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Update on BIPV market and stakeholder analysis

BIPVBOOST

"Bringing down costs of BIPV multifunctional solutions and processes along the value chain, enabling widespread nZEBs implementation"

Start date: October 2018. Duration: 4 Years

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Summary

This document describes the status of the BIPV market in Europe, exploring its existing products and segmentation. To provide an overview of the potential of BIPV, the total addressable BIPV market is estimated by following two different approaches, a demand-side approach based on the BIPV capacity required to fulfill the electricity needs of buildings, and a supply-side approach based on the BIPV capacity that could be installed if all BIPV suitable surfaces of buildings were covered. In addition, the possible evolution of the BIPV market is depicted within this deliverable as well, although it is difficult exercise as the situation can rapidly evolve based on the way market barriers are dealt with and on the way market drivers are confirmed and reinforced. Finally, a stakeholder analysis is conducted presenting the role of each actor in the BIPV value chain. This is completed by an evaluation of their interest in, and influence on the BIPV market. Moreover, the challenges they are facing are explained and put into perspective with the market barriers presented before.

Document Information

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1 EXECUTIVE SUMMARY

1.1 Description of the deliverable content and purpose

This document describes the status of the BIPV market in Europe, exploring its existing products and segmentation. The latter can be built on a combination of a building typology, a technical system and a cladding typology, as described in another deliverable of BIPVBOOST project[1] and completed by aspects related to the applicable business model (stakeholders involved, valuation of the BIPV system and the generated electricity, …). Such detailed market segmentation encompassing both technical and economic insides can potentially allow to highlight more consistently which segments could be more easily developed, and which will remain marginal.

Until today, the main factors that have been fostering the development of the BIPV market are the price decreases of PV-related components, improved performances as well as an increasing regulatory pressure for more sustainable buildings. This has been accompanied by rising interest for sustainable technologies and an increasing range of aesthetical possibilities for BIPV. Nonetheless, the development of BIPV can still be improved. Aspects such as standardization, enabling easier installation processes and reducing risk perception, can have a tremendous impact, for example. More knowledge and awareness regarding BIPV among the public and the construction sector are also crucial. The need for adapted regulatory frameworks, increasing the possibilities to value the electricity generated by distributed PV systems is another key driver.

Then, the total addressable BIPV market in analyzed countries has been estimated by following two different approaches, a "demand-side" approach based on the BIPV capacity required to fulfill electricity needs of buildings, and a "supply-side" approach based on the BIPV capacity that could be installed if all BIPV suitable surfaces of existing building stocks were covered. The analysis demonstrated that the theoretical market potential is tremendous, with hundreds of GWp of BIPV that could be installed. Even when considering as limiting factor the natural rate of renovation and new construction, this can represent a GW-scale market in various countries. The figures also show that, even in markets where BIPV has developed thanks to specific support schemes, only 1% to 3% of the potential has been achieved. On a country level, even the most conservative evaluations demonstrate that the market could be as high as 6 GW in Switzerland, up to 81 GW in Germany. On total, in the 6 analysed countries, the total addressable market is estimated to stand at approximately 290 GW, taking the low scenario of the "supply-side" approach.

Following that analysis, the possible evolution of the global BIPV market is depicted, based on two scenarios. In both, figures are far below the total addressable market figures computed previously. This can be explained by the fact that multiple challenges remain to be overcome before a significant share of this estimated addressable market can be achieved. Although, these forecasts are bound to be adapted in the following years based on these market barriers are dealt with and on the way market drivers previously cited are confirmed and reinforced. In this section, the forecasts are put in regards of other historical forecasts focusing on BIPV, underlining the difficulty of such exercise and highlighting the fact that they should be considered with caution.

