied to the front glass cover of the module. Multiple techniques to apply such treatment exist, as described below.

Spectrally selective coating: with a special sputtering process, a multi-layer reflective coating and spectrally selective coatings have been developed, that exploit specific sputtering nano-deposition technology for the colour coating of solar glass for photovoltaic and thermal panel applications. The conversion efficiency of these modules with a white coating is 11,4%, instead of 19,1% for standard modules. Different colours such as grey, terracotta, blue, bluish-green, green and yellow can be realized.

Coloured enamelled (or fritted) glass: a ceramic paste is applied to the glass prior to tempering of the glass. The additives bake out and the ceramic paste bonds strongly to the glass. By printing a dotted pattern, sufficient light can reach the cells (***Fig.7***).

Sandblasting: a technique that consists in spraying sand at high velocities onto the front glass surface, creating milky white patterns.

Digital glass printing: a process that allows printing special ink onto the glass surfaces in order to obtain a drawing.

Satin finish and glass printing: a satin finish on the outer glass surface is sometimes combined with screen-printing on the inner side. Therefore, there is a reduction of the glass transparency and a resulting coloured matt surface.

Products with coloured anti-reflective coatings on solar cells (c-Si)

When the anti-reflective coating is optimized, the colour is blue. The variation in thickness of an anti-reflective coating has an impact on the colour of the PV cell. As cell manufacturers are typically incapable of producing small batches for specific customers at acceptable price levels, this solution is not very widespread today.

Customization of dimension and shape

The dimensions of buildings are not always standard but defined by geometric proportions, normative, shapes and various other factors. The use of customizable modules in dimension and shape is required by architects to guarantee the homogeneity of the building's skin cladding, especially for façade solutions. To guarantee an efficient process, this should be considered from the very early design stage of the project. Such procedure can also help avoiding some of the critical problems that could affect the PV production by carefully taking into account basic design rules and optimizing BIPV factors according to the specific urban/building context. As explained in the chapter "Evolution in 40 years of BIPV: architecture, technology & costs", during the last decades a change of paradigm from standard to customized BIPV buildings has been accomplished. A BIPV cladding element should adapt to the building skin and not conversely. Not only to satisfy an aesthetic requirement should the BIPV modules be customizable in size and shape, but also because the built environment is often very complex. This can cause non-optimal scenarios for PV systems, which can affect the incident solar radiation on the buildings surfaces and create limitations or reduction of the solar potential in different ways. In addition, the variable production of photovoltaic modules can cause safety issues triggered by different levels of current in the solar cells. A customized dimension of each module together with an optimal planning strategy permits to maximize the efficiency of a solar system and exploit the maximum available surface of the building skin.

Today, the customized module is one of the pillar of the contemporary BIPV architecture, Most of the time, customizable solutions that are non customizable in size and shape are neither customizable in colour. Also, customized modules are often different in nominal power output, which can increase the level of complexity of the system. This can be overcome with an accurate design and the correct choice of BIPV modules.

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Technological systems and BIPV manufacturers database

1. Discontinuous roof

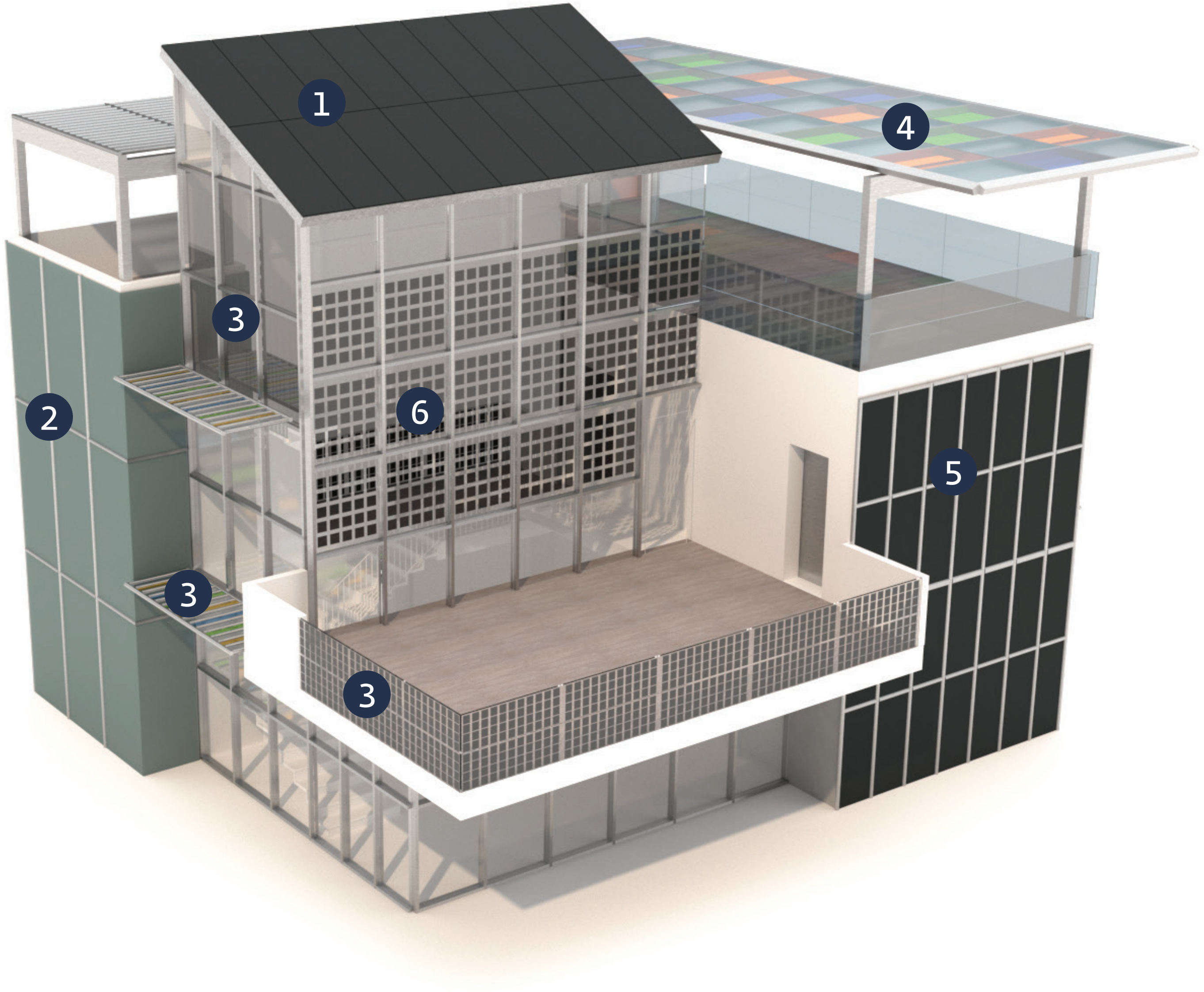
The cold roof (or shingled roof) typically consists in a pitched/sloped opaque envelope which is known as "discontinuous" due to the presence of small overlapping elements (tiles, slates, shingles, etc.) with the main function of water tightness. It is the part of the building envelope where the PV transfer has had its first successes due to the advantages of optimal orientation of pitches and the easiness of installation.

2. Rainscreen

Well known also as cold or ventilated façade, it consists in a load-bearing substructure, an air gap and a cladding. Usually, PV elements are integrated similarly to non-active building claddings. In summer, heat from the sun is dissipated thanks to the cavity that is naturally ventilated through bottom and top openings. The cold façade is ideal for enhancing rear ventilation. Many constructive models and technological solutions are available on the market, also with various joints and fixing options.

3. External integrated devices

Transparent or opaque multi-functional and photovoltaic solar shading devices (louvers or interpane venetian blinds) for façades or balustrades with the role of "fall protection" that are necessary for the safety of the building (e.g. in balconies, loggias, parapets). Transparent or opaque shading devices for roofs aimed to select the solar radiation. Integrated canopies, greenhouses and verandas.



4. Skylight

It is a light-transmitting building element that covers all or a part of the roof. They are typically (semi)transparent for daylight purposes with additional thermal, acoustic, waterproof functions when protecting an indoor environment. Alternatively, it serves mainly as a shelter if protecting outdoor (non heated) areas (atriums). They can be fixed or openable and retractable.

5. Prefab system

It is typically a unitized and pre-assembled multi-functional element installed on the façade or on the roof, composed of the PV cladding, protective layers and the substructure. Polyvalent components are able to satisfy more than a single technological requirement in a unitized way. Off-site manufacturing of building envelope can result in advantages in terms of process efficiency, installation time, cost, quality and safety management. These systems can also be integrated in massive walls/roofs (e.g. masonry walls).

6. Curtain wall

They are external, not ventilated and constitute continuous building skin fenestration systems, totally or partially glazed, composed of panels supported by a substructure in which the outer walls are non-structural. A curtain wall is designed to resist air and water infiltration, dividing outdoor and indoor environments, and is typically designed with extruded aluminium frames (but also steel, woods, etc.) filled with glass panes. The façade should satisfy multiple requirements, such as load-bearing function, acoustic and thermal insulation, light transmission, waterproofing, etc. and can be realized according to different construction systems such as Stick-system, Unitized curtain wall, Structural Sealant Glazing (SSG), Point-fixed or suspended façade. In their most basic form, they are windows, while in more complicated forms they can be used to realize complex double skin facades.

Rainscreen

3S Solarplus (CH)	www.3s-solarplus.ch
Antec Solar (DE)	www.antec-solar.de
Avancis (DE)	www.avancis.de
DAS Energie (DE)	www.das-energy.com
Energyglass (IT)	www.energyglass.grup-postg.com
Ertex Solar (AT)	www.ertex-solar.at
Flisom (CH)	www.flisom.com
Heliatek (DE)	www.heliatek.com
Kioto (AT)	www.kiotosolar.com
Megasol Energie (CH)	www.megasol.ch
Metsolar (LT)	www.metsolar.eu
MGT-eyes (AT)	www.mgt-esys.at
NICE Solar Energy (DE)	www.nice-solarenergy.com
Onyx Solar (ES)	www.onyxsolar.com
Soltech Energy (SE)	www.soltechenergy.com
Sunage (CH)	www.sunage.ch
Sunerg (IT)	www.sunergsolar.com
Sunovation (DE)	www.sunovation.de

Discontinuous roof

3S Solarplus (CH)	www.3s-solarplus.ch
Aerspire (NL)	www.aerspire.com
Aleo Solar (DE)	www.aleo-solar.com
Alwitra (DE)	www.alwitra.de
Antec Solar (DE)	www.antec-solar.de
Avancis (DE)	www.avancis.de
BIPV Solutions (ES)	www.bipv.solutions
BMI Monier (NL)	www.monier.nl
Cotto Possagno (IT)	www.cottopossagno.com
DAS Energy (DE)	www.das-energy.com
Energyglass (IT)	www.energyglass.grup-postg.com
Eternit (CH)	www.eternit.ch
Exasun (NL)	www.exasun.com
Flisom (CH)	www.flisom.com
Freesun (CH)	www.freesuns.com
Heliatek (DE)	www.heliatek.com
Kioto Solar (AT)	www.kiotosolar.com
Megasol Energie (CH)	www.megasol.ch
Metsolar (LT)	www.metsolar.eu
MGT-eyes (AT)	www.mgt-esys.at
Midsummer (SE)	www.midsummer.se
Nelskamp (DE)	www.nelskamp.de
NICE Solar Energy (DE)	www.nice-solarenergy.com
Romag (UK)	www.romag.co.uk
Roofit Solar (EE)	www.roofit.solar
Smartroof (BE)	www.smartroof.be
Solarwatt (DE)	www.solarwatt.com
Solibro (SE)	www.habergy.eu
Solinso (NL)	www.solinso.nl
Soltech Energy (SE)	www.soltechenergy.com
SolteQ (DE)	www.solteq.eu
Star Unity (CH)	www.starunity.ch
Sunage (CH)	www.sunage.ch
Sunerg (IT)	www.sunergsolar.com
Sunstyle (CH)	www.sunstyle.com
Tegola Canadese (IT)	www.tegolacanadese.com
Viridiansolar (UK)	www.viridiansolar.co.uk

Curtain wall

Antec Solar (DE)	www.antec-solar.de
BIPV Solutions (ES)	www.bipv.solutions
Energyglass (IT)	www.energyglass.grup-postg.com
Ertex Solar (AT)	www.ertex-solar.at
Hermans Techniglaz (NL)	www.hermanstechniglaz.nl
Metsolar (LT)	www.metsolar.eu
MGT-eyes (AT)	www.mgt-esys.at
OnyxSolar (ES)	www.onyxsolar.com
Sunage (CH)	www.sunage.ch
Sunovation (DE)	www.sunovation.de
ViaSolis (LT)	www.viasolis.eu

External integrated devices

Antec Solar (DE)	www.antec-solar.de
Avancis (DE)	www.avancis.de
BIPV Solutions (ES)	www.bipv.solutions
Colt (UK)	www.coltinfo.co.uk
DAS Energy (DE)	www.das-energy.com
Energyglass (IT)	www.energyglass.grup-postg.com
Ertex Solar (AT)	www.ertex-solar.at
Flisom (CH)	www.flisom.com
Heliatek (DE)	www.heliatek.com
Hermans Techniglaz (NL)	www.hermanstechniglaz.nl
Metsolar (LT)	www.metsolar.eu
MGT-eyes (AT)	www.mgt-esys.at
Midsummer (SE)	www.midsummer.se
Onyx Solar (ES)	www.onyxsolar.com
Soltech Energy (SE)	www.soltechenergy.com
Sunage (CH)	www.sunage.ch

Skylight

Antec Solar (DE)	www.antec-solar.de
BIPV Solutions (ES)	www.bipv.solutions
Energyglass (IT)	www.energyglass.grup-postg.com
Ertex Solar (AT)	www.ertex-solar.at
Metsolar (LT)	www.metsolar.eu
MGT-eyes (AT)	www.mgt-esys.at
Nermans Techniglaz (NL)	www.hermanstechniglaz.nl
OnyxSolar (ES)	www.onyxsolar.com
Sunovation (DE)	www.sunovation.de
ViaSolis (LT)	www.viasolis.eu

Prefab systems

Antec Solar (DE)	www.antec-solar.de
DAS Energie (DE)	www.das-energy.com
Flisom (CH)	www.flisom.com
Heliatek (DE)	www.heliatek.com
Kalzip (DE)	www.kalzip.com
Lucido Solar (CH)	www.lucido-solar.com
MGT-eyes (AT)	www.mgt-esys.at
Midsummer (SE)	www.midsummer.se

Mounting system

3S Solarplus (CH)	www.3s-solarplus.ch
Eigen Energie (NL)	www.eigenenergie.net
Emergo (NL)	www.emergo.nl
Ernst Schweizer (CH)	www.ernstschweizer.ch
GFT (CH)	www.gft-fassaden.swiss
GSE Integration (FR)	www.gseintegration.com
Irfts (FR)	www.irfts.com
Länge Glas-System (AT)	www.langleglas.com
Lithodecor (DE)	www.lithodecor.com
Mecosun (FR)	www.mecosun.fr
nD Solar Systeme (DE)	www.nd-system.de
Robisol (NL)	www.robisol.com
Sapa (BE)	www.sapabuildingsystem.com
Solar Retrofit (CH)	www.solar-retrofit.ch
Solarmarkt (CH)	www.solarmarkt.ch
Soltech (DE)	www.soltech.de
STO (CH)	www.stoag.ch
SunIntegration (FR)	www.sun-integration.com
Tritec (CH)	www.tritec-energy.com
Tulipps (NL)	www.tulipps.com
Zigzagsolar (NL)	www.zigzagsolar.com

Accessed the 01.10.2020

BIPV market analysis and new trends

In this section, the status of the stakeholders active on the European BIPV market is investigated. To do so, the inputs of a survey launched in late 2019 are used, whose results are presented and discussed. Then, the scope is enlarged, and the overall market conditions are examined, based on quantified estimations of BIPV market deployment in Europe. Finally, the situation of the European BIPV value chain and its actors is reviewed, and key issues as well as suggested solutions are highlighted.

Industry survey

To obtain a first overview of the situation of the BIPV industry in Europe, a questionnaire was distributed to key actors of the sector. In total, 56 representatives of European companies active in the upstream part of the BIPV value chain were contacted in January and February 2020. The questionnaire was constituted of a dozen of questions, both qualitative and quantitative, related to:

- The markets currently covered by the company, and to be covered in the short-term.
- The sales volumes of the last two years and the projected sales volumes for the next 5 years.
- The application area of company's product(s).
- The PV cell technology used, if applicable.
- The materials used.
- The performance and the cost of the product(s).

Overall, thirteen companies filled in the questionnaire. The profiles of the respondents are representative of the variety of profiles that exist in the BIPV industry, including mounting system, solar glass, solar tile, colouring foil and lightweight module manufacturers. Approximately one third of the respondents work for companies manufacturing mounting systems, should it be for conventional PV modules and/or BIPV modules. Then, with the same number of replies, comes the category gathering manufacturers of solar glass, i.e. producers of glass-based BIPV modules. These can be applied both on façades and roofs, but also used as accessories, such as balustrade, for example. The last two categories, with very limited respondents, consist in lightweight module manufacturers and colouring foil manufacturers. Note that all together, the three categories of module manufacturers represent nearly two-thirds of all respondents.

Regarding the country of origin of the survey respondents, almost half of the sample (46%) is constituted of Swiss based companies. Then, approximately a quarter (23%) of the responding manufacturers are Dutch, while Austria, Belgium, France, and Spain accounted for the remaining countries of origin of the sample.

Moving on to market-related questions, most of companies unsurprisingly focus on their home market, as well as on neighbouring countries. But the global trend appears to be positive as most consider expansion to further markets in the near future. Some of the survey respondents are even already active on other continents or will soon be.

In terms of average sales, answers vary widely across the sample. First, an outlier can be identified, among the manufacturers of mounting structures, with about 70 MWp of annual sales, both in 2018 and 2019, as shown by the green line on the ***Fig.8***. This can be explained among others by the fact that these mounting structures can accommodate conventional PV modules to create BIPV systems, which enlarges its potential range of applications as well as the cost competitiveness of systems integrating it.

In addition, the company is active on a multiplicity of markets, within but also outside Europe.

Aside of this manufacturer of mounting systems, other responding companies show contrasted performances. Indeed, the volumes sold by the remaining manufacturers in 2018 range from 0,1 to 7,6 MWp, and from 0,1 to 10,3 MWp for 2019. Although, these figures do not fully reflect the fact that most of the responding companies' sales volumes lie in the lower part of this range. Indeed, while the average volume sold in our sample equals 6,5 MWp in 2018 and 6,8 MWp in 2019, the median values give a draw a totally different picture, with median volume sold of 0,5 MWp in 2018 and 1 MWp in 2019. Note that sales volumes mentioned here refer to the global market, and not only to Europe.

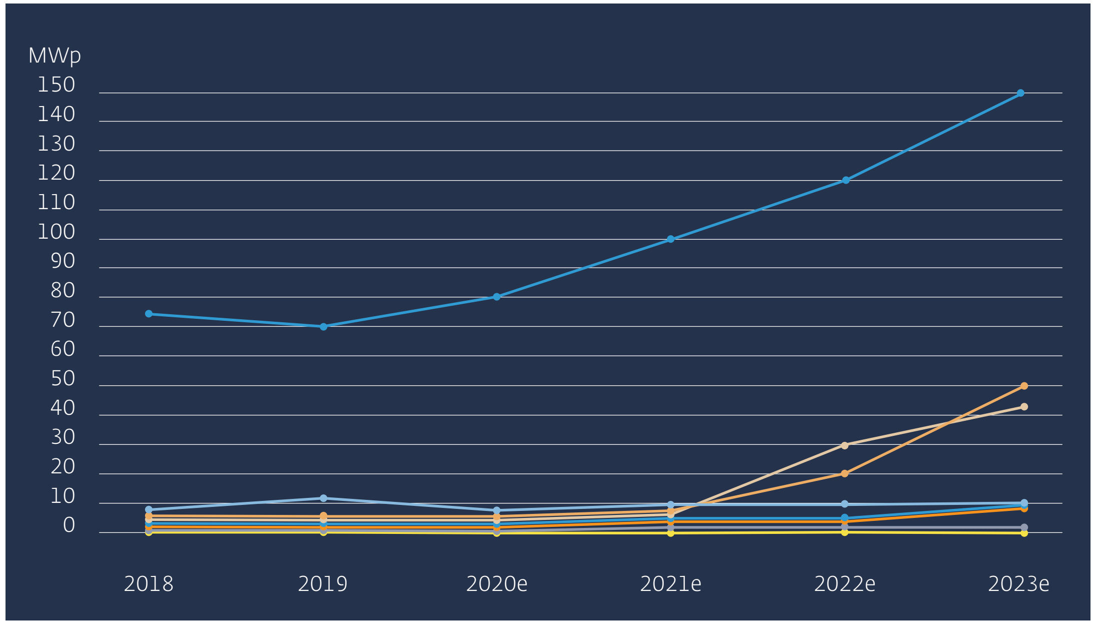
The projected sales volumes show no different trend. Indeed, from 2020 to 2023, these demonstrate significant variance, ranging between 0,2 MWp and 8 MWp in 2020, and between 0,2 MWp and 50 MWp by 2023. Again, it is crucial to look at average and median values to obtain more information. As shown on ***Tab. 1***, the average and the median are significantly different, and few data points push the former upwards. The median annual sales volume is much lower and is forecasted to grow steadily, from 1,5 MWp in 2020 to 3 MWp by 2023. While these figures are reduced in scale, they demonstrate an optimistic trend among responding companies. The yearly growth rate of cumulative sales volumes of responding companies is expected to consistently stand at double-digits values. On the period 2020-2023, this translates into a median compound annual growth rate of 62%, which is very promising.

Overall, these figures demonstrate that a vast majority of European companies active in BIPV are small and medium enterprises, and that the future is expected to be positive, with double-digits growth rates anticipated by all survey respondents.

Another interesting point highlighted by our survey is the great variety of contact points that manufacturers can interact with. While most of the respondents point out building owners as key, they also mention at multiple occasion the crucial role of architects, installers, distributors, constructors, property developers as well as technicians.

Finally, concerning the PV cell technologies used, what can be highlighted is that in our sample, most of BIPV modules manufacturers follow a comparable trend to the rest of the PV market, as most have adopted monocrystalline silicon PERC cells. Another interesting trend is that all responding manufacturers of solar glass indicate that they offer colouring possibilities, which confirms that such customization feature is more and more widespread on the market.

Fig.8 Historical and projected sales volumes of the 12 responding modules and mounting systems manufacturers.



in MWp	2018	2019	2020e	2021e	2022e	2023e
Average	6,5	6,8	7,7	10,1	15,0	21,9
Median	0,5	1,0	1,5	1,7	2,0	3,0
Maximum	7,6	10,3	8,0	8,0	28,0	50,0
Minimum	0,1	0,1	0,2	0,2	0,2	0,2
Average growth	/	145%	141%	78%	91%	61%
Median growth	/	143%	75%	52%	37%	34%

Tab. 1 Key values of the descriptive analysis of the sales volumes, as self-declared by survey respondents (excluding the outlier), in MWp.

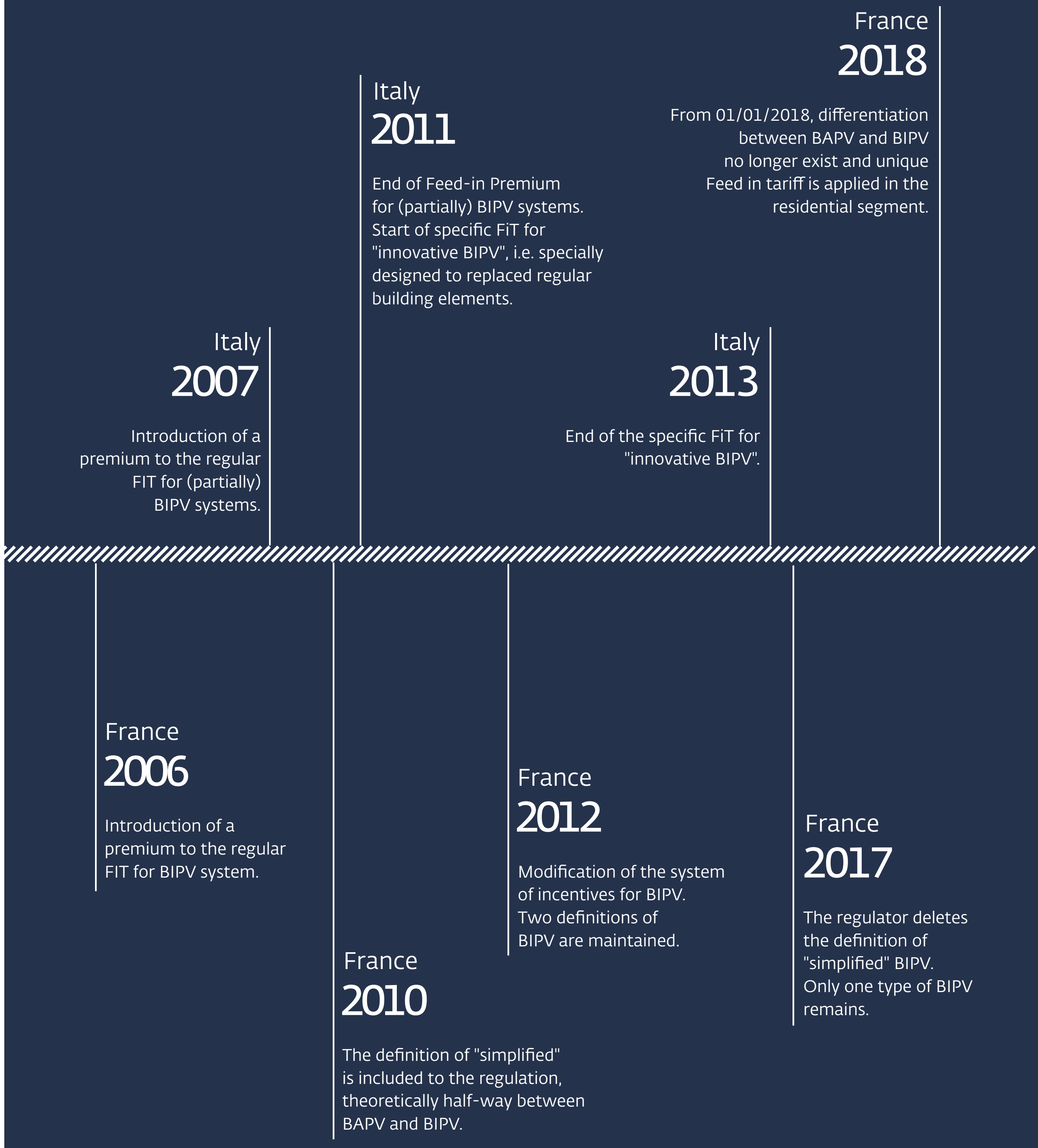
Market analysis

The results of the survey presented in the previous section are informative, but they only give a limited view of the situation of market, as the size of the analysed sample is extremely reduced. Thus, to provide a more global understanding, quantified estimations of past and future BIPV market deployment, at the European scale, are provided in this section.

To begin with, it is worth highlighting that few precise information, if any, is available regarding BIPV market penetration, as in most countries it is inventoried as any other distributed PV system and numbers are scattered among large datasets, without differentiation made between BIPV and BAPV. In addition, historically, there were no commonly accepted definition of BIPV products or systems. Thus, across countries which have been supporting BIPV market development with specific incentives, the definition of BIPV products and systems varied, and might not be in line with what is today considered as BIPV, for example by the standard EN 50583. In France, for example, for a few years two definitions of BIPV co-existed, differentiating "regular" BIPV from "simplified" BIPV. In Italy, the first definition of BIPV was also non-restrictive, which led to abuses, and forced an update of the regulation in 2011. Overall, these examples illustrate the fact that, even in countries where BIPV installations have been officially recorded, uncertainty exists and a more precise analysis of market numbers is necessary, in combination with some hypothesis.

The data presented here is based on an analysis of national PV market databases and, in some cases of non-publicly available data but exceptionally accessed for research purposes. It is completed by an inventory of BIPV projects and discussions with local PV associations, experts, regulators or other market and industry stakeholders. By cross-checking these data sources, applying a critical analysis based on their knowledge of this sector and making sound assumptions when necessary, we can provide numbers with an acceptable degree of certainty. Still, we advise to use these estimations with caution and consider them for what they are: a tool to describe and understand the meta-trends ongoing on the European BIPV market.

In the last decade, most BIPV market developments in Europe have been driven by France and Italy, where specific support schemes were put in place early on to stimulate the BIPV sector. A timeline of the history of these BIPV specific support schemes is presented above. While the support schemes were established in 2006 and 2007, it took some time for the market to take off. As shown on ***Fig.9***, the BIPV market started to really develop in these two countries in 2009 and boomed in 2010 before peaking in 2011, mainly led by the Italian market. Note that in Switzerland as well, a specific regulation for BIPV has been introduced in the form of a premium to the regular feed-in tariff for BIPV installations, which was put in place from 2009.



France
2006
Introduction of a premium to the regular FIT for BIPV system.

Italy
2007
Introduction of a premium to the regular FIT for (partially) BIPV systems.

France
2010
The definition of "simplified" is included to the regulation, theoretically half-way between BAPV and BIPV.

Italy
2011
End of Feed-in Premium for (partially) BIPV systems. Start of specific FiT for "innovative BIPV", i.e. specially designed to replaced regular building elements.

France
2012
Modification of the system of incentives for BIPV. Two definitions of BIPV are maintained.

Italy
2013
End of the specific FiT for "innovative BIPV".

France
2017
The regulator deletes the definition of "simplified" BIPV. Only one type of BIPV remains.

France
2018
From 01/01/2018, differentiation between BAPV and BIPV no longer exist and unique Feed in tariff is applied in the residential segment.

Fig.9 Timeline of the history of BIPV specific support schemes in Italy and France. Source: Becquerel Institute.

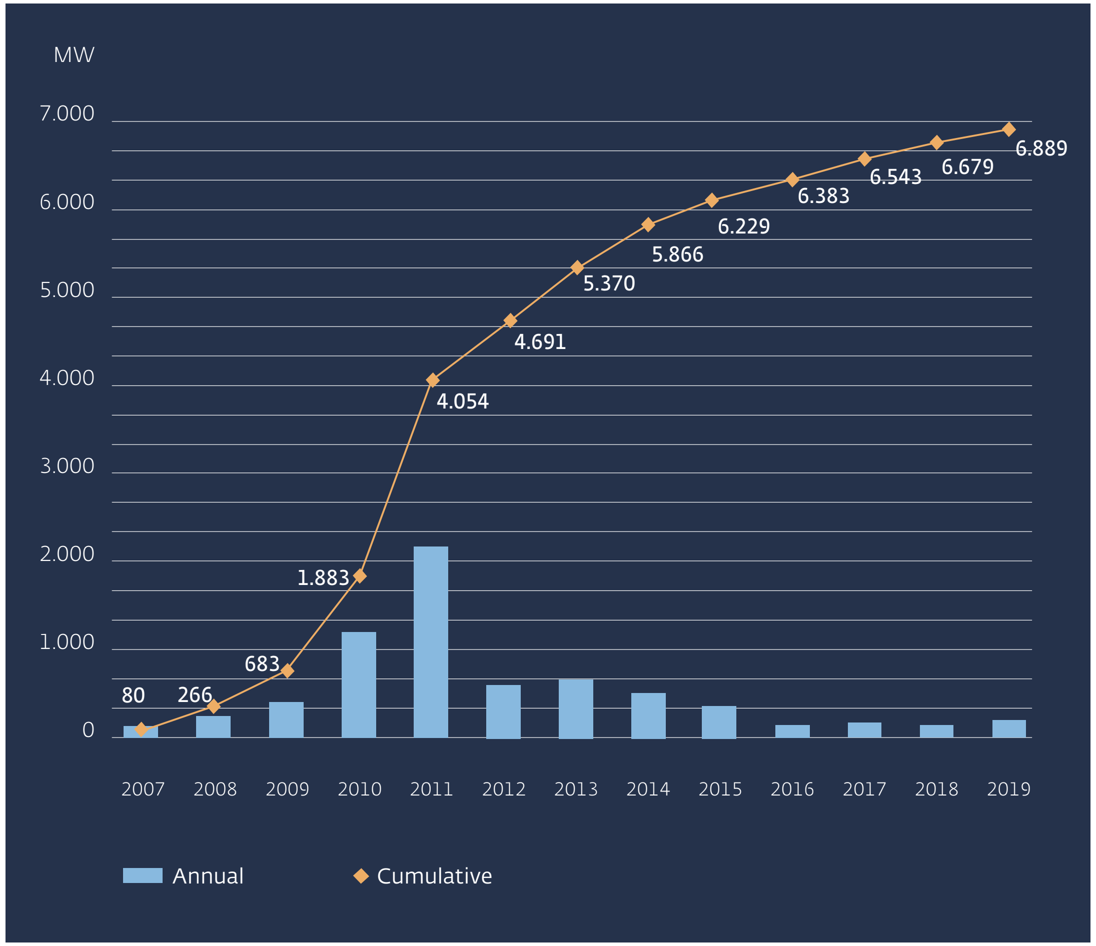


Fig.10 BIPV market history in Europe (covering EU-27 + UK + CH + NO). Source: Becquerel Institute.

Although, the market impact of these premium was of lower magnitude compared to the two previously mentioned neighbouring countries.

Looking at the annual installed BIPV capacity in the ***Fig.10***, a major drop can be noticed between 2011 and 2012. This corresponds to the regulatory change occurring in Italy. Indeed, in 2011, the definition of BIPV changed and became stricter. Even though during a short period of time the two support schemes co-existed on the market, this significantly impacted the market and reduced the number of installations eligible to receive the advantageous feed-in tariff for BIPV. Another steep decrease took place between 2013 and 2014, when the differentiation of BIPV was completely erased from the regulation. In the case of France, the market has been less distorted and the installations of BIPV systems have been more evenly spread between 2010 and 2015. But similarly to what was witnessed in Italy, as soon as the regulation became more restrictive, BIPV deployment decreased and once it did not benefit from a privileged political support anymore, the market plunged.

Due to this policy-led market push, the majority of the cumulative BIPV market in Europe is explained by the contribution of Italy and France. In Italy, between 2007 and 2013, approximately 2,5 GWp of BIPV systems were installed. It is difficult to estimate it precisely, but it is highly probable that a large part of this capacity was "modified" BAPV rather than actual BIPV. In France, between 2006 and 2017, around 2,4 GWp of BIPV capacity was deployed. Overall, considering the cumulative BIPV capacity of 6,9 GWp installed in Europe by the end of 2019, more than three-quarters of it is due to the two countries, France accounting for ~35% and Italy for ~38%. Since the end of BIPV-specific regulations in these two countries, other markets, such as Switzerland and the Netherlands, for instance, have also been showing market growth.

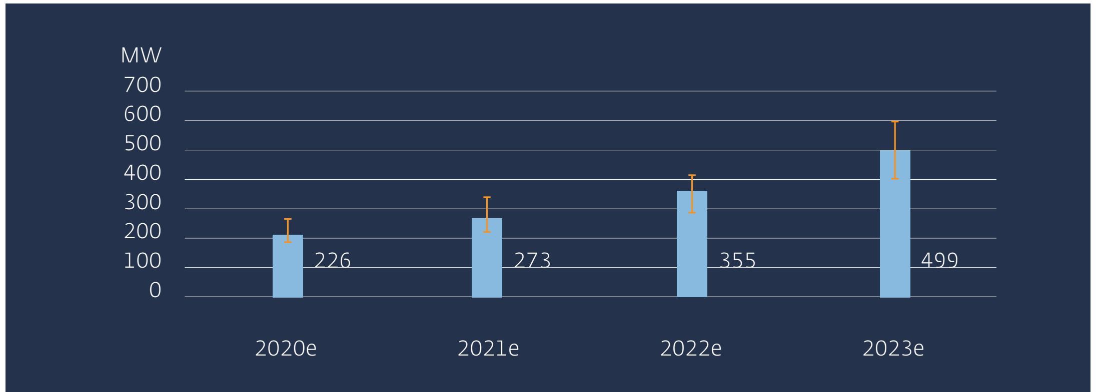
Today, the BIPV market in Europe is of much lower scale, standing at approximately 150 MWp per year. A majority of this capacity is estimated to be due to systems that can be seen as "simplified" BIPV systems, i.e. constituted of conventional PV modules in combination with a specifically designed mounting system, allowing to replace conventional building envelope solutions, mainly on roofs.

Then, after having analysed past trends, it is also valuable to explore future pathways. But forecasting the evolution of the BIPV market is no easy task. Indeed, it is dependent on constraints and forces at play within both the PV sector and the construction sector. Moreover, these constraints can be of multiple natures. One can mention for example the regulatory environments and their likely evolution. But other factors can be highly influential as well, such as the characteristics of the building stock, the maturity of the BIPV sector or the availability and acceptance of workforce can also be cited. To establish short-term forecasts and account for all these elements, an approach based on "back-casting" is developed. It estimates the likely long-term penetration of BIPV on the market before evaluating the "natural" pathway leading to these figures. In our case, a maximal theoretical market potential is estimated at 2100. It is determined based on an estimation of building stock's size and characteristics, as well as its energy demand. This date was preferred to others that are often defined as "long-term" targets in the energy sector, e.g. 2050 when talking about PV, for different reasons. First, even if there is a commitment at European and National level to decarbonize the building sector, there is strong inertia, which can be illustrated by reduced construction and renovation rates, as well as a relatively high resistance to change of its incumbent actors. Then, even if BIPV has a real added value, there are multiple situations in which competing technologies can reveal to be more cost-efficient, both when aiming at improving energy performances of the building or maximizing renewable energy generation. This can be caused by geographical constraints or specific regulatory aspects, which can make one or the other technology more advantageous.

On ***Fig.11*** the BIPV market forecasts for the short-term, based on the methodology briefly explained in the previous column are displayed. The bars represent the value of the "most probable" scenario, while the yellow bar, stylized as an error bar, shows the potential range of variation, the upper limit representing our "high" scenario and the lower limit our "low" scenario. As shown, the scale of the BIPV development expected in the coming years is incomparable to what was seen on the market around years 2010. Nevertheless, growth compared to the last years is foreseen, which is promising. More importantly, this growth is expected to remain a lasting trend, and the yearly BIPV market in Europe could double within a 5-year span. Also, this development is anticipated to be healthier than the strong development that occurred a decade ago, and BIPV deployment should be primarily led by the intrinsic attractiveness of the solutions rather than financial incentives. Countries such as Switzerland, the Netherlands, France, or Austria are expected to be leading the market penetration of BIPV in Europe.

Overall, no major boom is forecasted in the short term, even if nZEB regulation is on the corner. Indeed, the inertia of the building and construction sector is high, and competing investment strategies still prove to be more cost-efficient in many situations, both when aiming at improving energy performances of buildings or maximizing on-site renewable electricity generation.

Translating these market projections into economic opportunity give a somewhat more optimistic vision (***Fig.12***). By using a weighted average selling price of BIPV systems, which is steadily decreasing in time, it is estimated that the European BIPV market represents an annual opportunity of approximately 500 million € in 2020, and that by 2023, this market value could almost reach 1 billion € in the best case scenario.



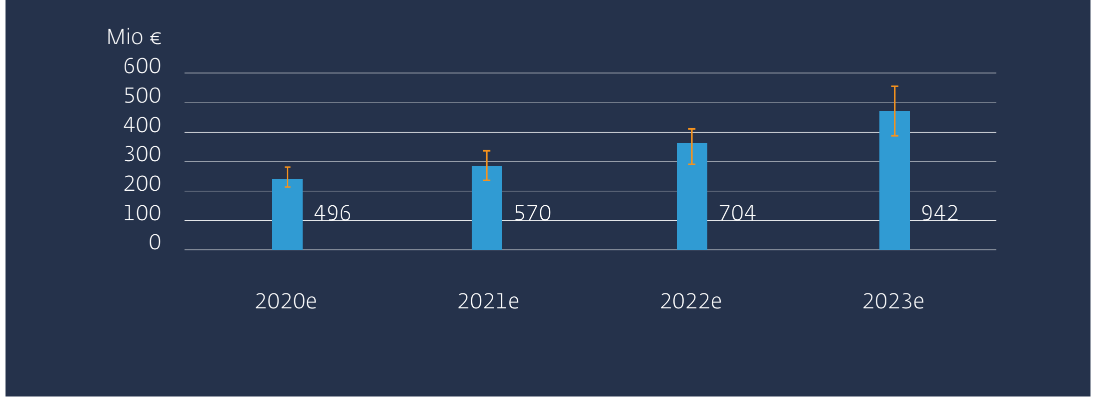


Fig.11 Short-term forecasts of the BIPV market in Europe (covering EU-27 + UK + CH + NO). Source: Becquerel Institute.
Fig.12 Short-term projections of the value of the European BIPV market. Source: Becquerel Institute.