[1] D1.3 "Collection of building typologies and identification of possibilities with optimal market share"

Finally, a stakeholder analysis is conducted presenting their respective role in the BIPV value chain, their interest in this sector and the influence they can have on the BIPV market. This allows to identify two groups of stakeholders: primary and secondary stakeholders. The challenges they are facing are linked to BIPV specific aspects (complex technology, limited aesthetical and design possibilities, high investment costs, …) and also linked to the fact that because of BIPV's bi-functionality, including a BIPV element in a project needs an enhanced collaboration and communication between historical projects actors (building owners, architects and general contractors) and the BIPV industry. Furthermore, stakeholders such as BIPV installers or experts in both PV and construction fields are key. Indeed, the formers can reduce the risks associated to BIPV system installation, as regular façade or roof installer, or electricians can be reluctant to deal with innovative aspects of BIPV. Then, experts in both PV and building-related aspects, who are today too few, can facilitate project development and the integration of BIPV by advising other stakeholders in the planning and design phases.

Relation with other activities in the project Table 1.1 depicts the main links of this deliverable to other activities (work packages, tasks, deliverables, etc.) within BIPVBOOST project. The table should be considered along with the current document for further understanding of the deliverable contents and purpose.

Table 1.1 Relation between current deliverable and other activities in the project

Project activity	Relation with current deliverable
T1.3	Market segmentation and building typologies

1.2 Reference material

This deliverable has taken some data from the deliverable 1.3.

1.3 Abbreviation list

aSi – Amorphous Silicon
BAPV/ BIPV – Building Applied/Integrated Photovoltaics
BREEAM - Building Research Establishment Environmental Assessment Method
CAPEX – Capital Expenditures
CdTe – Cadmium Telluride
CIGS - Copper Indium Gallium Selenide
cSi – Crystalline Silicon
DSO – Distribution System Operators
EPC – Engineering, Procurement and Construction
LEED – Leadership in Environment and Energy Design
FiT – Feed-in-tariff
HVAC – Heating, Ventilation and Air Conditioning
nZEB – Nearly Zero Energy Building
OPV – Organic Photovoltaic
STC Power – Standard Test Conditions Power
TSO – Transmission System Operator

2 INTRODUCTION & OBJECTIVES

This report is divided in two main parts. The first one focuses on the BIPV market while the second treats of stakeholders active on this market. As presented in the document, BIPV solutions and ways to value them are numerous and varied, thus analyzing and defining a detailed market segmentation is necessary. Forecasts for the evolution of the BIPV market are depicted within this deliverable along with an analysis of the main market barriers and market drivers. The elaboration of total addressable BIPV as well as a stakeholder's analysis have also been conducted in this document. The purpose followed by this deliverable is to improve the understanding of market dynamics by analyzing challenges and drivers it faces. This document also serves the objective of estimating the size of the market and highlighting key stakeholders. Finally, the idea is to outline requirements and adaptations to be introduced, for BIPV to gain shares of the total addressable market.

3 BIPV MARKET ANALYSIS

3.1 Product types

In this section the different products currently available on the BIPV market are presented and explained. [1]

	Application area	
Type of product	**Roof**	**Façade**
Tiles and shingles	x	
In-roof mounting system	x	
Full roof solution	x	
Glazed roofing	x	
Standing Seam Metal Sheet	x	
Flexible lightweight modules	x	x
Non-ventilated façade elements		x
Rainscreen façade elements		x
Accessories (balustrade, shading…)		x

Most of the terms used in the table are self-explanatory. However, some of them might require clarification. "In-roof mounting systems" here encompasses mounting systems which integrate classic PV module (frameless or not) to the roof. These systems fulfill some functions usually devoted to construction materials. But with the use of regular PV modules, aesthetical integration is not optimal. In this case, the integration can be defined as partial. "Full roof solutions", on the contrary, are more integrated, both aesthetically and in terms of functionality. These solutions fulfill the functions of usual roofing, sometimes even thermal insulation for example, and are made with BIPV elements specifically designed for this usage, with even different choices of color. Therefore, integration can be considered as optimal.