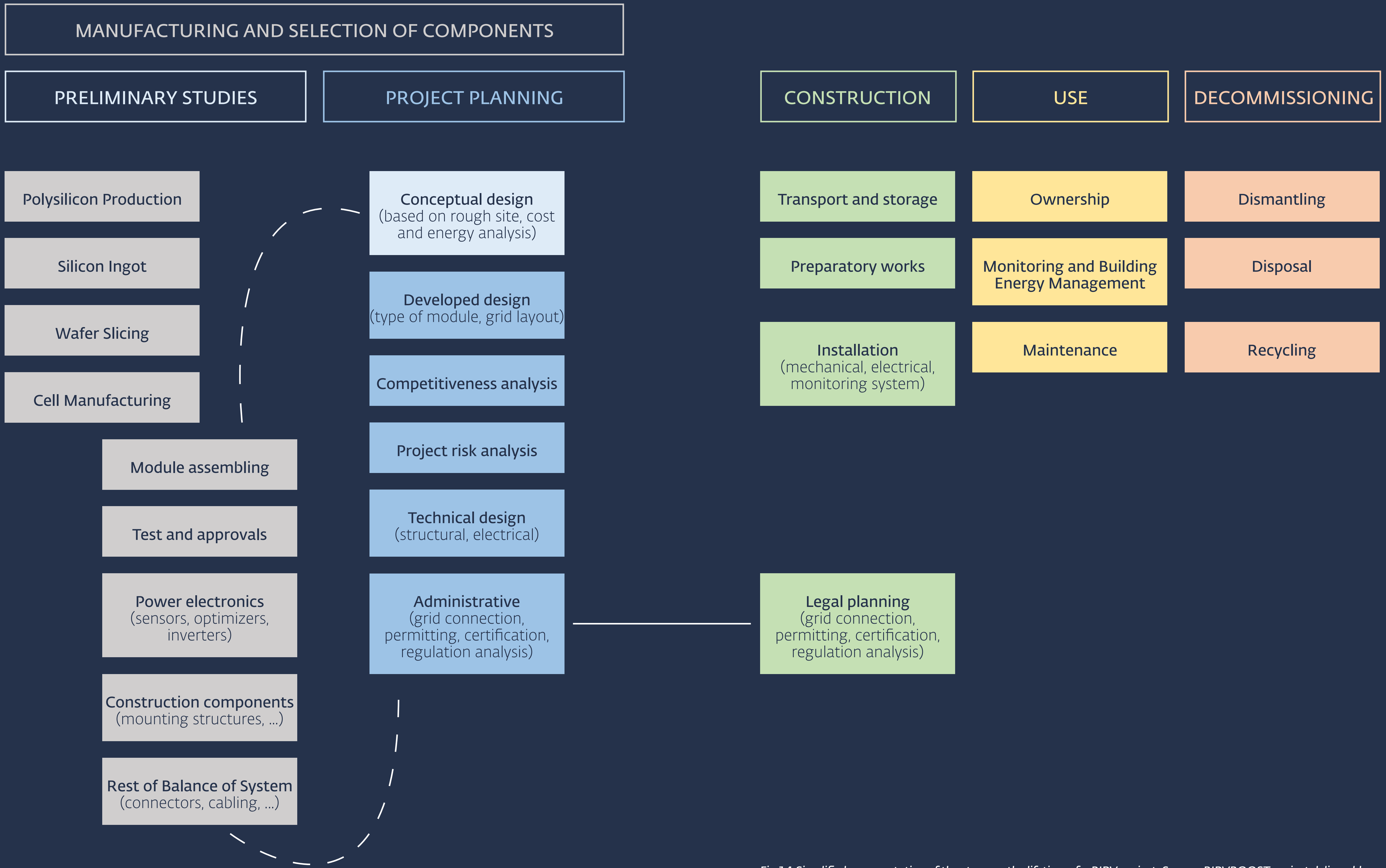
Value chain analysis

The BIPV value chain is at the crossroad of the construction and PV sector, and the multiplicity of stakeholders involved in the BIPV value chain can create complexity. Therefore, a detailed analysis of this value chain is provided in this section, mainly based on the work conducted in BIPVBOOST research project[3]. To provide a comprehensive overview of these stakeholders, the ***Fig.13*** is provided. It maps all actors and categorizes them based on their respective position in the BIPV ecosystem. First level stakeholders are directly in touch with the owner (assumed to be the final user) of the BIPV system. Second level stakeholders have a crucial role as they provide key materials or service but are not in direct touch with the owner of the BIPV system. Third level stakeholders have the least links with the final customer and are placed further away in the value chain. In addition, on the map below, stakeholders are also defined by the sector of activities they belong to. The different sectors can intersect one another, and some stakeholders can be considered as belonging to two of them. It is typically the case of BIPV manufacturers and installers which can be seen as being part of both the solar PV and the construction sectors. Note that this infographic only aims at providing an inventory of all possible stakeholders involved in the development, installation and operational life of a BIPV system, in order to demonstrate how complex it can be. But from one project to another, and from one BIPV product to another, stakeholders involved can vary a lot. It depends on, among others, whether it is a new construction or a renovation, if the installation of BIPV product is made by the manufacturer or via a partner, on how is the project financed, if the investor is the final user or not, etc.

Fig.13 BIPV stakeholders' map. Source: Becquerel Institute.

In addition to the number of stakeholders, the BIPV process can also be illustrated by its different steps. On the flow chart available in ***Fig.14***, the different steps of the lifetime of a BIPV project are presented, from the manufacturing of components to its dismantling. A crucial aspect to mention is that, contrary to conventional PV projects, early phases of project development can influence some manufacturing steps, as represented by the feedback loop on the left part of the flow chart. Indeed, in function of the requirements and demands of the building owner or the architect in charge of the project, the design and characteristics of the BIPV modules can be modified. This can impact other steps of project planning, such as competitiveness or risk analysis, but also technical design or administrative and legal planning. This can also explain why it is crucial to consider the inclusion of BIPV in any construction project as early as possible.

This analysis of the different steps of the lifetime of a BIPV project emphasises the fact that stakeholders, in addition to the nature of their interaction with system owner/end user, can also be characterized by their degree of influence on the development of BIPV projects. This logic can lead to another categorization of stakeholders involved in BIPV projects' development, with one category of stakeholders having a medium to



MANUFACTURING AND SELECTION OF COMPONENTS

PRELIMINARY STUDIES

- Polysilicon Production
- Silicon Ingot
- Wafer Slicing
- Cell Manufacturing
- Module assembling
- Test and approvals
- Power electronics (sensors, optimizers, inverters)
- Construction components (mounting structures, ...)
- Rest of Balance of System (connectors, cabling, ...)

PROJECT PLANNING

- Conceptual design (based on rough site, cost and energy analysis)
- Developed design (type of module, grid layout)
- Competitiveness analysis
- Project risk analysis
- Technical design (structural, electrical)
- Administrative (grid connection, permitting, certification, regulation analysis)

CONSTRUCTION

- Transport and storage
- Preparatory works
- Installation (mechanical, electrical, monitoring system)
- Legal planning (grid connection, permitting, certification, regulation analysis)

USE

- Ownership
- Monitoring and Building Energy Management
- Maintenance

DECOMMISSIONING

- Dismantling
- Disposal
- Recycling

Fig.14 Simplified representation of the steps on the lifetime of a BIPV project. Source: BIPVBOOST project deliverable D9.1[3].

Influence of stakeholders	low	medium	high	
high	Facility managers General contractors Architects Project investors	Policymakers BIPV manufacturers and suppliers	Building owner Experts on both PV and construction aspects	primary stakeholders
low	Grid operators Maintenance Recycling companies	Construction companies Building occupants	BIPV system installer	secondary stakeholders
	Interest of stakeholders			

Tab. 2 Categorisation of BIPV stakeholders in function of their influence and interest. Source: PVSITES & BIPVBOOST project deliverable D9.1 [3].

strong influence, defined as "primary stakeholders", and the stakeholders with low to no influence in BIPV project development, defined as "secondary stakeholders". Based on this, architects, general construction companies, facility managers, policy makers, building owners, project investors and the BIPV manufacturers have been identified as primary stakeholders. Indeed, architects can decide whether and how to integrate BIPV in project's design. Which can impact multiple other steps of the process, as illustrated on ***Tab.2*** by the feedback loop. The influence of project investors is also obviously quite high as they make the project possible or not by making capital available. Regarding policy-makers, their interest is medium, but their influence is high. By implementing regulatory frameworks, they can increase the pressure to integrate renewable energy sources. Plus, by introducing financial incentives they can make BIPV more or less attractive. Other stakeholders, among which grid operators or even BIPV system installers, have been identified as secondary stakeholders, because they have limited or no impact in the decision process and in the definition of project's characteristics. The interest that stakeholders have in a project is mostly a financial interest. The interest of a stakeholder whose business relies on the success of the BIPV market can be characterized as high. If a stakeholder has only a few projects a year related to BIPV, and who therefore consider BIPV as a niche have a medium interest. We speak of low interest for stakeholders who are rarely linked to the BIPV sector and who are almost independent from this sector[3].

Based on this identification and categorization of BIPV stakeholders, the challenges that they face can be defined. As already evoked in the previous section, these are numerous. ***Fig. 15*** presents a summary of the different challenges that stakeholders may face, in particular during the early phases of the development of a BIPV project. The stakeholders, which are represented by bubbles with plain or dotted perimeters, have been positioned based on how they interact with the system owner.

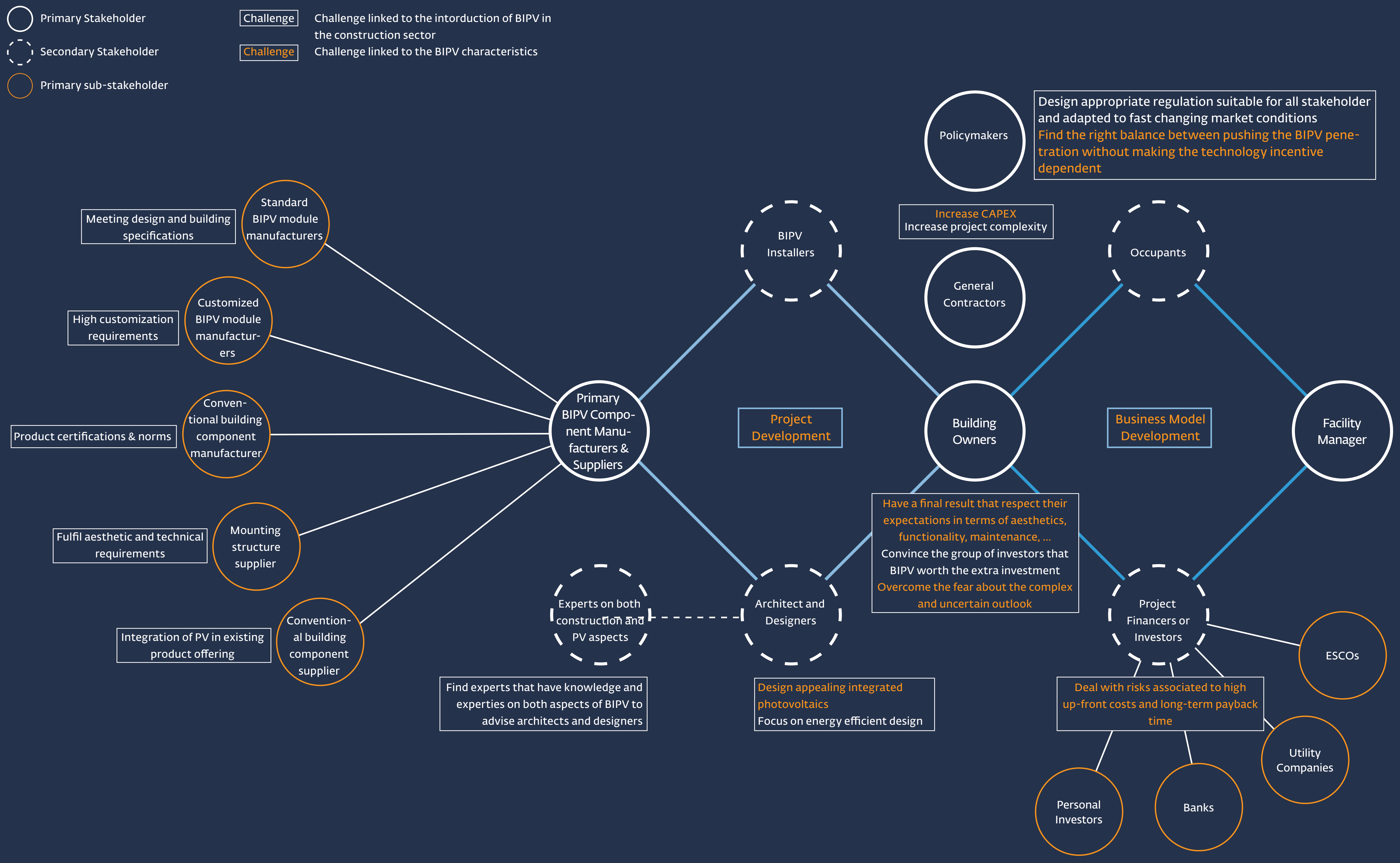
The light blue diamond represents the four main actors involved in project development: architects, building owners, system installers and BIPV components manufacturers/suppliers. Then, the blue diamond gathers the stakeholders that contribute to define the business model applied to the installation. Note that policy makers are not represented in any of the diamonds and have been placed on top of them. Even if they of course influence both the project's development and the definition of the business model, they do not play an active role in it. Then, focusing on the challenges, two main types can be distinguished. These are represented with different colours. Challenges specifically due to BIPV's unique characteristics are in orange. Challenges not directly due to BIPV itself but more to its introduction and insertion to the established construction sector are in white.

Among first type's challenges, stakeholders must deal with complexity as well as aesthetical and cost characteristics that are specific to BIPV. For example, general contractors will likely face an increase in terms of cost. This cost impact can also make building owners and investors reluctant to invest in BIPV. Architects, on their side, must deal with the new constraints imposed by BIPV, for example in terms of design, but also in terms of technical and structural characteristics. Therefore, they may need additional knowledge or skills. This could be provided by experts whose skills set encompasses both PV and building expertise. Such profile remains rare on the market, while their role is crucial, especially in the preparatory steps. Indeed, these experts can help to optimally integrate BIPV in the project design and planning phase, by offering support to architects and construction companies, thus facilitating the project and reducing costs. Note that such role could potentially be covered by BIPV installers, who have the expertise of both aspects.

When it comes to the second type of challenge, stakeholders face difficulties caused by the necessity to adapt the existing procedures of the construction sector to BIPV. The integration of an innovative technology generates knowledge and processes gaps. Indeed, stakeholders taking part in the installation must potentially acquire a new qualification, or even a permit in order to be allowed to work on both aspects of BIPV. If not, a specialist of one or the other aspect has to be called in. This justifies the role of BIPV installers, who not only have capabilities in both aspects of BIPV, but more importantly can be the stakeholders that can carry the potential risks associated with BIPV. This clearly has an added value as both PV installers and building element installers remain reluctant to do so. Architects, on their side, will need to focus more on green design and especially energy efficient design, taking into consideration at the same time the added value of multifunctional BIPV products. Finally, BIPV can also create fear among investors due to their associated extra-investment, or among building owners because of the uncertainty it adds. Thus, training and education, but also communication between both sectors from the beginning of the project planning are crucial.

This stakeholder analysis pointed out that collaboration and communication between the BIPV industry and the incumbent construction actors such as architects and general contractors imperatively needs to be improved. Education is also crucial. This will permit to reduce the knowledge and skills gap with regards to BIPV unique features and, consequently, will contribute to overcome most of identified stakeholders' challenges. Experts on PV and building aspects as well as BIPV installers can contribute to close this gap by respectively providing help to architects in the project planning and design phase, and having needed skills to shoulder the potential risks associated to BIPV in the installation phase. This can also be achieved with the help of appropriate digital tools, such as simulation and BIM-based software. Moreover, to mitigate these risks, or at least reduce how they are perceived, standardization in terms of product and system design, or mounting structures, should also be prioritized. It would allow to hedge against the close of business of the manufacturer of the BIPV product or of the BIPV installer.

This would also limit the negative consequences of product failures, as replacements or repairs could be taken in charge by another professional. In the best case, BIPV products shall be "plug and play". In addition, in case of problem, modules should be possibly updated individually, reducing the cost of maintenance as well as risks, as mentioned already. Such strategy, although, is not easy to put in place. Firstly, technical requirements vary across countries, which can limit the level of standardization that can be reached. Secondly, some stakeholders (e.g. architects or building owners) would prefer to see more customization possibilities, which could hinder standardization. Even if standardization could also benefit them, as it could reduce costs by, among others, enabling economies of scale. Hence, a global challenge lies in the fact that compromises must be found between standardization for easier processes and cost reductions on the one hand, and customization for more aesthetical possibilities on the other hand, including colour, shape or patterns.



Challenge linked to the intorduction of BIPV in the construction sector

Challenge linked to the BIPV characteristics

Design appropriate regulation suitable for all stakeholder and adapted to fast changing market conditions

Find the right balance between pushing the BIPV penetration without making the technology incentive dependent

Meeting design and building specifications

High customization requirements

Product certifications & norms

Fulfil aesthetic and technical requirements

Integration of PV in existing product offering

Increase CAPEX

Increase project complexity

Have a final result that respect their expectations in terms of aesthetics, functionality, maintenance, ...

Convince the group of investors that BIPV worth the extra investment

Overcome the fear about the complex and uncertain outlook

Find experts that have knowledge and experties on both aspects of BIPV to advise architects and designers

Design appealing integrated photovoltaics

Focus on energy efficient design

Deal with risks associated to high up-front costs and long-term payback time

Fig.15 Challenges of BIPV stakeholders. Source: Becquerel Institute and BIPVBOOST project deliverable D9.1 [3].

Key topics to boost the BIPV sector

The use of BIPV solar construction products should be mainstreamed in the EU's buildings stock, as part of the European Green Deal's Renovation Wave[4].

The positive market trend aforementioned is explained by different factors, among which the decrease of manufacturing costs and the increase of product performances, a growing regulatory and social pressure to decarbonize the energy supply and reduce the environmental footprint of buildings and the high customization potential of current BIPV products, which are ready to be introduced in the construction sector as conventional elements. However, some obstacles still need to be overcome to permit a solid entry in the mass EU construction market. Within this chapter, the key drivers impacting the possible development of the BIPV sector in the coming years are presented and discussed. The content of this chapter is partially based on the public reports "Collection of building typologies and identification of possibilities with optimal market share" and "Update on BIPV market and stakeholder analysis" of BIPVBOOST[1][3].

Technology and technical standards

PV modules are considered building integrated if they satisfy the functions of construction products, as defined by the European Construction Product Regulation CPR 305/2011, including: mechanical rigidity or structural integrity, primary weather impact protection, energy economy (shading, daylighting, thermal insulation), fire and noise protection, separation between indoor and outdoor environments, security, shelter or safety. Although this norm has been introduced, it does not help tackling all issues, and some problems remain. For instance, a high number of manufacturers complain about the lack of long-term guarantees of available BIPV solutions and impossibility to certify/mark a BIPV products according to one clear approach/standard. National building codes sometimes impose too restrictive constraints for BIPV (e.g. in terms of fire safety), and in any case remain inconsistent between countries, even across Europe, which generates high customer acquisition costs. This prevent BIPV manufacturers and installers to rapidly expand their customer base and increase production capacities to reduce costs through economies of scale.

Integrating PV in a construction technological unit or subsystem requires an accurate performance assessment in accordance with construction norms and PV standards, depending on the type of use in building. Performances of construction kits are well described in building regulations. Harmonized standards originated from the Construction Product Regulation (CPR) determine the product quality, the design principles and the certification strategies in the EU framework. Moreover, these standards today refer to the Low Voltage Directive (LVD) where wiring or electrical connections are concerned. However, since standards derived from LVD are basically developed for conventional PV plants, there is still a missing gap if PV cells and related electrical components are included in a construction element. The regulatory framework actually does not include any specific reference to electrical limit states or to the presence of PV cells (e.g. as defined in IEC 61215) in building skin elements. Thus, when today a BIPV component is tested for use in building, there is some lack of information about the potential effects of electrical parts on building classification and performance, both in terms of safety and operation conditions. Vice versa, if such a component was tested as a traditional PV module, all the building related performance would not be considered. Even though the EN 50583 made a first step towards a normative harmonization, the complex and costly testing approach deriving in many cases from the separated application of LVD and CPR, due to the lack of harmonized procedures and the growing BIPV customization, are the strong missing gap and barrier for the market. Current research aims to provide an overview of the current normative framework in BIPV field, the definition of the relevant missing gaps, and the key aspects for grounding a new testing approach with a focus on flat glass products integrating PV cells[5]. Developing new testing procedures according to a performance-based approach and considering the aspects of multi-functionality is one of the key strategies under development in some projects such as H2020 BIPVBOOST[6] as well as at the international level such as in Task 15 IEA PVPS [7][8]. The implementation of these new qualification procedures, as a follow-up of this pre-normative research, is expected to provide a starting point to support operators and upgrade the normative accordingly, ensuring a higher product quality, helping to reduce costs and contributing to initiate a stronger penetration of BIPV in the construction sector.

Acceptance

A BIPV system/product is accepted by the stakeholders if it satisfies both the aesthetical aspects and functional/energy requirements. Today, a PV module on which cells are visible is categorically not accepted as architectonic material[1]. This shows aesthetical aspects are of primary importance for these stakeholders. Overall, the acceptance of BIPV buildings will be reached by acting at three different levels: final user, society and architects.

Final users: a BIPV product should be aesthetically pleasant, it should not compromise the operation of the building skin and the business plan must be cost-effective. A BIPV solution can increase the value of the building and it can be beneficially associated to a trademark by giving an eco-friendly and technological image.

Society: the potential of BIPV products and the validity of architectonic projects is already recognized. Furthermore, these processes are supported by social/political movements. The adapting time to technological changes of the building construction sector are usually long. New normative frameworks, and easy regulation as well as the right business plans would permit to attract new potential users and investors.

Architects: a BIPV system/product, in order to be accepted, should combine high flexibility in module dimensions, colours, distribution of the PV cells, and high energy production as well as cost effectiveness. This can be reached by ensuring the possibility to integrate the BIPV in the conventional cladding system, using the same installation solution. The active cladding is expected to be comparable to a traditional non-active material in terms of flexibility, safety and reliability. The electric production, sometimes, is even considered as a nice-to-have in this approach, rather than the main driver. All the features of a standard material (e.g. colour, transparency, aesthetic, thermal and noise protection) cannot be compromised or substituted because of the ability to produce energy.