Then, metal roofing refers to regular lightweight roofing made of metal, with an additional layer of photovoltaic thin film, typically composed of CIGS photovoltaic cells. Products classified in the “flexible lightweight module” category are lightweight BAPV modules, such as membranes and rolls. These can be placed on different surfaces without mounting system, most of the time by simply sticking them onto the surface, which is why they are suited both for façades and roofs. These are not per definition BIPV elements, but they are direct competitors of BIPV due to their unique characteristics. In addition, combined with regular building component at the manufacturing stage, they can fulfill additional functions and can be defined as BIPV elements.

Regarding the BIPV solutions designed for façades, non-ventilated (“warm”) façade elements” are BIPV elements constitutive of BIPV systems installed as curtain walls. Rainscreen (“cold”) façade elements are BIPV elements constitutive of BIPV systems installed as façade cladding. These are called “cold” because most of the time there is a ventilation space between the BIPV elements and the second layer of façade elements. “Accessories” encompasses shading devices such as louvers, or balustrade and balconies’ components.

The following figure can help to better understand the different type of BIPV applications.

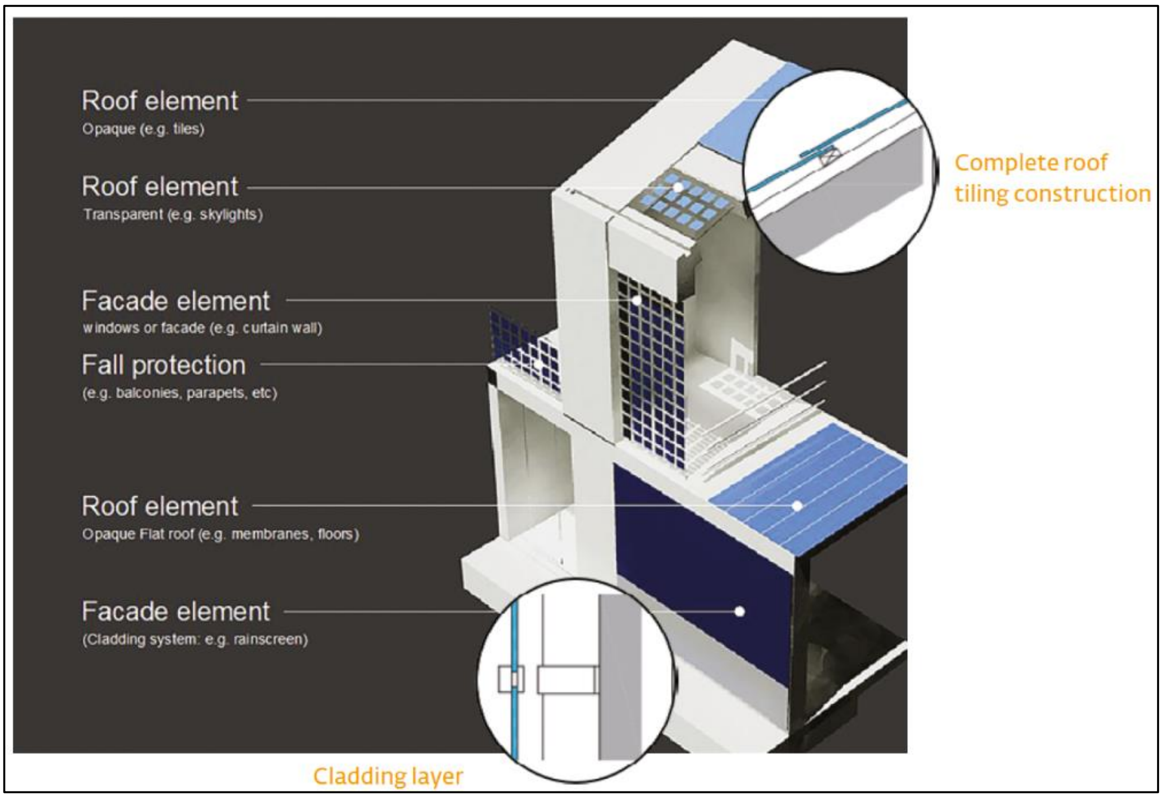


Figure 3.1 The possible ways to integrate photovoltaic elements into the envelope of a building [1]