BIPV as an integrated process

The optimization of the BIPV process, from the manufacturing stage to the installation stage, would permit to reduce the BIPV costs and capture new shares of the market. Flexible product concepts (such as back-rail mounting systems, allowing to compensate construction tolerance), could accelerate the time of installation and reduce the costs. Mounting systems or pre-assembled products that require less time for installation and reduce the need of experienced workmanship, are required by the stakeholders.

The planning process, that now represents an important share of the BIPV costs, could be simplified through the introduction of a digital process, including specific tools that permit to solve non-standard situations such as non-regular shapes and customized modules.

Today, the installation of a BIPV system often frightens façade makers, electrical installers, and in general the stakeholders of the traditional building process. The lack of experience and knowledge of architects and installers and the lack of coordination among the key partners (building owners, material suppliers and installers) should be solved (via a BIPV consulting service or a digital process) to ease the BIPV building process. Handbooks for certifications, installation details and tutorials could simplify the planning activities and the installation on site.

In addition, the BIPV stakeholders should be involved in the project in an early stage of the development process. This ensures that the BIPV must be forcibly adapted to an existing architecture. A cooperation from the planning stage between all the stakeholders, including the responsible of BIPV, could simplify the whole process.

BIPV and digitization

Digitization can help optimize distributed PV generation and facilitate its management but it can also be a valuable support in overcoming the fragmentation of the BIPV project development process that typically affects the sector. The adoption of a more open and collaborative workflow based on data-sharing among different stakeholders from the design till O&M, can play a key role to optimize the procedures and reduce costs, making the sector more competitive. The digital transition has been progressively implemented in the last 20 years in the construction sector trough BIM (Building Information Management), which demonstrated its effectiveness to support an integrated process based on a collaborative digital environment and data sharing, thus enhancing communication, quality and optimizing costs. Considering that the building envelope is today one of the most complex parts of a sustainable building, the "BIM-ization" of its construction process could potentially tackle the challenges associated with a more sustainable built environment. This is particularly relevant for multifunctional systems producing energy such as "solar skins". Typically, the building process is highly fragmented so that the information flow is not linear, many information are lost, missed or need to be re-entered with additional rework and request for information. An integrated and collaborative digital process would reduce efforts, time, repetitive work, risk of mistakes, information losses, etc., transforming an almost "manual" and fragmented work into an interoperable work-flow along the value chain. To be widely adopted, digitization of solar building envelopes requires dedicated specifications on information modelling/management, process workflows, interoperability aspects and a translation of objects into the BIM environment. The development of methods, models and tools is a crucial aspect to overcome the obstacles still existing towards a full "interoperability" between PV and building fields. Ongoing research is focusing on the development of reference process maps, Information Management approaches, LOD (Level Of Development) for e-objects and the design of software platforms mainly conceived for designing and analysing a BIPV system within a project environment along the real development process. Flexible, interoperable and attractive platforms capable to motivate architects in creating customizable elements since the early design phase until the more detailed project stages are needed to support design, engineering, energy and cost estimations. Many crucial innovations for the sector could be enabled by digitization, such as collaborative platforms and "digital twins" designed to reduce projects' risks and allow projects' teams to collaborate more effectively along the whole process, with real time access and data analysis from different devices, on a network or in the cloud, eventually helping to identify critical issues along the value chain. Key technologies such as big data analytics, artificial intelligence, Internet of Things, robotics, drones, blockchain, mobile connectivity, cloud computing, etc. are providing the framework to realize the ambition to combine the energy and digital transitions and to advance towards a solar building industry 4.0. Beyond technology, the expected result is to concretely support the sector by encouraging prosumer choices, improve flexibility and break boundaries (nZEB, BIPV, EV, grid), create new business models and foster the market to initiate the boost for BIPV industrial and R&D leadership.

Cost-effectiveness

One of the main obstacles to the development of the BIPV market is the higher upfront costs compared to conventional construction solutions, depending on the project. Moreover, conservatism, resistance to change and misperception of incumbent actors of the construction value chain (from product manufacturers to architects and general constructions companies) can also be evoked as obstacles to BIPV development. At the moment, these stakeholders have few interests in BIPV, as the volumes remain very limited and there are no legally binding constraints to develop this segment.

A BIPV system integrated into a façade or into a roof is often classified as a cost ineffective building solution. This happens when the BIPV envelope is directly compared with a similar non-photovoltaic solution (cladding in fibrocement, stone, glass, tiles, etc.) or with a conventional ground-mounted or roof-applied PV plant. In reality, if the integration in to building project and process is solid, the BIPV represents no more than an extra cost to make the building skin active. This extra cost can be considered as the "price" difference between the cost of the active cladding, plus the accessories to make it active such as electrical components, and the cost of a similar solution without the photovoltaic components (e.g. the same façade construction support such as a glass cladding without PV cells). The extra cost of a BIPV solution, in this form, assumes a realistic payback time, not exceeding a certain surcharge compared with conventional building skin materials. Of course, this approach requires to deeply understand and analyse the cost breakdown of a construction building skin solution, by considering PV just as a part of a more complex layering, including all the functional sub-systems and construction aspects. An in-depth analysis of this aspect will be developed in the next chapter.

Since most European countries abrogated or reduced the support schemes and incentives to PV systems, such as feed-in tariffs, it is necessary to maximize the self-consumption of the energy produced, in order to maximize the economic benefits of a photovoltaic system. Thus, a photovoltaic system should be designed considering the energy demand hourly profile of the building. A photovoltaic installation on an east or west oriented roof or façade, compared to a traditional south-oriented one, can for instance allow to better cover the morning and afternoon electric load peaks. To optimize the benefits of a BIPV system, a detailed business plan should be developed for each specific case study, including the analysis and selection of optimal scenarios in terms of cost/benefits. Hence, new tools for an easy and fast evaluation of the perfect business plan for each case study should be developed. Details related to the cost analysis will be developed within the next chapters.

Finally, the constraints imposed by the PV-related regulation can be mentioned. In most European countries, the possibilities to value the generated electricity of distributed PV systems remain limited. As a consequence, the design of profitable business models at manageable complexity levels is quite difficult, if only allowed by the regulation. Indeed, except if the building owner and occupant are the same person or entity, the administrative and legal burden to develop attractive business models (where the energy is for instance shared by multiple persons or entity in the same building or across different buildings) can be so restrictive or heavy that it consists in an insurmountable barrier. This aspect also significantly limits the potential for expansion of the BIPV market.

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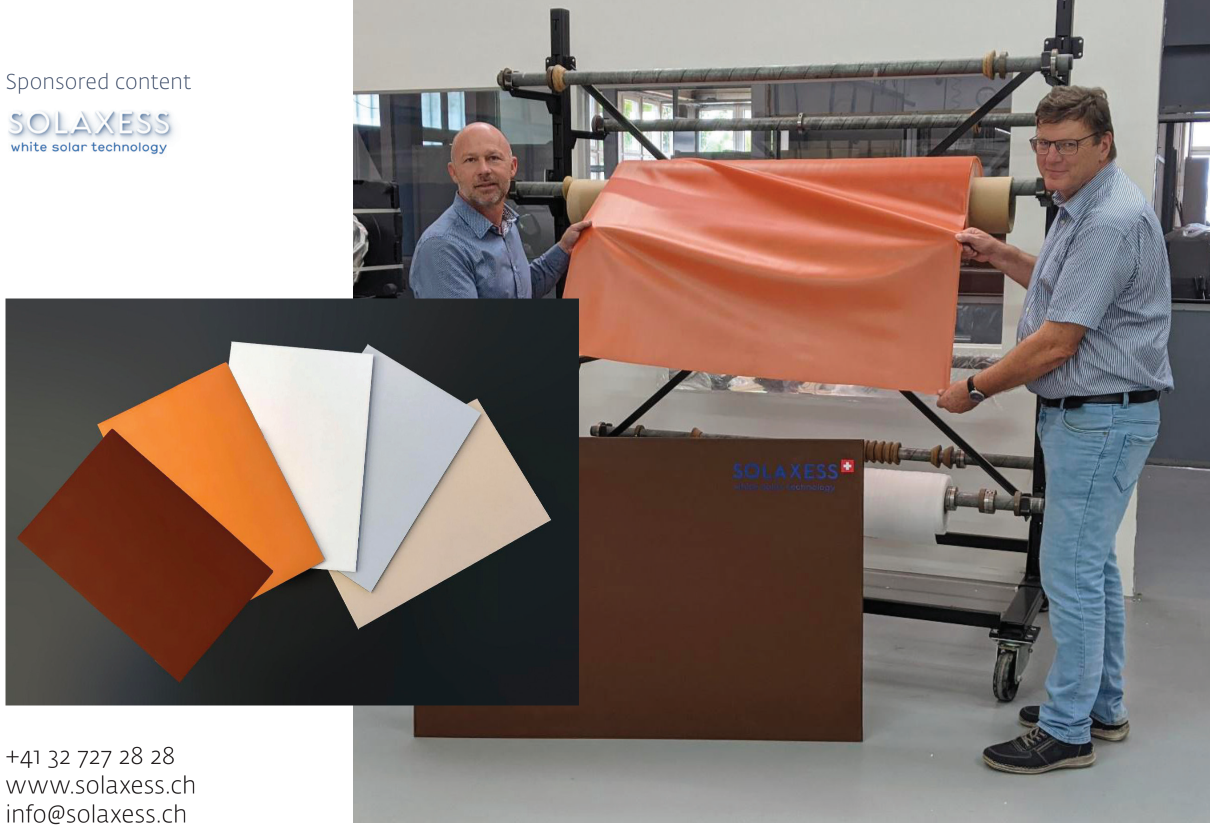

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CEO Sébastien Eberhard and COO Peter Röthlisberger with their films in terracotta at their entity in CH-Marin.

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More than 15 different colors will be produced in an adapted technology which is no more as the first films were. From white to grey, from red to blue, green to yellow, from terracotta to brown. No more limits for creating wonderful and activated facade-elements which cannot be detected as such.

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Architects, building owners and investors are equally satisfied:

Architects because their creativity to design buildings as per their intention is not hindered at all. Activated facades do look the same way as non activated ones.

Dummy modules are looking exactly the same way as real modules – no difference.

Building owners and investors can calculate a ROI and create new ways of leasing agreements and include the consumtion (and reduction) of the electrical energy into their contracts.

Big advantages also for the module-manufacturers: No change of their current manufacturing-process.

The application during the manufacturing process into or onto the pv-module becomes easy for every producer. It works with each and every pv-technology and -type – also on flexible modules.

We deliver our films in rolls which can be used by all automated or manual production equipments.

Cover our film with ETFE or glass – whatever you prefer. Smooth or structured surfaces can be realized.

Costs are cut down by 2/3 which makes it possible to get high values at low price.

3

Competitiveness and cost-effectiveness of BIPV in Europe

Among the challenges faced by BIPV, one can mention the lack of understandable means to evaluate BIPV's cost competitiveness. The difficulty to combine economic, energetic and architectural aspects can be repelling, especially for those who approach BIPV for the first time. Within this chapter, we focus on the economic aspect, which is still perceived by many as a barrier that limits the spread of BIPV systems, because of their higher upfront costs. More precisely, we will provide a methodology to evaluate the economic competitiveness of BIPV installations. In addition, the results of such cost competitiveness evaluation are presented, for various BIPV solutions across Europe.

What is BIPV cost competitiveness?

The competitiveness is defined as "the fact of being able to compete successfully with other companies, countries, organizations, etc."[1]. Thus, in this case, BIPV competitiveness could be defined as the fact of being able for a BIPV construction material, system, and electricity generating unit to compete successfully with other traditional construction materials, systems and electricity generating units. Here below four perimeters are presented that can be used to estimate the competitiveness of BIPV:

- The competitiveness as a **construction component**, i.e. single building component such as a cladding module or a tile.
- The competitiveness as a **construction system**, i.e. building envelope technological unit such as a cold façade or a curtain wall.
- The competitiveness as an **electricity generating unit**, i.e. focusing on the LCOE[2], which is extensively used for assessing conventional PV plants.
- Finally, a fourth type of competitiveness analysis can be conducted, providing a holistic project-based evaluation of the economic attractiveness of BIPV solutions. Indeed, this consists in an analysis of all cash-flows generated by a specific project, allowing to obtain an estimation of all costs but also all revenues associated with the BIPV systems on their operational lifetime. This fourth type of competitiveness is called "**total cost and revenues of ownership**" and will be the focus of this chapter. Indeed, such business model based on the valuation of the generated electricity, including a part of incentives when possible, represents the typical business model applied to BIPV installations[3][4]. It will be commonly referred to as BIPV competitiveness in the following pages. It is also important to highlight that these competitiveness assessments will focus exclusively on values that can be quantified. But other values linked to aesthetics, multi-functionality and environmental aspects, which are key advantages of BIPV, exist. These values can be a cornerstone of on-site renewable energy production, thus contributing to building stock's decarbonization. Although, these values cannot easily be quantified, as they are partially subjective or not easily accountable. Hence, they are not part of this evaluation.

Fig.1 Copenhagen International School, detail of the BIPV cladding. Credits: C.F. Moller Architects.

Status of BIPV cost competitiveness

Component-level competitiveness

On the ***Fig.2*** and ***Fig.3*** the costs of the basic active components used as part of the various cladding typologies, for roofs and façades are shown. It can be noticed than, on average, BIPV components are more expensive than conventional construction elements, especially for roofs. Nevertheless, in many cases, the cheapest BIPV products can also come at a lower cost than high-end conventional construction materials (e.g. slate tiles in the case of roofing solutions or stone and glass in the case of façades).

System-level competitiveness

In this section, the perimeter is enlarged and the cost competitiveness of BIPV systems is investigated. BIPV system's cost refers to the end user cost of the BIPV-based building envelope solution as a whole (***Fig.4***, ***Fig.5***). This includes the BIPV modules (the outer layer of the building skin used as cladding), as well as the other anchoring and mounting parts of the related building skin system, ensuring the complete functionality, safety and performance/normative compliance of the construction kit. For instance, in the case of a cold façade: frames, fixing clamps and load-bearing anchoring for a cold façade; or in the case of a cold roof: substructures for single ventilation chamber, water/windtight outer layer, anchoring to load-bearing slab, excluding insulation and other layers, flashings. This system cost also encompasses the electrical parts such as cabling and inverter(s), and soft costs such as labour (construction and electrical installation), transport of the components on site, planning/engineering and permitting. In the case of projects with high levels of complexity, additional parts can be required, pushing the prices even higher.

Globally, similar trends as for the component cost comparison can be observed, even though the gap has diminished for façade solutions. Except for the very competitive metal sheets-based roofing solution for industrial buildings, other conventional roofing solutions can be challenged by BIPV solutions. The BIPV solutions based on "in-roof mounting systems" in particular can be very competitive, as in most cases they are made of conventional PV modules, which are relatively low-cost. Roofing systems with tailor-made BIPV solutions are more expensive and regrouped in a specific category. They are more expensive than a conventional tiled roof but often provide the advantage of a better aesthetical integration, and possibly additional building-related functionalities, compared to the "in-roof mounting system". As far as façades are concerned, BIPV systems can be competitive with some conventional systems, or on the same level as high-end systems, such as glazed warm façades or stone opaque claddings. This result is understandable as the additional functionality of BIPV (electricity generation) compared to a conventional system is logically associated to an extra cost. In addition, it is interesting to note that the combination of a BAPV system with a conventional roofing system, by summing the orange bar and one of the light blue bars, can result in a substantially higher system cost than for a BIPV system. In the case of façades, the wide range of costs at system level can be explained by multiple factors. First, the variety of projects' characteristics that can exist on the market, including the size, type and thickness of the modules, the building skin technological alternatives, the complexity of the project, the location of the building or the size of the installation. Then, the local regulation, which can impact the permitting as well as legal and administrative planning, can increase costs. In addition, in some cases, financial incentives, direct or indirect, still exist due to the local regulation. These can benefit to BIPV systems, which can incite some stakeholders to increase prices in order to capture a share of these financial incentives.

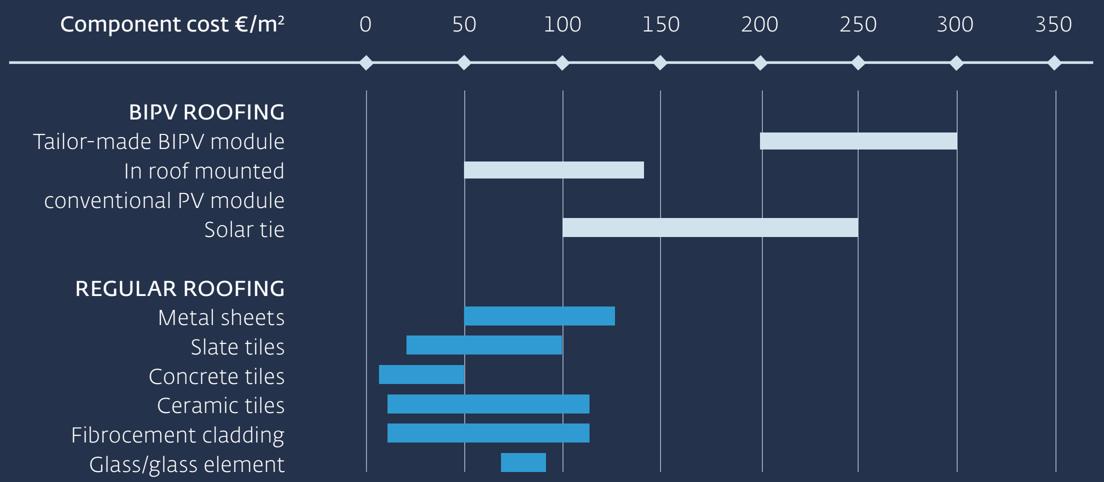


Fig.2 Component cost of BIPV and regular roofing.

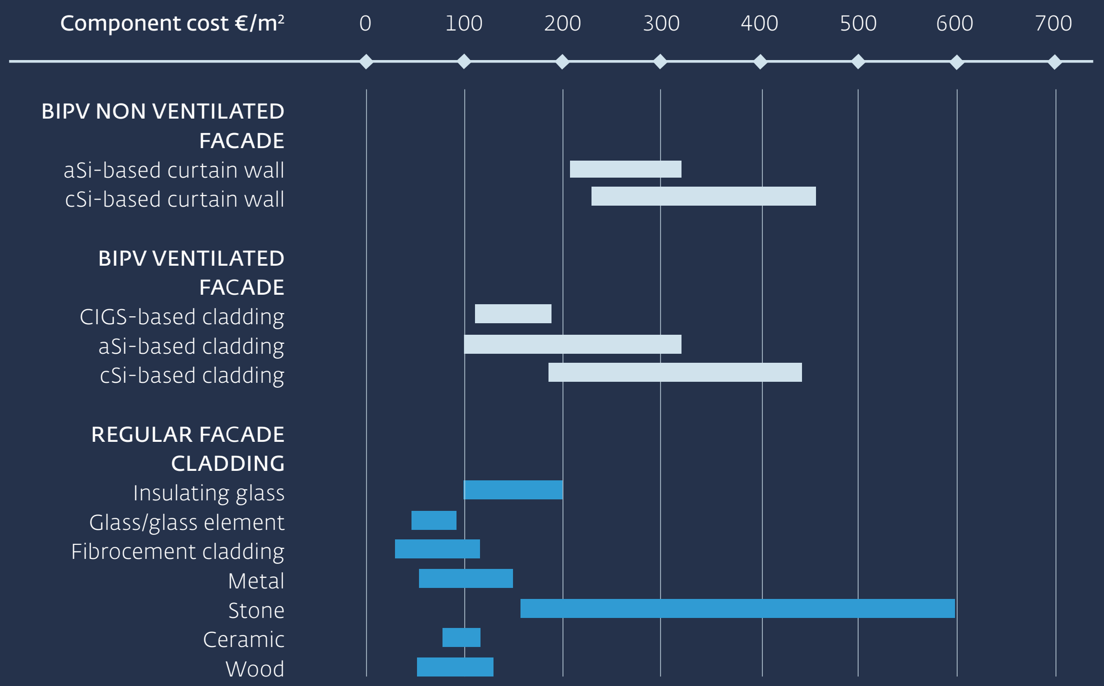


Fig.3 Component cost of BIPV and regular facades.