Note that for most these products, multiple solutions exist on the market, with various shapes, colors and performances, as well as based on different PV cell technologies, mostly crystalline silicon (multi or mono) or thin-film (mostly CIGS and amorphous silicon, even if products based on CdTe and OPV can be witnessed). This aspect will be further discussed in a following section.

3.2 Market segmentation

BIPV systems encompass both energy-related aspects (linked to the production of electricity) and building-related aspects (bond to the construction material function). Therefore, the BIPV market can be segmented in categories that are based on one or the other mentioned aspect. Then, a final market segmentation can be established based on the different categories in order to highlight relevant and clear combinations.

Today, we can identify three meta-categories of buildings on which BIPV products listed in the previous section are installed: residential buildings, tertiary buildings and lightweight industrial and commercial structures. Each of these meta-categories has its own specificities, in terms of technical and economical characteristics. They can be sub-segmented into nine building typologies. For example, in the case of residential buildings, single-family and multifamily buildings must be differentiated. Of course, they do not have the same architectural characteristics. In addition, the occupancy profile is likely to vary, with a higher rate of ownership in the case of single-family buildings, and a higher rate of tenancy in the case of multifamily buildings. This influences the business models that can be applied, hence the economic attractiveness of BIPV systems. Among tertiary buildings as well, multiple different sub-segments exist, such as educational buildings, commercial buildings, sport centers, hospitals or office buildings. [2]

Then, eleven technological systems can be distinguished and can be quite equated with the abovementioned products. (Appendix 1) They refer to the types of roof or façade the BIPV system replaces. They encompass curtain walls, rainscreen façades, walkable roofs, canopy, skylight, double skin, … They are the bridge between the construction material aspect and the architectural value of BIPV. Indeed, a skylight for example is a light-transmitting building element that covers all or a part of the roof, therefore it is a pure architectural element. But, because of the transparency characteristic it owns, it implies that only a BIPV element with this same characteristic would be suitable as a replacement, and therefore it gives a first direction towards the kind of technology or as it will be mentioned as throughout the rest of the document the kind of cladding typology, fulfilling an electricity generation function, that would be applicable.

A cladding typology is a combination of the material used (glass, prefab, …), the thermal property (insulation property or not) and the visual property (transparent or opaque) of a BIPV technology. Five cladding typologies can be considered. (Appendix 2)

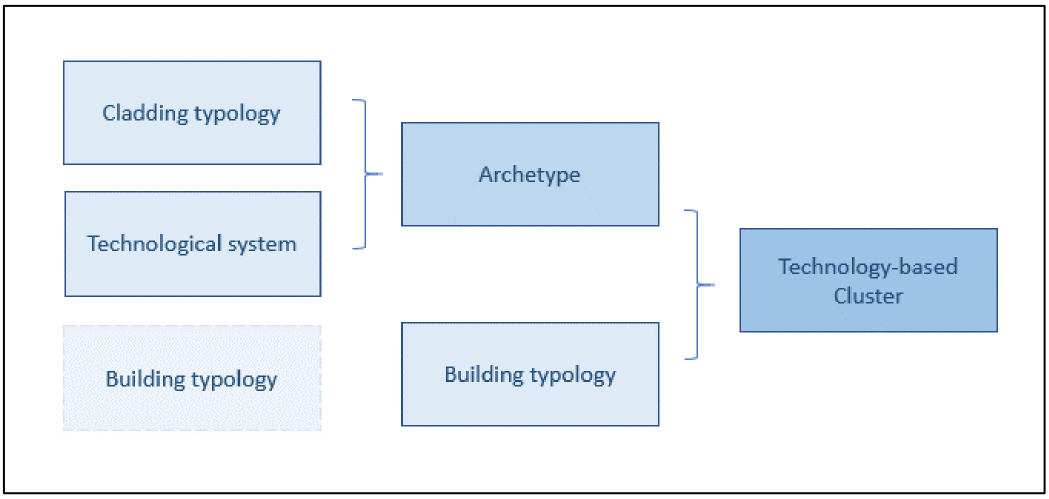


Figure 3.2 Market segmentation based on technical aspects (Elaboration by Becquerel Institute, based on [2])