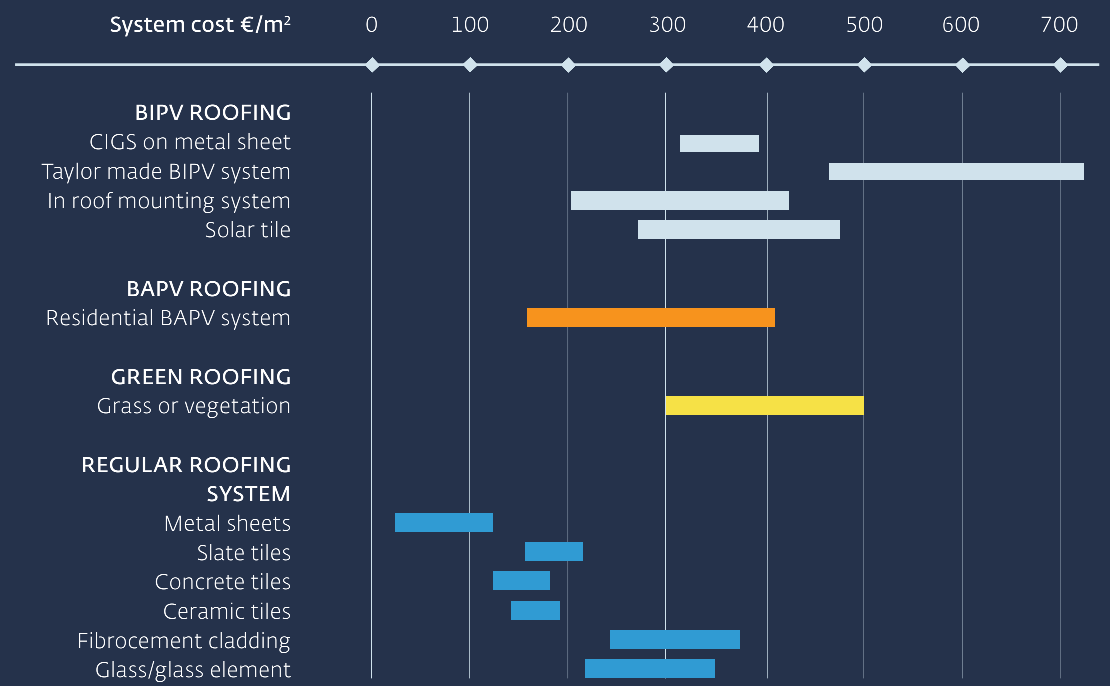


Fig.4 System cost of BIPV, BAPV and regular roofing.

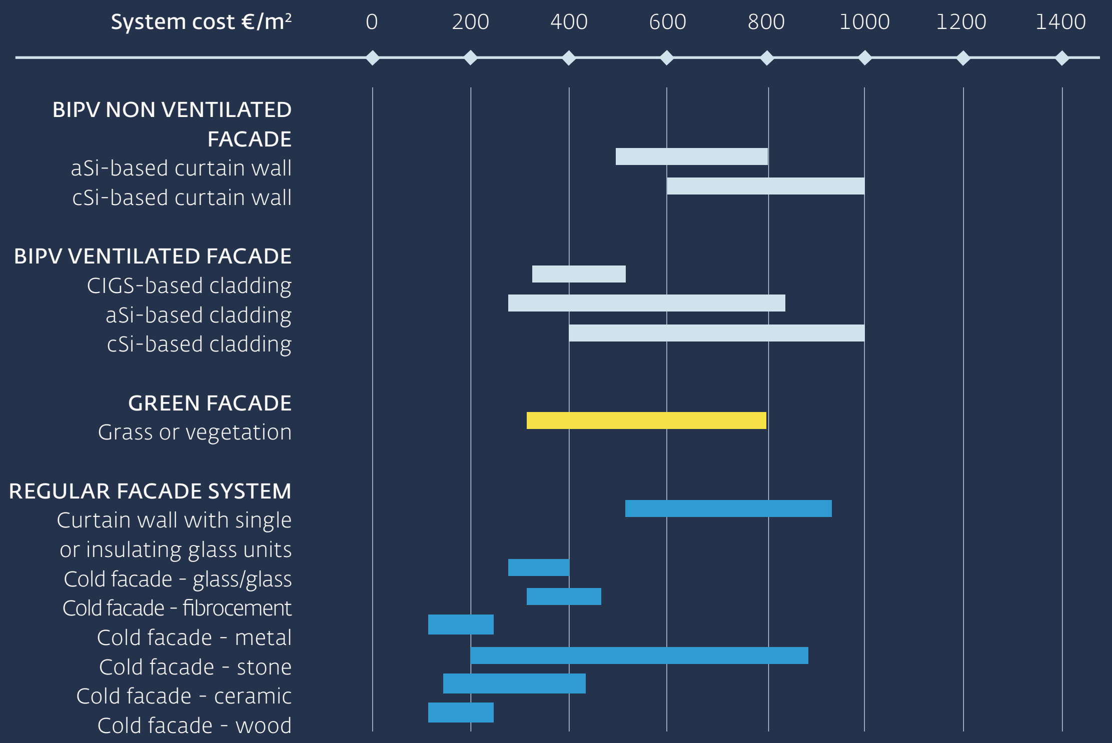
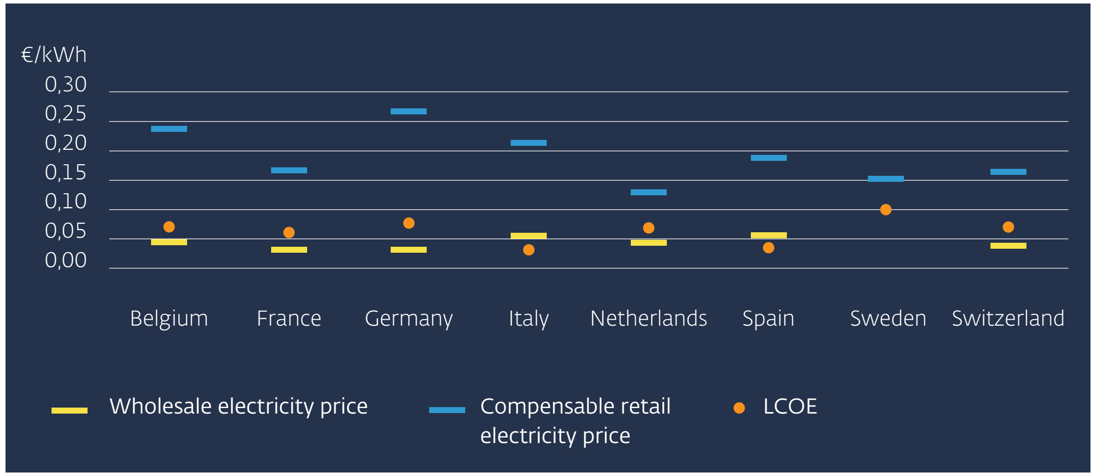


Fig.5 System cost of BIPV and regular facades.

Levelized cost of electricity (LCOE)

For this third comparison, the BIPV systems are assessed based on the average cost at which they can generate electricity, similarly to conventional PV plants. The results are then compared to the compensable retail electricity price and the wholesale electricity price. This latter is based on the average day-ahead spot price on the wholesale electricity market. Note that the notion of "compensable" retail electricity price is defined as the amount of money that can be saved on the electricity bill for each self-consumed kWh. In other words, this corresponds to the variable part of the retail electricity price as opposed to the fixed part. Then, the lifetime of the BIPV system is estimated to be equal to 30 years. This was chosen as it is the standard lifetime considered today on the PV market, and it is also coherent with the lifetime of conventional building envelope solutions (*Fig.6*). Results presented here are only partial, and are part of a larger study, available in a publication from the BIPVBOOST project[5]. The LCOE results for a roofing BIPV system on an archetypal single-family house across 8 locations in Europe show that, as an electricity generating unit, BIPV systems can be competitive. Indeed, the LCOE always lies below the compensable retail price. This means that each self-consumed kWh generates more savings on the electricity bill than what it costs to be produced. Yet, to benefit from these savings on the electricity bill, sufficient self-consumption rates are required. This is achievable through a detailed analysis and accurate conception of the solar skin architecture, in line with the building's energy consumption pattern, since the early-design stages, especially in the case of buildings targeting net or nearly-zero energy needs. Apart from some archetypal scenarios, due to the variety of building typologies and building skin situations such as façade integrated BIPV systems, conclusions are more difficult to draw. Indeed, the results highly depend on the type of building and the building skin technology, on the building envelope architecture and construction typology, morphology (volumes, surfaces segmentation/modularity, protruding parts, etc.), orientation, urban scenario, location and the profile of its occupants. Results from a recent research project show that when installed on multi-family houses, educational, commercial or office buildings, the LCOE of BIPV façade systems does not always compete with the compensable retail electricity price. Indeed, compared to roofs, façade installations are associated with lower yields, higher end user costs and higher operation and maintenance costs, which all penalize the LCOE results. Moreover, non-household customers often benefit from lower compensable retail electricity prices, thus increasing the gap with the LCOE. These disparities in compensable retail electricity prices can also explain some of the differences between countries, which can be of course amplified by solar irradiation gaps. However, some advantages can also be mentioned in the case of façade installations. One can mention the case of high-rise buildings where roof surfaces are not sufficient, or the case of buildings in which roofs are occupied for vegetation. In addition, BIPV façade can help to exploit different orientations and thus potentially enhancing self-consumption by optimally matching the intra-day consumption profile. Moreover, as conventional façade systems are already very expensive, BIPV façades can have a reduced initial extra cost. Finally, in many cases, achieving nearly-zero energy or plus-energy targets required the whole building skin to become active.

Fig.6 LCOE of a BIPV roofing solution on a single-family house.



Holistic evaluation of competitiveness

As previously mentioned, the last economic competitiveness assessment of BIPV consists in a project-based holistic evaluation, taking into account not only the total costs of ownership but also the total revenues. To do so, an analysis of the yearly cash-flows associated with the BIPV case study is first conducted, allowing to estimate all costs and revenues occurring over the lifetime of the system.

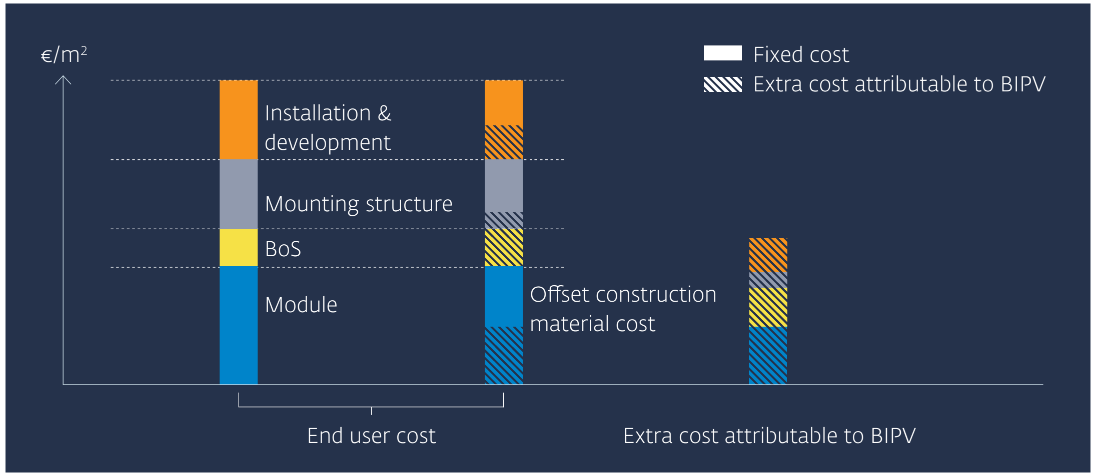
Focusing first on positive cash-flows, three main revenues can be considered:

- The revenues associated to the self-consumed electricity, which consist in savings on the yearly electricity bill, can be mentioned. For each kWh that is self-consumed, a saving up to the amount of the compensable retail electricity price can be made.
- The revenues due to the excess electricity that is fed-back to the grid are considered. The way this excess electricity is valued directly relates to the specificities of the regional or national regulation. Different business models exist and sometimes coexist within a country such as feed-in tariffs, green certificates, net-metering, etc.[6].
- Finally, a third revenue, related to the unique multifunctionality of BIPV solutions (i.e. as a construction material and an electricity generation unit) can be considered. Indeed, in addition to producing electricity, building integrated photovoltaics fulfil the functionalities of a building component. Therefore, BIPV systems replace conventional building envelope solutions and offset the cost linked to it. This aspect should be valued when assessing the competitiveness of BIPV. To do so, two different approaches can be taken, as described below.

Valuing the building-related functionality of BIPV

In order to quantify the value linked to the functionality of BIPV as a building material, a proxy can be used. This proxy is estimated by considering the avoided investment into a conventional construction material as a revenue. The amount of this revenue is calculated based on the value of a competing mainstream building component, i.e. its cost as a material. It is thus called the "offset cost of conventional construction material". To make sure this revenue is relevant, an alternative conventional construction component having similar characteristics to the selected BIPV element, in terms of aesthetics (colour, transparency, etc.), quality and functional contribution to the building envelope (fire safety, insulation, etc.) must be chosen. In the following pages, the offset construction components considered for each reference case and their associated cost are presented along with the remaining characteristics of the reference cases.

Fig.7 Schematic view of the determination of the extra cost of BIPV.



Extra cost approach

Going one step further than the value-based approach described above, an extra cost approach can be applied. This is based on the logic that the competitiveness of BIPV should only be assessed based on the extra cost that BIPV represents compared to a competing conventional building envelope solution (***Fig.7***). Indeed, some costs such as transportation or installation costs, or even some material costs, would be incurred in any case, at least to a certain extent, should the building envelope solution be conventional rather than BIPV-based. Hence, for each cost item of the total end user cost of the BIPV installation, it is necessary to determine what share is exclusively due to BIPV. While module costs are largely attributable to BIPV, installation and development costs are only partially attributable to BIPV, among others.

For the purpose of this extra-cost approach, the structure of the end user cost of a BIPV system must be investigated. It can be broken down into four main categories: materials, labour, logistics and indirect costs (***Fig.8***). The material costs remain the most important cost item, led by the module cost. Among the cost items exclusively due to BIPV, one can mention the costs due to the grid connection or electric materials such as cabling or the inverter(s). Among partially extra costs are a share of the costs due to permitting and the administrative and legal planning. A part of the BIPV module is also considered as an extra cost, estimated using the offset cost of construction materials. This cost breakdown approach is based on different studies[5][7].

Eventually, the net present value (NPV) of the BIPV project is calculated, by summing identified costs and revenues for each year and discounting the result back to the base year to obtain their present value. The result obtained in € can then be converted into €/m² which is a metric more commonly used in the construction sector. Thus, a positive competitiveness indicates an economically attractive project, as its owner/user earns money for every m² installed. A negative competitiveness, on the contrary, indicates that investing in such system is not economically attractive as the costs surpass the revenues. **Therefore, the competitiveness allows to determine whether an investment in a BIPV system is attractive or not, compared to investing in a competing conventional building envelope solution**.

$$Competitiveness = -I_0 + \sum_{i=1}^{system\ lifetime} \frac{(revenues - remaining\ costs)}{(1+d)^i}$$

Where I_0 is the extra cost due to BIPV calculated as explained before, i is the year, and d is the discount rate, often the weighted average cost of capital (WACC).

Within the ***Fig.9*** a list summarizing the key steps to follow in order to define the economic competitiveness of a BIPV solution is presented. One should note that in a conventional construction system, the economic competitiveness is typically negative. Indeed, no energy is produced thus no revenues are generated, whilst only maintenance costs occur on the lifetime of such system.

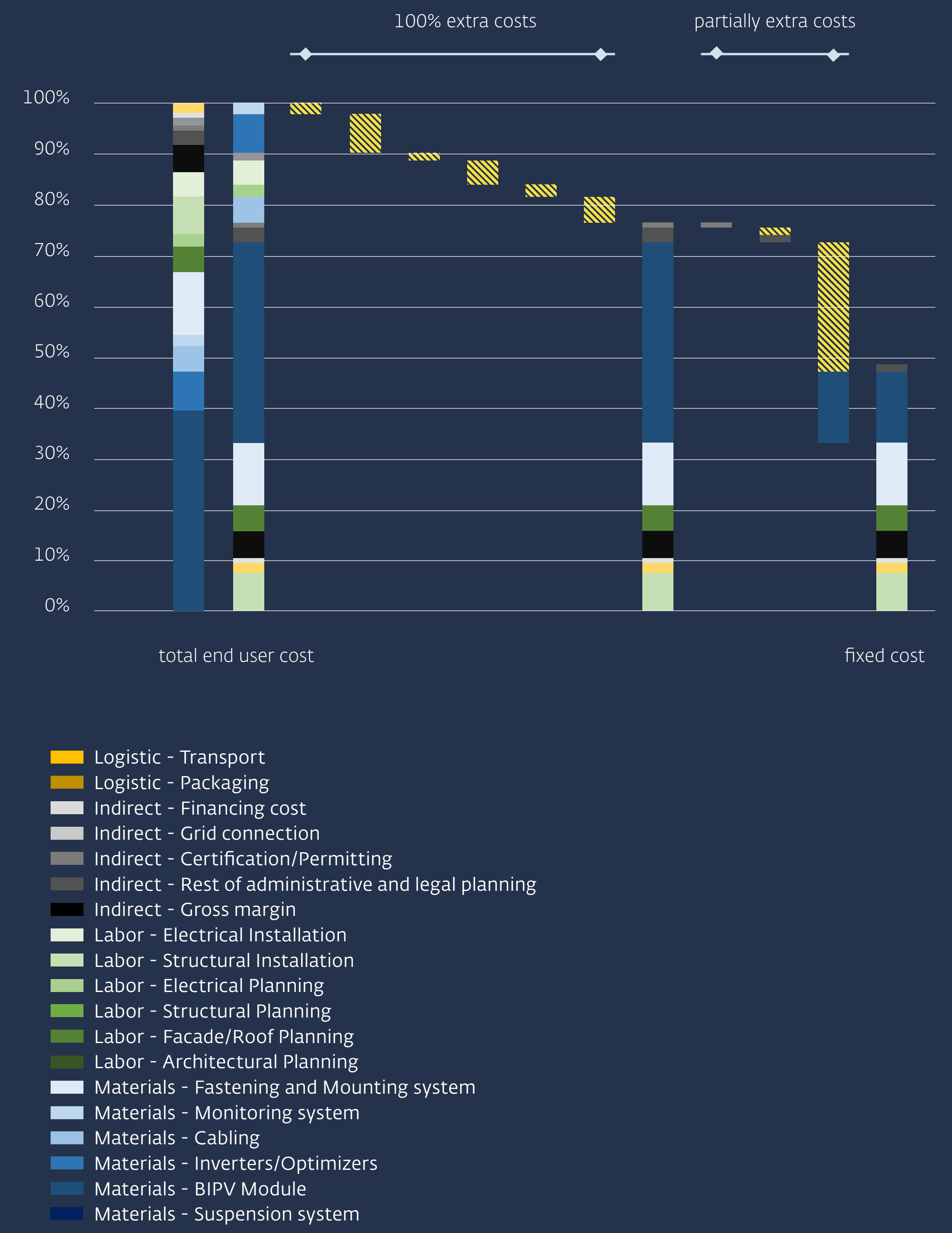


Fig.8 Example of the cost breakdown of a BIPV residential roofing system (Assumptions: Roof typology: single pitched roof of regular and modular shape without chimneys or other obstructions; PV plant power capacity: 5 kWp; BIPV system typology: PV tiles; no BIPV customization; roof complementary parts considered (flashings, roof finishing, etc.). Source: BIPVBOOST project deliverable D1.1[5].

Make an inventory of all costs over the system's lifetime

End user cost (I_0)
In order to apply the extra cost approach you need to determine the part of the BIPV end user cost that is attributable to BIPV

Operation and maintenance costs

Taxes and fees (if applicable) (amount and duration)

Make an inventory of all revenues over the system's lifetime

Investment support (amount and duration)

Saving on the electricity bill for the self-consumed electricity
Determine the variable part of your electricity bill.
Determine your projected annual production via a dedicated software (ex: BIM Solar).
Determine the part of your production that will be self-consumed (typically 30% in the residential segment)

Remuneration for the electricity that is fed-back to the grid (amount and duration)

Determine the remaining parameters

System lifetime
Typically 30 years

Discount rate (d)
Typically 2% in the residential segment

Fig. 9 Parameters checklist to evaluate the competitiveness of a BIPV project.

Results of holistic competitiveness assessment

To provide an overview of the competitiveness levels that can be achieved for some typical BIPV installations, four reference cases have been defined. These reference cases are representative of commonly observed architectural characteristics of the European building stock. The main parameters allowing to grasp an overview of the studied reference cases are presented in the ***Tab. 1***. A more exhaustive presentation of the reference cases including technical aspects (e.g. PV system's degradation rates), regulatory aspects (e.g. electricity prices, subsidies) or financial aspects (e.g. weighted average cost of capital) is available in a publication from the BIPVBOOST project[5].

The competitiveness analysis has been conducted for all four reference cases in four selected geographical locations across Europe, following the extra cost approach. Under such approach, an investment in a regular cladding solution would yield a NPV of 0 as both the extra cost and the revenues of this project would be null. This value can be used as a comparison point.

Tab. 1 Reference cases' main characteristics presentation.

Building typology	Unit	Single family house		Office building	
Technological system	[-]	PV tiles	In-roof mounting system	Ventilated façade	
PV technology	[-]	Mono c-Si PERC		CIGS	Mono c-Si PERC
Capacity installed	[kWp]	6	8	36	41
Surface covered	$[m^2]$	50		270	
Self-consumption rate	[%]	30%		90%	
Yield range for considered countries	[kWh/kWp]	[850 ; 1430]		[600 ; 930]	
End user cost (without VAT)	$[€/ m^2]$	332	208	412	462
Offset construction material (OCM)	[-]	Ceramic tiles		Stone	
Cost of OCM	$[€/m^2]$	45		150	
End user cost (extra cost approach) (without VAT) (I_0)	$[€/m^2]$	172	91	132	166

As shown on the ***Fig. 10,*** roofing BIPV solutions in the residential segment are globally already competitive or close to reach the competitiveness threshold. Particularly good competitiveness results are achieved for the in-roof mounting systems which have a both a better system power surface density and a lower end user cost than competing solutions based on PV tiles. Note that the difference of results between France and the Netherlands can be explained by the reduced VAT applicable to residential systems in the Netherlands, as well as the advantageous support scheme applicable for installations smaller than 15 kWp, called net-metering, which remunerates the electricity sent back to the grid at the full retail electricity price. In any case, it is clear that in all analysed countries, and for the two types of BIPV systems, it is more attractive to invest in BIPV than in a conventional roofing solution. Indeed, in all cases, the generated electricity largely covers the marginal extra cost due to BIPV and even generates revenues, resulting in a benefit of more than 200€ per installed square meter of BIPV (when considering the entire lifetime of the system), in the case of an "in-roof mounting system".

Then, the results for the considered façade BIPV systems are more mixed (***Fig. 11***). Out of four cases, two do not reach competitiveness. Overall, the contrast with BIPV systems on roofs can be generally explained by surface exposure and orientation (leading to often non-optimal irradiation conditions) on the façade as well as substantially higher than average end user costs in the analysed cases. Under the assumptions made for the reference cases, in the case of Italy, the positive results can be explained by the high irradiation as well as relatively high retail electricity prices. In the Netherlands, the compensable retail electricity prices are quite low, and irradiation is less optimal than in southern European countries. A similar explanation can be given for France, where an irradiation for the centre of the country was taken. The case of Switzerland is specific, as the BIPV installations benefit from direct incentives, which is the main factor explaining the very positive results. Also, the electricity fed-back to the grid benefits from a relatively generous feed-in premium.

Note that in the presented examples, optimal orientations where considered. But in the case of retrofit projects, where pre-defined and non-optimal surfaces of the building skin are available for PV integration, BIPV design options are limited. Such restraints also include architectural, typological and construction aspects, both at urban and building level. For BIPV façades, some limitations in existing urban areas (shading, non-optimal orientation, etc.) are the typical boundary conditions, which can be moderated through design and technical decisions. At urban level, it is possible to define a series of limitations for PV installations due to the intrinsic physical characteristics of urban environments (morphology, density, presence of obstacles, value, etc.). For what concerns the building scale, the integrability of BIPV can significantly differ depending on the building typology (functional, dimensional, distributive and organizational features, building size and geometry/shape and geometry of the façade, window to wall ratio, year of construction, etc.). This means that the architectural design and a careful typological analysis, both at an urban and building scale, along with a detailed component engineering from PV module/system to building/electrical level, can make the difference. These should be embedded in an integrated process and collaborative approach, to effectively support the economic and technical feasibility by overcoming the major constraints/limitations of the urban/building integration[8]. Moreover, it has to be highlighted that the realization of a BIPV system, and this applies to both retrofit and new buildings projects, has also better gains when combined with an intervention of refurbishment, because numerous works and costs in common (scaffold, insulation, construction site, etc.) can reduce the added cost and labour efforts. In the next chapter, some retrofit case studies are presented and analysed in details.

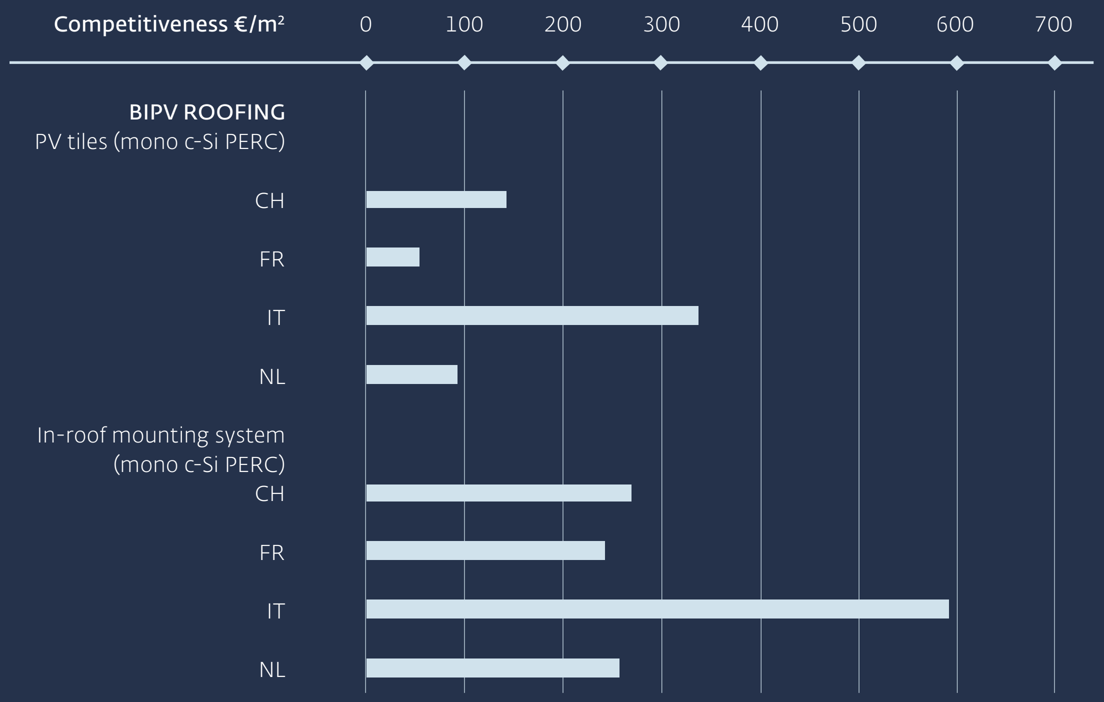


Fig.10 Competitiveness results under the extra cost approach for BIPV roofing solutions

Fig.11 Competitiveness results under the extra cost approach for BIPV facade cladding solutions.

Most influencing parameters of BIPV competitiveness

The ***Fig. 12*** presents the results of a sensitivity analysis on key parameters of the BIPV economic competitiveness evaluation. These parameters have been tested individually. It allows to identify which of them have the most influence and should be focused on, in order to improve the competitiveness of BIPV systems. This is for example of most interest in the case of façade BIPV installations. Indeed, as shown in the previous pages, it is more challenging to reach competitiveness in such configuration, as the production of electricity is reduced due to the vertical position.

Unsurprisingly, the most influential parameters among the eight tested ones are the module efficiency and the yearly yield of the system, i.e. the kWh produced per kWp installed. In other words, all other parameters remaining equal, increasing the module efficiency by 10% allows to increase the competitiveness of the BIPV installation by 30%. The same conclusion can be drawn for the yield. However, in a conventional BIPV process, acting on these parameters is very often uneasy. Choices related to the PV technology are typically a design starting point (e.g. choosing the family of c-Si or thin film due to aesthetical or functional reasons) but power optimisation is not really the main goal of an architect. In some cases, the transparency level of semi-transparent applications (such as curtain walls, skylights, etc.) can be a design element but installed PV capacity is only one of the variables for architecture and building skin performance, along with the visual comfort, daylighting design, heat gain protection, etc. Similarly, the yield is mainly related to the location (geographical area, albedo, etc.), to the local urban environment (topography, site orientation, urban density, urban elements and obstructions, etc.) and to the building typology (surface exposure, orientation, building morphology, etc.) which are all part of the same design process within which solar optimisation is one of the many variables.

Following these two factors, the most impacting parameters to maximise benefits are the **end user cost** and the **self-consumption rate**. Indeed, the economy on the electricity bill allowed by a produced kWh is always higher or equal to any incentive, so that increasing the self-consumed electricity significantly increases the revenues. For example, by increasing the self-consumption rate from 30% to 33% (i.e., a 10% relative increase, as shown on the graph), the competitiveness of the BIPV installation will increase by almost 20%. It is thus crucial to ensure that the configuration of the BIPV system, which influences the electricity it will generate, allows to fit the electricity demand of building occupants. Finally, an increased system lifetime would also greatly benefit the competitiveness results of BIPV. An integrated design approach where BIPV enters the project development process since the conceptual stage is the key-approach.
Studying the influence of the abovementioned parameters is also relevant as diverse innovations are being developed across the BIPV value chain, with expected positive impacts on these parameters in the near future. Which would induce competitiveness improvements, as presented in the following section.

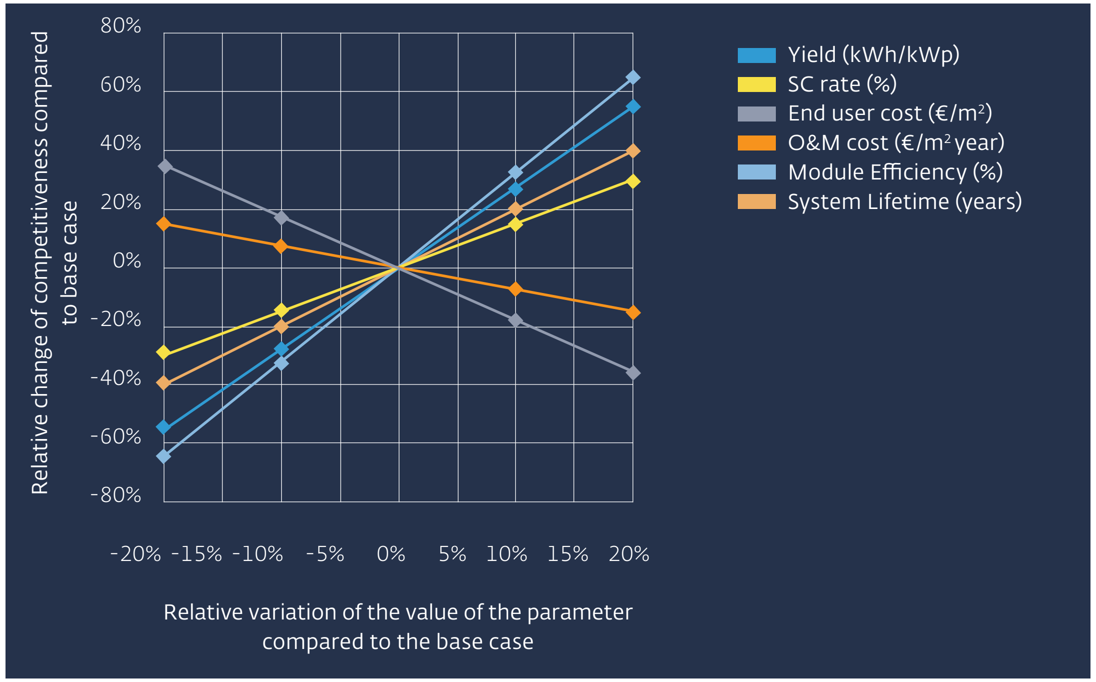


Fig.12 Sensitivity analysis on main influencing parameters.

Outlook

The future is promising with many sources of improvements in the BIPV sector, which could eventually positively impact the competitiveness of BIPV solutions. These improvements may arise from the BIPV sector specifically, but not only. Indeed, as the BIPV sector is positioned at the intersection of the PV sector and the construction sector, improvements related to these sectors can also benefit BIPV.
Two main types of improvement can be highlighted: technical innovations and market maturation improvements. Two examples per improvement category are presented along with the KPI (Key Performance Indicator) they impact. A more detailed overview of these can be found in another report[5].

As shown on the ***Fig. 13***, ***Fig. 14***, ***Fig. 15***, the four selected improvements allow to significantly decrease the total end user cost of the BIPV solutions, i.e. by 10% to 25% depending on the considered system. This shows that with the right efforts from all actors across the value chain, as well as of policy-makers, the cost of BIPV can be substantially decreased. Which would also improve BIPV competitiveness, as shown on the ***Fig. 16***. Note that for this competitiveness assessment, the improvements in terms of module efficiency have been considered, in addition to end user cost decreases.
Indeed, results show that the four considered improvements allow to significantly improve the competitiveness results. Four cases remain uncompetitive, yet the competitiveness threshold is within reach. As the four presented improvements are only some selected examples among a wide variety of potential innovations arising from the PV, the BIPV and the construction sectors, it is likely that the remaining improvements could contribute to reaching this threshold. Eventually, the combination of all potential improvements could lead to an end user cost decrease of 19% to 34% depending on the considered BIPV system by 2025 and of 35% to 62% by 2030. Thus, greatly benefiting to the competitiveness of BIPV solutions in Europe, which can be positive for the presented reference cases by 2030 if technical innovations keep on being developed, and if the right regulatory environment is set by policy-makers[5].

Technical innovations:

Improvement of substructure for BIPV modules for façade applications. (TI_1)

Through less complex and lighter mounting systems, the total end user cost can be decreased.
Indeed, the lower complexity diminishes the manufacturing and the installation time of those systems, while a lower weight allows cost reduction for the logistics and transportation.

KPI impacted:
- Substructure cost
- Installation time
- Transport and logistics cost

Improvement of BIPV module (based on crystalline silicon cells) manufacturing. (TI_2)

Increasing the automation level of BIPV modules based on crystalline silicon cells production lines allows to achieve gains in terms of production time, precision and fault detections without lowering flexibility. Thus, module production costs are reduced while their quality is enhanced allowing better performances and durability.

KPI impacted:
- Module cost
- Module efficiency
- System lifetime

Market maturation improvements

Simplifying administrative and legal procedures (MM_1)

Through more transparency, efficiency, standardization, use of online tools and engagement of local dialogue, the time required for administrative and legal procedures such as permitting delivery, certification delivery or grid connection authorisation, can be significantly reduced.

Impacted KPI:
- Legal and administrative planning costs

Improving the acceptance and knowledge of professionals (MM_2)

By optimizing the information circulation between the different and numerous stakeholders along the BIPV value chain, collective awareness and knowledge can be increased thus decreasing the end user cost. Developing guidelines on BIPV could also help stakeholders involved in the design and installation of BIPV solutions to become more acquainted with this technology.

Impacted KPI:
- Customer acquisition cost
- Workload associated to design
- Installation time

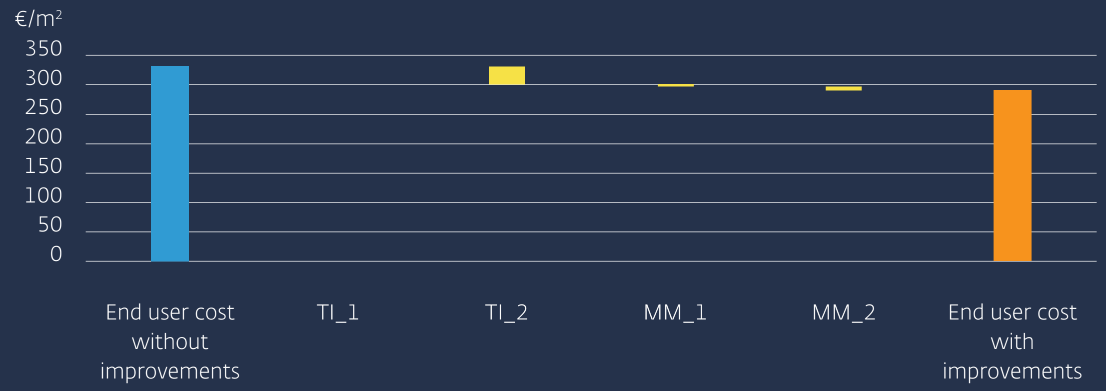


Fig.13 Impact on selected improvements on the end user cost for a PV tiles BIPV system.

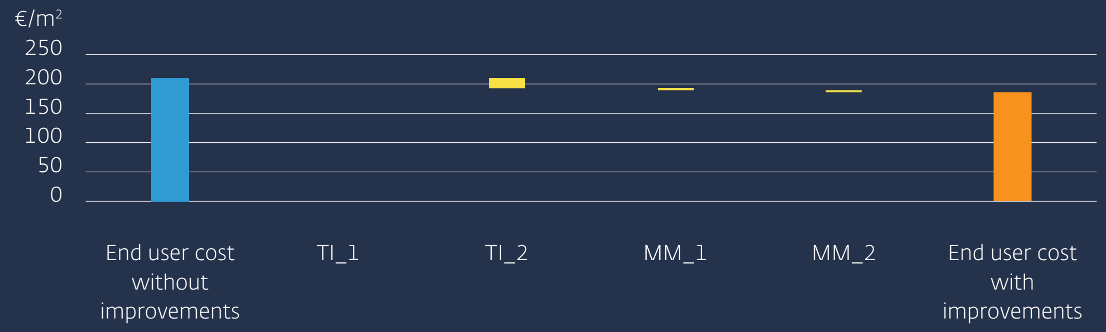


Fig.14 Impact on selected improvements on the end user cost for an in-roof mounting BIPV system.

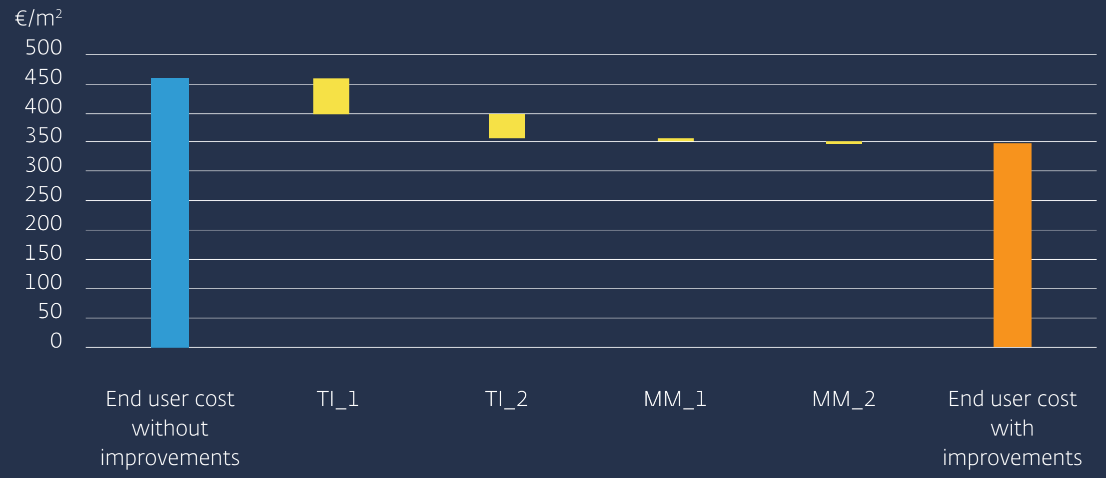


Fig.15 Impact on selected improvements on the end user cost for a ventilated façade BIPV system.

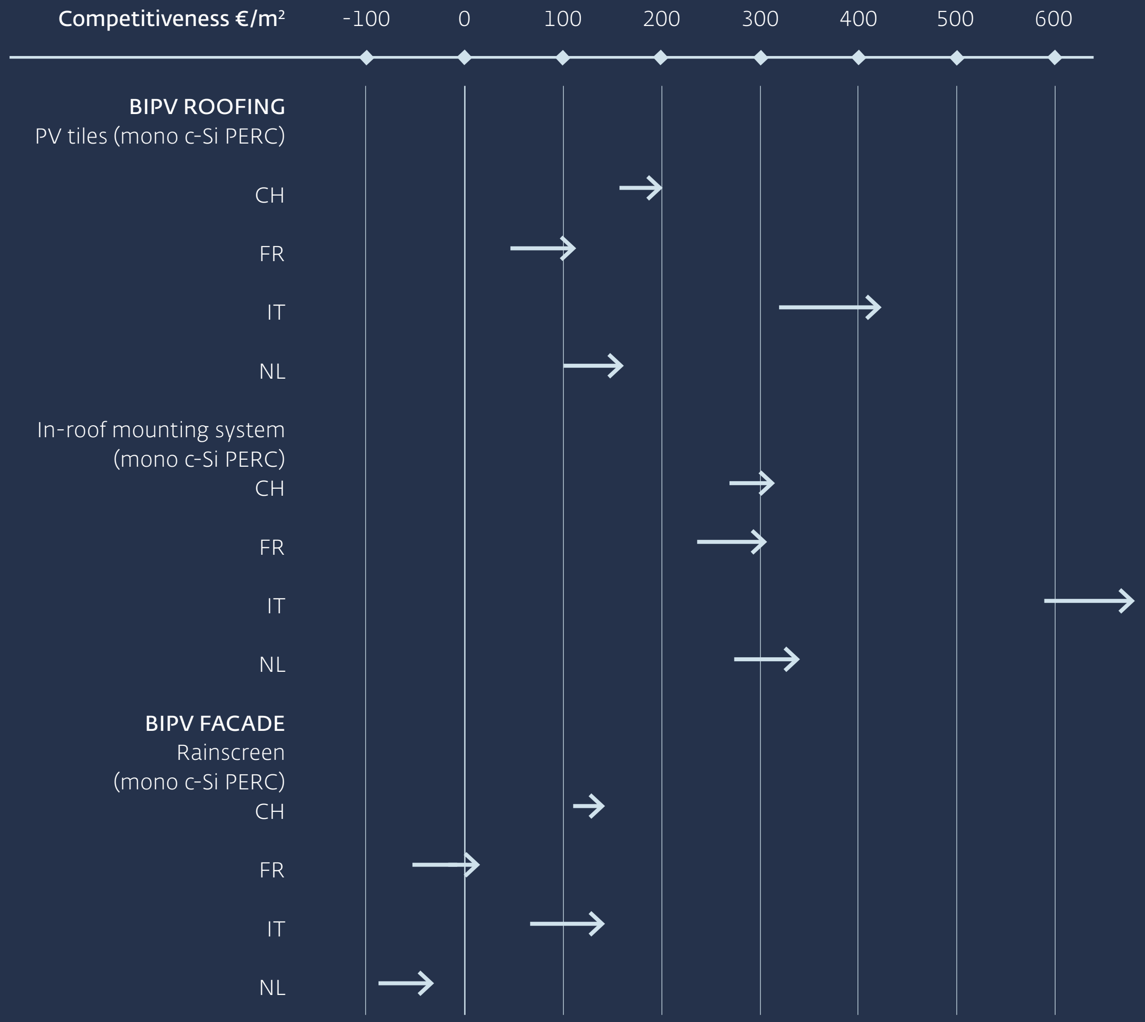


Fig.16 Competitiveness increase thanks to the four selected improvements with the extra cost approach.

Key takeaways

In this section, the cost competitiveness of BIPV was analysed and discussed, which allowed to highlight some key trends.

First of all, unsurprisingly, investing in BIPV solutions still induces a higher upfront cost compared to conventional building envelope solutions, at the level of the material itself as well as at the level of the system. Although, some BIPV solutions can be competitive, on a pure cost basis.

While conducting such cost-based comparison provides valuable information, it is limited by the fact that it fails to consider the benefits that BIPV can bring on its lifetime. Thus, a methodological approach which allows to assess the economic attractiveness of BIPV on a project-based approach, and considering the entire value created on its useful lifetime, has been presented with clear guidelines.

Based on this approach, it was demonstrated that the extra cost due to BIPV, compared to a competing conventional building envelope solution, can be covered by the additional revenues linked to this unique "active" characteristic, in many cases.

In the cases where this competitiveness is not reached yet, improvements of various factors can have great positive impacts. If policy-makers improve the regulatory frameworks impacting BIPV systems, and if all stakeholders keep on working together strengthening a strategic solar value chain, from researchers to installers, BIPV solutions could also become competitive investments compared to conventional building envelope solutions, in most countries and under many configurations, by 2025 already[5].

Since the built environment remains a strategic research and innovation domain in view of the goal of full decarbonization by 2050, the priority is today the design and construction of new buildings, or the retrofit of existing ones. This will contribute to reach (net) zero emission and positive energy buildings within sustainable neighbourhoods. In this shift of paradigm for the building stock, as well as within the overall energy transition, the on-site production of renewable energy is a major component. Hence, BIPV has a key role to play thanks to its unique features and benefits that conventional materials cannot compete with. Finally, it is worth reminding that the value of BIPV is not purely the economic value from electricity generation; it can also be connected to contributing to the local transition of the energy system, locally produced electricity, sustainability and marketing.

The value of BIPV can be leveraged by companies willing to highlight a vision or mission that reaches beyond profit-oriented goals. Also, as a building component, BIPV can provide the same or better building functionalities as other building materials and help at the same time to meet legal requirements in terms of energy performance of buildings. In addition, a BIPV system can be preferred to a conventional rooftop PV system in some cases, for example if the roof is already occupied for other usages, such as HVAC. Finally, the potential ability of BIPV solutions to improve real estate value can be evoked as well, increasing the attractiveness of such investments, provided that the involved stakeholders can take advantage of this value[3][4].

Sponsored content

SOLAXESS
white solar technology

Multifamily house in Männedorf, Switzerland

100% nice active façades

Completion year	2020
Architect	René Schmid
White PV manufacturer	New ISSOL, Belgium
Building typology	Residential
Category	New building
Total installed PV power	>80 kWp

+41 32 727 28 28
www.solaxess.ch
info@solaxess.ch

April 2020: realization in Männedorf (Zurich), CH.

This multifamily house, designed by the architect René Schmid, combines the latest innovations in terms of energy production. In addition to heat pumps and a high-efficiency energy management system, the two buildings consist of 900 m^2 of photovoltaic panels installed on the façade.

Aesthetic strenghts

- Building whose façades are 100% active, both the rust brown and the white parts;
- Respect of the contrasts desidered by the architect René Schmid;
- The authentic character of the building is preserved thanks to the use of the latest photovoltaic technologies.

Simple integration into PV modules

- The film is simply added over the PV cells when the module is laminated;
- This technology ensures perfect uniformity and excellent stability;
- Solaxess supplies films in different colors for the integration of photovoltaic panels in façades.

White panels technical data

- Active façade of 90 m^2 white photovoltaic panels per building, using Solaxess technology (>9 kWp);
- Multiple PV panels dimensions up to 2.060 x 1.100 mm;
- Glass/glass modules, frameless, ETFE finished, 4mm tempered glass;
- Up to 210 Wp per panel;
- PV module manufacturer: New ISSOL, Belgium.

Peter Röthlisberger, COO Solaxess

4

Residential and administrative building, Lugano

Rainscreen, 2018

Building and system description

In 2018, Zurich Insurance decided to retrofit the building envelope of its seven floors tall agency in a densely populated district of Lugano, Switzerland. The client required cost-efficient solutions compatible with the energetic standards required by the local energetic normative. A new cold façade with three different cladding typologies has been installed, including a glass/glass BIPV cladding, a composite lightweight cladding and a green façade.

The design of the BIPV façade aims to maximize the energy production rather than the architectonic design of the building envelope. A c-Si glass/glass cladding solution, defined as "opaque glazed BIPV solution without thermal properties", was adopted. The morphology of the neighbour buildings creates important shadows during the year on the three façades of the building envelope to which the BIPV system is integrated: South, East and West.

The multi-orientation of the system, the attempts to maximize the energy production and the use of standard PV modules places this building in a position between two of the identified groups, namely, "architecture of standard PV" and "energy integration: BIPV as a building's skin material".

The BIPV cladding surface covers about 150 m² of the building envelope with a peak power installed of 25,5 kWp divided into three similar stripes installed on the three façades. No particular layers or films are used to colour the modules that result black and homogeneous.

Building typology	-	MFH/Admin.
Technological system	-	Cold facade
Active cladding surface	m²	150
Orientation	°	West; East; South
Tilt	°	90
Nominal power	kWp	25,5
System power density	Wp/m²	170

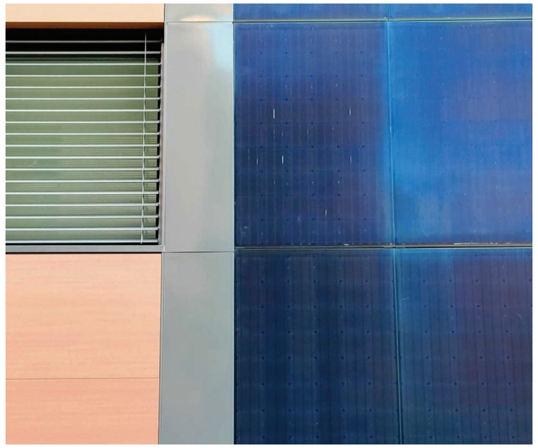
Tab. 1 System features.

BIPV technology	-	Opaque glazed BIPV solution without thermal properties
PV technology	-	Mono c-Si
Degradation rate yr 0	%	1,80
Degradation rate yr >0	%	0,45
Customization in size	-	No
Customization in colour	-	No

Tab. 2 Product features.

Fig. 1, 2 General view of the building after and before the retrofit of the facade. Source: P. Corti.

Fig. 3 Detail of the BIPV façade. Source: P. Corti.



Energetic evaluation

The morphology of the urban context defines the configuration of this solar system, that aims to maximize the energy harvesting. The consequence is a multi-oriented system. The presence of nearby buildings drastically reduces the operation of the solar system during the summertime, due to shadowing. If in winter the southern oriented PV façade produces a large amount of electricity to satisfy the energy needs (mainly heating), in summer the combination of the three façades provides the electricity for the cooling system (*Fig.4*). This smart combination optimizes the self-consumption by avoiding peaks of electricity production, which are typical of south mono-oriented PV systems.

The ***Fig.5*** shows the energy produced by the analysed system on the 29th of July, a clear sky day. The total amount of energy produced is quite flattened throughout the day without any major peak during the day. A negative peak is visible from 1pm to 3pm but no high electricity need is necessary during that time period for an administrative building. The energy produced by the East façade covers the morning needs, while the South and West façades cover the afternoon needs. In addition, this flattened production curve allows to obtain a better match with the energy demand curve, thus increasing the self-consumption rate and consequently, increasing the revenues.

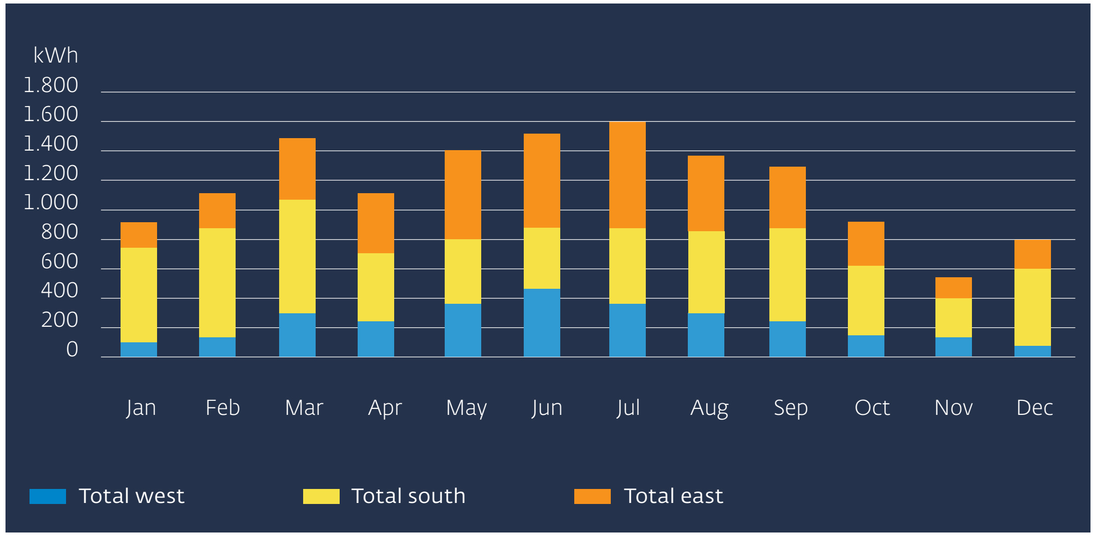
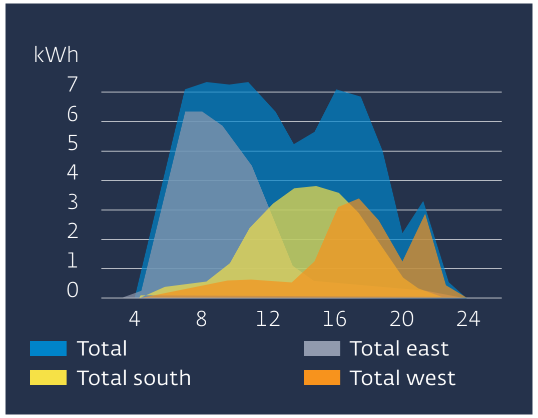


Fig. 4 Monthly energy production by orientation.



Energy production	kWh/yr	14.245
Average yearly yield	kWh/kWp	559
Energy demand	kWh/yr	38.782
Self-consumption	%	100
Self-sufficiency	%	37

Tab. 3 Energetic features.

Fig. 5 Daily energy production by orientations (29th July).

Economic evaluation

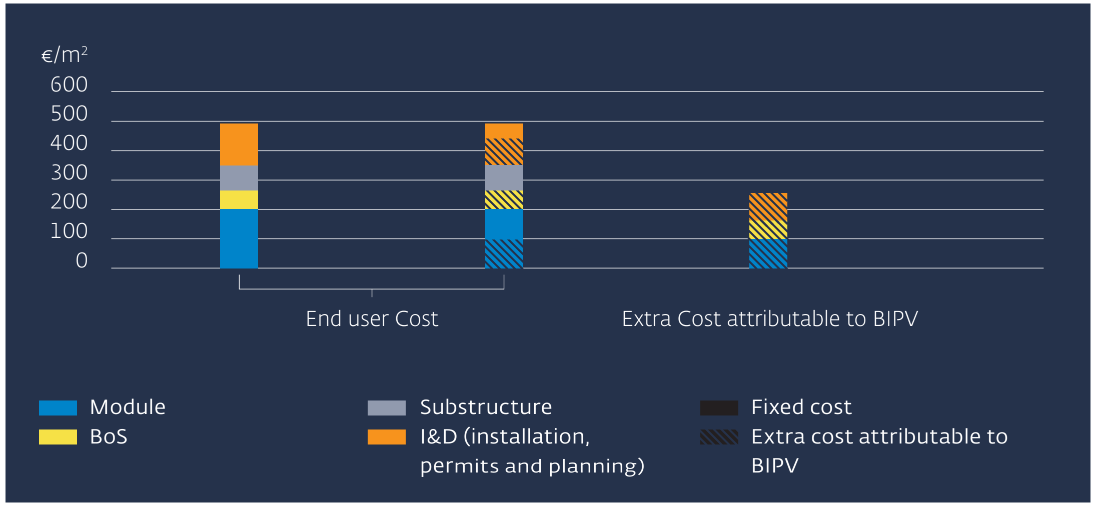


Fig.6 Estimation of the extra cost due to BIPV.

Extra cost	€/m²	264
System lifetime	Yr	30
Business model	-	FiP
Value self-consumed electricity	€/kWh	0,1664
Value injected electricity	€/kWh	-
Nominal WACC	%	4
Yearly O&M	€/m²	1,78
Subsidies	€	13.968
Competitiveness normalized	€/m²	33
Competitiveness (NPV)	€	4.950
MIRR	%	4,4
LCOE	€/kWh	0,141
Payback time	yr	22

Tab. 4 Cost competitiveness analysis.

The cost breakdown of the case study has been evaluated through the extra cost approach. It was estimated that the extra cost has a value of 264 €/m² divided in BIPV modules (37%), BoS (17%) and installation & development (46%). The extra cost of the BIPV modules is defined as the extra cost that BIPV represents compared to a composite module. The favourable combination of a competitive BIPV solution, an important self-consumption rate and the subsidies allows a payback time of 22 years which is smaller than the system lifetime. The MIRR (Modified Internal Return Rate) of 4,40% also indicates a profitable investment as it is higher than the considered nominal WACC. Indeed, this demonstrates that the return rate exceeds the estimated average cost of the capital used to finance the project.

The analysis shows that this BIPV system is cost-competitive and permits to earn about 30€ for each installed m², calculated throughout the whole system lifetime of 30 years. In other words, the project has a net present value of approximately 5.000€. The LCOE level lies below the compensable retail price even though administrative buildings, due to their higher electricity needs compared to households, benefit from lower retail electricity prices. In addition to the benefits of BIPV systems that were presented in chapter 1 (social, energetic, architectonic, etc.), this competitive assessment also demonstrates an additional economic benefit.

5
Multifamily house, Zurich

Rainscreen, 2016
Architect Viridén + Partners

Building and system description

This multi-family building was built in 1982 and retrofitted by the architect Viridén + Partners in 2016, with a fourth-floor extension and the attic floor. Despite the fact its surface area was increased by 36%, the energy consumption was decreased by 72%, from 343.400 kWh/yr to 96.900 kWh/yr.
The use of 34 cm of thermal insulation made it possible to obtain a very energy-efficient building whose photovoltaic façades and roofs systems combined allow a production of 75.076 kWh/yr, thus making it almost totally autonomous. The BIPV cladding surface covers about 1.600 m^2 which corresponds approximately to the totality of the building skin. The system is oriented towards South, East, West and even North.
The monocrystalline PV modules are covered with a layer of coloured glass which reduces their efficiency of ca. 35%. Nevertheless, it also adds architectural quality to the building, blending this technology into the façade in a discrete manner. The new active layer smartly incorporates the extended part with the existing one. Even though the shape of the building is very articulated, thus not the most appropriate for a solar installation, this building proves that with a proper planning it is possible to integrate a photovoltaic system even in situations that are not optimal, whether they are new buildings or renovations.

Building typology	-	Residential
Technological system	-	Cold facade
Active cladding surface	m^2	1.586
Orientation	°	W; E; S; N
Tilt	°	90
Nominal power *	kWp	159
System power density	Wp/m^2	98

Tab. 1 System features.

BIPV technology	-	Opaque glazed BIPV solution without thermal properties
PV technology	-	Mono c-Si
Degradation rate yr 0	%	1,80
Degradation rate yr >0	%	0,45
Customization in size	-	Yes
Customization in colour	-	Yes

Tab. 2 Product features.

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* In addition a traditional BAPV system of 31 kWp is installed on the roof. West and East orientation and 15° tilted.

Fig. 1 Detail of the BIPV facade. Credits: Viridén + Partner / Nina Mann, Zürich-.
Fig. 2, 3 General view and detail of the electrical installations. Credits: Viridén + Partner / Nina Mann, Zürich.

Energetic evaluation

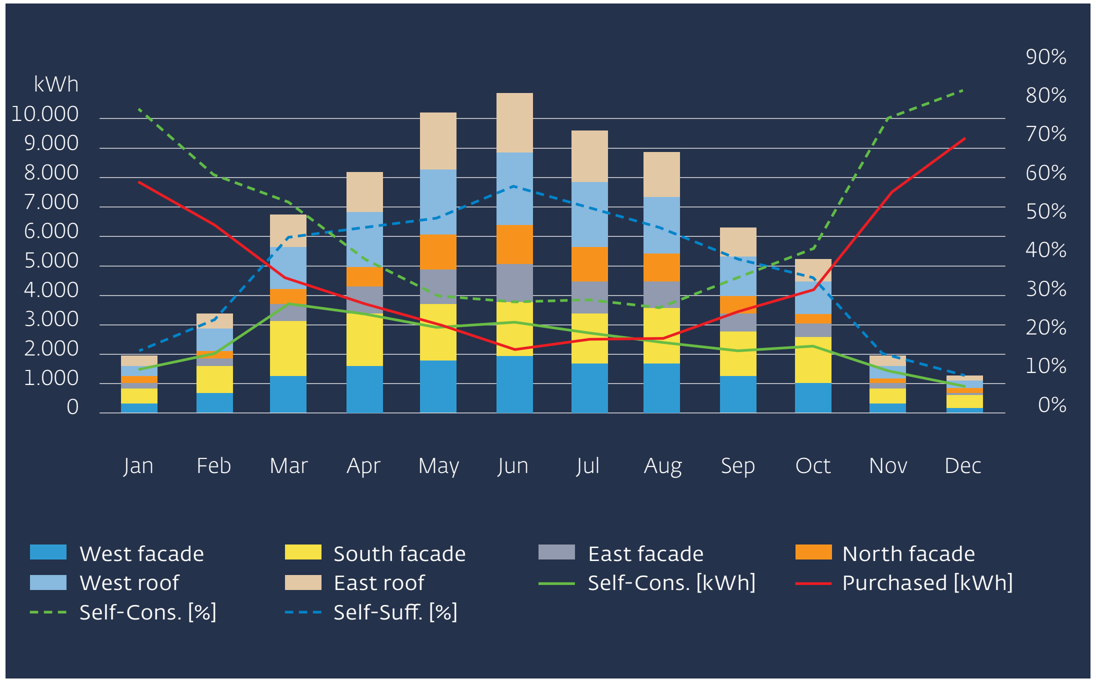
Due to the morphology of the surrounding buildings, the energy production of the BIPV façade which is south-oriented is similar from March to October. On the contrary, the production of the East and North façades is more variable over this same period with the highest peaks in May and June. In general, the BAPV production generates high peaks in summer. During this season, the production of the BAPV system is about 70% of that of BIPV. In winter, the production of the BAPV system only amounts to 50% of that of BIPV. These numbers show that a flattened production curve which can be obtained with BIPV façade systems could contribute to preserve the electric grid in comparison with BAPV solutions (or BIPV roof solutions) which come with a higher seasonal variability (***Fig.4***).
The ***Fig.4*** shows also that the highest self-consumption rates are reached in winter with values around 70 to 80%. Nevertheless, to satisfy the full electricity demand during this season, a large amount of energy needs be bought from the retail energy provider thus resulting in a lower self-sufficiency rate. On the contrary, higher self-sufficiency rates are reached in the summer when the self-consumption is at its lowest rate.

Energy production *	kWh/yr	45.977
Average yearly yield	kWh/kWp	289
Energy demand	kWh/yr	86.354
Self-consumption **	%	40
Self-sufficiency **	%	35

Tab. 3 Energetic features.

* The additional BAPV system produces 29.099 kWh/yr.
** It is calculated considering the both the BIPV and BAPV systems.

Fig. 4 Monthly energy production, self-consumption, energy purcased and self-sufficiency by orientation.



Economic evaluation

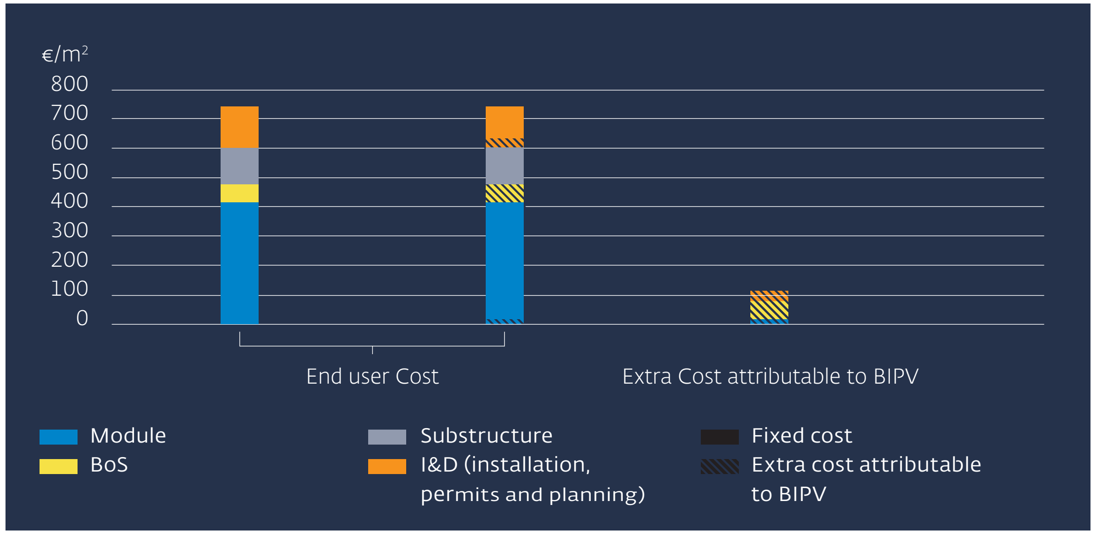


Fig.5 Estimation of the extra cost due to BIPV.

Extra cost	€/m²	145
System lifetime	Yr	30
Business model	-	FiP
Value self-consumed electricity	€/kWh	0,1879
Value injected electricity	€/kWh	0,1012
Nominal WACC	%	2
Yearly O&M	€/m²	1,78
Subsidies	€	131.600
Competitiveness normalized	€/m²	-11
Competitiveness (NPV)	€	-18.596
MIRR	%	1,75
LCOE	€/kWh	0,131
Payback time	yr	NA

Tab. 4 Cost competitiveness analysis.

This building, in line with the architect's idea, should balance the energetic and the aesthetic aspects. The building envelope should not only produce energy but also keep the same architectonic language with a homogeneity of the building skin. This is achieved by the special colouring of the cladding and by the fact that the non-active cladding chosen uses the same colour and material as the active cladding. For this reason, the extra cost is mainly composed by the BoS (ca. 70%) and, to a lesser extent, by the installation and development costs.
From a pure economic perspective, the analysis shows that this BIPV envelope, realized in 2016, is not paid back at the end of the 30 years lifetime with a calculated loss of 11 €/m² within this period. Nevertheless, the competitiveness threshold is almost reached and considering the pioneering nature of this project, one of the first cases in Switzerland of a coloured and fully covered BIPV façade, the result can be considered as a promising perspective for these kind of applications, even from an economic perspective.

6
Single family house, Knivsta
Discontinuous roof, 2019

Building and system description

The case study is a single family house in Knivsta, Sweden, which is representative in terms of dimension, nominal power and design of common, small size, BIPV European residential PV systems. Unlike the glass/glass crystalline cladding of the case studies in Lugano and in Zurich, the single family house in Sweden is a one floor building. The BIPV system, a flexible thin film solution, was installed on the seam metal roof, retrofitted in 2019. The chosen solar technology is CIGS, which is encapsulated in a lightweight and flexible encapsulant.
The case study is located in a residential area sparsely populated. The configuration of the solar system is designed on the base of the shadows of the surrounding elements, including mutual shadows of the building itself and the vegetation. The system is oriented South, East and West and the tilt angle corresponds to the slope of the roof and is about 34-42 degrees. The case study has been classified as "architecture of standard PV" since the integration of the PV system is partially limited to a functional aspect.
The BIPV cladding surface covers about 33 m² for a nominal power installed of around 3 kWp. This classifies the system as a very small power plant. No particular layers or films are used to colour the modules that result black with the shape of the cells.

Building typology	-	Residential
Technological system	-	Discontinuous roof
Active cladding surface	m²	33,4
Orientation	°	West; East; South
Tilt	°	34-42
Nominal power	kWp	3,1
System power density	Wp/m²	93,7

Tab. 1 System features.

BIPV technology	-	Opaque glazed BIPV solution without thermal properties
PV technology	-	CIGS
Degradation rate yr 0	%	0,70
Degradation rate yr >0	%	0,70
Customization in size	-	No
Customization in colour	-	No

Tab. 2 Product features.

Fig. 1 General overview of the BIPV roof. Source: Midsummer.
Fig. 2 Detail of the BIPV roof. Source: Midsummer.

Energetic and economic evaluation

The extra cost of this case study is 158 €/m² and is due to the BIPV cladding, BOS and installation of the solar system. The extra cost of the BIPV modules is defined as the extra cost that BIPV represents compared to the installation of a non-active seam metal roof. The BIPV system is paid back after a period of only 8 years and the return rate on the project (MIRR) is 2,48%. Since this value is higher than the considered nominal WACC, this indicates a competitive solution.

The solar system is more competitive than an equivalent conventional non-active seam metal roof solution and generates, on its entire lifetime, positive cash-flows of about 25 €/m². Overall, the net present value of the project equals 830€, which shows that the extra cost due to the "active" functionality of BIPV compared to a conventional roofing solution can be covered and even exceeded by the revenue it generates.

The average cost at which this system can generate electricity (LCOE) lies below the compensable retail electricity price. This means that each self-consumed kWh generates more savings on the electricity bill than it costs to be produced and this, in spite of both lower irradiation levels in Sweden and of lower retail electricity prices compared to other European countries located more South.

Energy production	kWh/yr	2.053
Average yearly yield	kWh/kWp	656
Energy demand	kWh/yr	2.546
Self-consumption	%	26
Self-sufficiency	%	21

Tab. 3 Energetic features.

Extra cost	€/m²	158
System lifetime	Yr	30
Business model	-	FiP
Value self-consumed electricity	€/kWh	0,1514
Value injected electricity	€/kWh	0,1015
Nominal WACC	%	2
Yearly O&M	€/m²	1,78
Subsidies	€	4.230
Competitiveness normalized	€/m²	25
Competitiveness (NPV)	€	830
MIRR	%	2,48
LCOE	€/kWh	0,102
Payback time	yr	8

Tab. 4 Cost competitiveness analysis

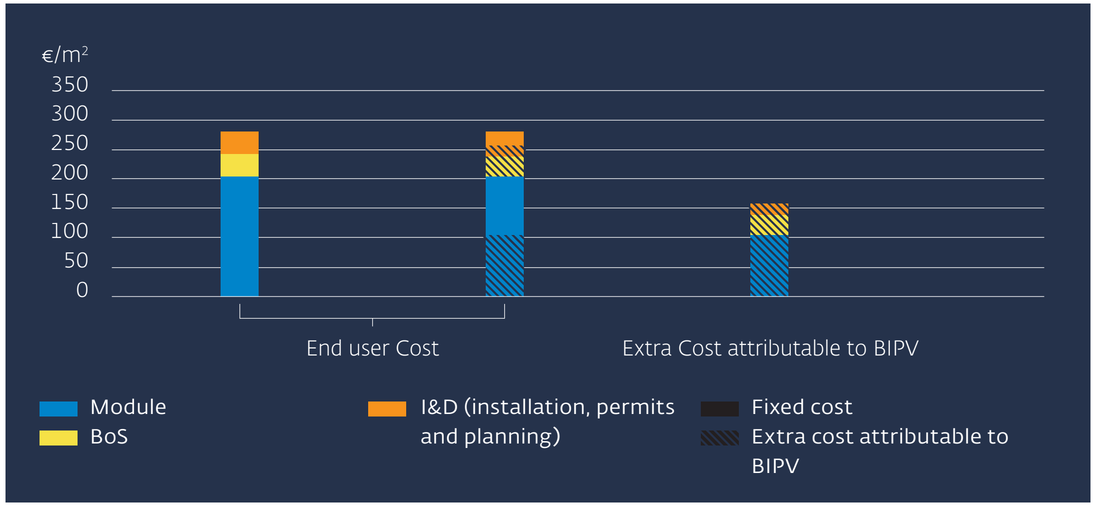


Fig.3 Estimation of the extra cost due to BIPV.

Conclusions

After a crisis comes recovery. With many expectations challenged by the pandemic, this is the occasion to reconsider opportunities. We have to outline our future, but which future do we actually want to shape? The European Green Deal sets out one of the most determined roadmaps to decarbonize our cities and buildings. Building and renovating in a resource and energy efficient way is a key pillar, promising vital opportunities for BIPV as long as the industry, planners, researchers, investors and policy-makers decide to operate together in a multi-disciplinary and cohesive approach.

The building sector is typically perceived as the industry with the longest response times to innovations. However, as already demonstrated during history of construction, also in recent years, revolutionary waves have existed in construction sector. Today's wave is linked to a sustainable transition, thanks to an alliance between public policies, research & industrial efforts as well as common will.

A year after the Bauhaus centennial, European Commission (EC) president called for a new "European Bauhaus" to put the EU on track to be carbon neutral by 2050 and to promote "smart building" technologies as ways to reduce the environmental impact of constructions, and to jump-start the post-COVID economy recovery. A co-creation platform for architects, engineers, and designers is what already started in the BIPV sector where, thanks to this principle of integration, solar elements progressed from satellites to become an integral part of today's building and construction materials. But challenges remain.

The evolution of BIPV has been largely discussed within the chapter 1 where it emerged that many trends define today's routes to innovation even though some barriers remain to the replicability of BIPV throughout the EU. In chapter 2, the variety of BIPV product technologies showed that integration means a strong alliance between architecture and technology. The future of the BIPV industry is a mass-market, cost-effective approach, with a clear focus on ordinary built stock and a more integrated value chain. Flexibility and automation in manufacturing, multifunctional products for the building skin, process management based on digitization, advanced schemes for performance assessments and to streamline the certification process, are the challenges of the ongoing revolution at the forefront of innovation within the PV and construction industries.
In chapter 3, we presented a holistic discussion on cost competitiveness, focusing on different methods to evaluate the economic attractiveness of BIPV investments on a project-based approach and considering the entire value created on its useful lifetime. It confirmed that the extra cost, compared to conventional building envelope solutions, can be covered by the additional revenues linked to this unique "active" material.

Many visions and scenarios describe how buildings in our cities could look and function in relation to future cities, urban infrastructures and urbanization. Climate change, the post-pandemic world, digitization or new mobility will frame a combination of strategies.

PV power is only one of the variables, but it will shape the future buildings.

References

PREFACE

[1] Method for the cost evaluation of BIPV facades and multilevel cost analysis of six Swiss case studies. Corti, Paolo, et al. Aarau: Brenet Status Seminar, 2020.

CHAPTER 1

[1] Loud, Patricia Cummings and Kahn, Louis. The art museums of Louis I. Kahn. Durham: Duke University, 1989.

[2] [Online] SUPSI. [Cited: 23 09 2020.] www.bipv.ch.

[3] [Online] SUPSI. [Cited: 09 23 2020.] www.solarchitecture.ch.

[4] [Online] European Union. [Cited: 23 09 2020.] www.bipvboost.eu.

[5] BIPV meets history: Value-chain creation for the building integrated photovoltaics in the energy retrofit of transnational historic building. Interreg V-A Italia-Svizzera for the Project (Interreg A, ERDF Transnational Cooperation Programmes 2014-2020). Operation co-financed by the European Union, European Regional Development Fund, the Italian Government, the Swiss Confederation and Cantons, as part of the Interreg V-A Italy-Switzerland Cooperation Program, within the context of the BIPV meets History project (grant n. 603882). [Cited: 23 09 2020.] www.bipvmeetshistory.eu.

[6] Šúri M., Huld T.A., Dunlop E.D. Ossenbrink H.A., 2007. Potential of solar electricity generation in the European Union member states and candidate countries. Solar Energy, 81, 1295–1305, http://re.jrc.ec.europa.eu/pvgis/.

[7] Eiffert, Patrina and Kiss, Gregory J. Building-Integrated Photovoltaic Design for Commercial and Institutional Structures: A Source Book for Architects. s.l.: DIANE Publishing, 2000.

[8] [Online] [Cited: 23 09 2020.] www.iec.udel.edu.

[9] [Online] Bund Deutscher Architekten. [Cited: 23 09 2020.] www.bda-bund.de/awards/wohnanlage-richter-muenchen.

[10] Feldman, David, et al. Photovoltaic (PV) Pricing Trends: Historical, Recent, and Near-Term Projections. s.l.: U.S. Department of Energy, 2012.

[11] 2012-2019: EU spot market price by technology. [Online] [Cited: 23 09 2020.] www.pvXchange.com.

[12] Building with Photovoltaics — The Challenge For Task VII Of The IEA PV Power Systems Program. Schoen, T., et al. Vienna: Proceedings of the EC Photovoltaic Energy Conference, 1997.

[13] Charter of European Cities & Towns Towards Sustainability. Aalborg: s.n., 1994.

[14] Roberts, Simon and Guariento, Nicolò. Building Integrated Photovoltaics: A Handbook. Basel: Birkhäuser, 2009.

[15] Koolhaas, Rem, AMO and Harvard Graduate School of Design. Elements of Architecture. s.l.: Taschen, 2018.

[16] [Online] Passive House Institute. [Cited: 23 09 2020.] www.passivehouse.com.

[17] [Online] Minergie. [Cited: 23 09 2020.] www.minergie.ch.

[18] James, Ted, et al. Building-Integrated Photovoltaics (BIPV) in the Residential Sector: An Analysis of Installed Rooftop System Prices. s.l.: National Renewable Energy Laboratory (NREL), 2011.

[19] Method for a cost evaluation of BIPV facades and multilevel cost analysis of six Swiss case studies. Corti, Paolo, et al. Aarau: Brenet Status Seminar, 2020.

[20] Bundestag, German. Act on the Development of Renewable Energy Sources (Renewable Energy Sources Act – RES Act 2014). 2014.

[21] Economico, Ministero dello Sviluppo. Decree of the 19th of February 2007. 2007.

[22] Development of BIPV Business Cases: Guide for stakeholders. Task15-10. s.l.: IEA-PVPS, 2020.

[23] [Online] European Union. [Cited: 23 09 2020.] www.constructpv.eu.

[24] [Online] European Union. [Cited: 23 09 2020.] www.pvsites.eu.

[25] [Online] European Union. [Cited: 23 09 2020.] www.besmartproject.eu.

[26] Performance Assessment of BIPV Systems: From Current Normative Framework to Next Developments. Bonomo, Pierluigi, et al. s.l.: EUPVSEC, 2019.

[27] SUPSI, Tecnalia, CSTB. Standardization, performance risks and identification of related gaps for a performance-based qualification in BIPV. s.l.: BIPVBOOST, 2019.

[28] Braun, D. and Langenkiöld, E. Das erste energieautarke Mehrfamilienhaus. Energie. 2016.

[29] ICARES, EURAC, Onyx Solar, Optimal Computing, PIZ, Ernst Schweizer, SUPSI, TULiPPS, Viridén+Partners. Competitiveness status of BIPV solutions in Europe. s.l.: BIPVBOOST, 2020.

[30] Establishing a cost-effective BIPV sector in Europe. Bonomo, Pierluigi and Frontini, Francesco. s.l.: PV-Magazine, 2019.

[31] Tettonica e architettura. Poetica della forma architettonica nel XIX e XX secolo. Konstantinidis, Aris. s.l.: Skira, 1999.

[32] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). s.l.: Official Journal of the European Union, 2010.

[33] Directive 2009/28/EC of The European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. s.l.: Official Journal of the European Union, 2009.

[34] Directive 2012/27/EU of The European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. s.l.: Official Journal of the European Union, 2012.

[35] ATLAS research project. The research project ATLAS: Advanced Tools for Low-carbon, high-value development of historic architecture in the Alpine Space (Interreg B, ERDF Transnational Cooperation Programmes 2014-2020). [Cited: 23 09 2020.] www.alpine-space.eu/atlas.

[36] [Online] [Cited: 23 09 2020.] www.task59.iea-shc.org.

[37] Energy performance requirements for buildings in Europe. Economidou, Marina. s.l.: European Commission, 2012.

[38] Il Programma edifici, Rapporto Annuale 2017. s.l.: Federal Office of Energy, 2017.

[39] BIPV in the Refurbishment of Minor Historical Centres: The Project of Integrability between Standard and Customized Technology. Bonomo, Pierluigi and de Berardinis, Pierluigi. 9 (Serial No. 70), s.l.: Journal of Civil Engineering and architecture, 2012, Vol. 7.

CHAPTER 2

[1] SUPSI, Viridén+Partners, Onyx Solar, Ernst Schweizer, Comsa, Flisom, TULiPPS. Collection of building typologies and identification of possibilities with optimal market share. s.l.: BIPVBOOST, 2019.

[2] Coloured BIPV. Market, Research and development. Task15. s.l.: IEA-PVPS, 2019.

[3] ICARES, TECNALIA, SUPSI, WIP, Onyx Solar, Ernst Schweizer. BIPV market and stakeholder analysis. s.l.: BIPVBOOST, 2019.

[4] [Online] [Cited: 23 09 2020.] www.solarpowereurope.org/ bipv-can-unlock-new-opportunities-for-european-green-deal/.

[5] SUPSI, Tecnalia, CSTB. Standardization, performance risks and identification of related gaps for a performance-based qualification in BIPV. s.l.: BIPVBOOST, 2019.

[6] [Online] [Cited: 23 09 2020.] www.bipvboost.eu.

[7] Analysis of requirements specifications regulation of BIPV. Task15-08. s.l.: IEA-PVPS, 2019.

[8] Multifunctional Characterisation of BIPV. Proposed Topics for Future International Standardisation Activities. Task15-11. s.l.: IEA-PVPS, 2020.

CHAPTER 3

[1] [Online] [Cited: 23 09 2020.] www.dictionary.cambridge.org.

[2] The "levelized cost of electricity" is obtained by dividing all discounted sources of costs associated with the system on its operational lifetime (material, installation, planning, as well as operation and maintenance costs) by the discounted total energy produced. The discounting to the base year allows to provide a single value, in € of the base year per kWh. It is summarized by the equation

$$\left(I + \sum\nolimits_n^N \frac{Costs_n}{(1+d)^n}\right) \Big/ \sum\nolimits_n^N \frac{Qn}{(1+d)^n}$$

where I is the end user cost invested in the system, is the year, N is the system lifetime, d is the discount rate and Qn the energy produced in year n.

[3] Inventory on Existing Business Models, Opportunities and Issues for BIPV. Task15-03. s.l.: IEA-PVPS, 2018.

[4] Development of BIPV Business Cases: Guide for stakeholders. Task15-10. s.l.: IEA-PVPS, 2020.

[5] ICARES, EURAC, Onyx Solar, Optimal Computing, PIZ, Ernst Schweizer, SUPSI, TULiPPS, Viridén+Partners. Competitiveness status of BIPV solutions in Europe. s.l.: BIPVBOOST, 2020.

[6] A feed in tariff provides a fixed amount for the electricity that is fed back to the grid. With a green certificate business model, for each produced MWh of electricity a green certificate of a certain value is obtained.
In the net-metering business model, the electricity bill takes into account the electricity taken from the grid minus the electricity fed back into the grid.

[7] Method for the cost evaluation of BIPV facades and multilevel cost analysis of six Swiss case studies. Corti, Paolo, et al. Aarau: Brenet Status Seminar, 2020.

[8] Overcoming barriers for the BIPV diffusion at urban and building scale. Corti, Paolo, et al. Zurich: Brenet Status Seminar, 2018.

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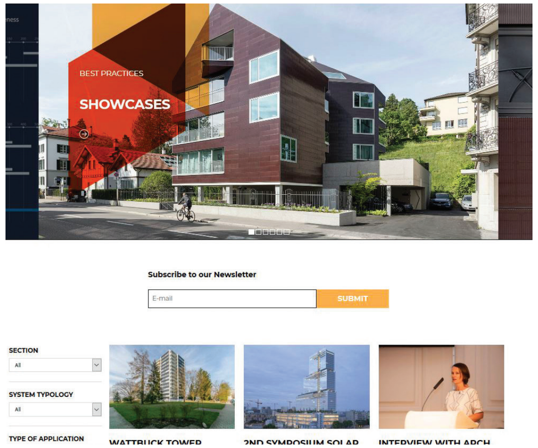

The website **www.solarchitecture.ch** is one of the communication means of the Swiss BIPV Competence Centre.
Here you find essential information concerning PV technology, integration in buildings and different projects realized both in Switzerland and abroad. Moreover, you can consult a large database of BIPV modules and fastening systems collecting the main product's information in a datasheet. The website is an active interface opened towards different stakeholders thanks to the possibility to upload and store your BIPV examples (architects, installers, owners, etc.) or products (manufacturers, suppliers, installers, etc.) as well as to the technological/client support through the contact info@bipv.ch.

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