Having eleven technological systems and five cladding typologies, fifty-five different combinations could theoretically result but as evoked above no all of them are relevant or meaningful. Indeed, an opaque cladding for a skylight is an impossible combination. The suitable combinations are called archetypes. By combining an archetype with a building typology, technology-based segments can be formed as resumed on the following figure.

A market segmentation developed as explained before allows to take the building itself and its associated characteristics (owners, users, consumption, typical available surface, …), the building skin and its linked particularities (tilt, transparency, thermal property, …) as well as the BIPV system and its parameters (transparency, nominal power, PV technology, …) into account. It also permits to highlight and then analyze each segment individually. Indeed, different technology-based clusters can have different market dynamics. While some have multiple applications possibilities and limited market barriers, some other, on the contrary may face stronger market obstacles and will therefore only represent a small share of the

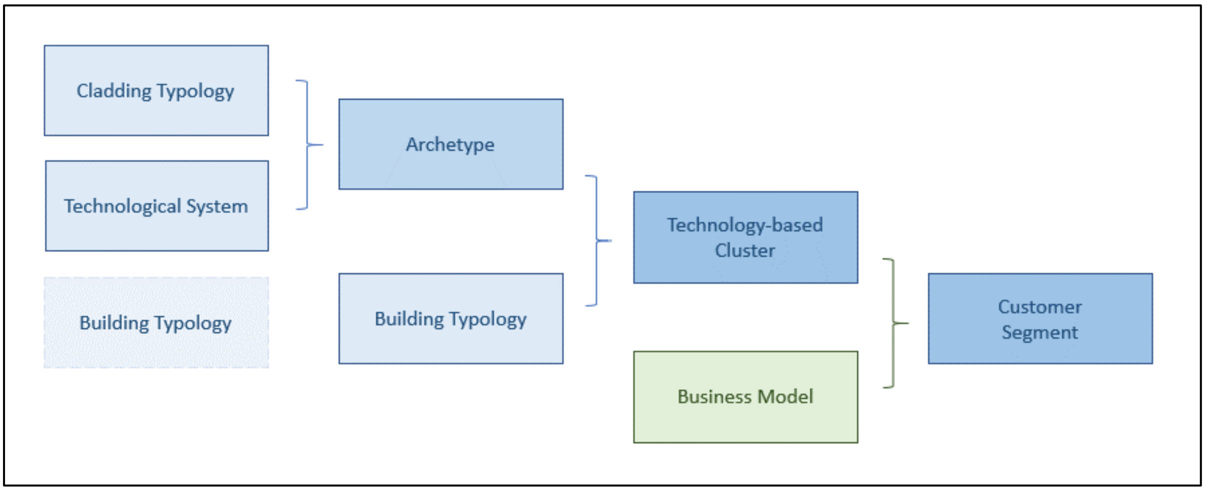


Figure 3.3 Market segmentation encompassing technical and economic aspects

BIPV market. A market segmentation as presented above has further advantages. Given the multiple and various possibilities when it comes to BIPV, and given the fact that it is a quite new market and that just a few experts have experience and knowledge on both aspects of BIPV together, having these technology-based segments allows to have clear package of mutually compatible technological systems, building typologies and cladding typologies. This enables and simplifies the development of planning and installation processes, for instance, and makes it more understandable.

This first way of seeing the market segmentation is mainly based on technical constraints. But some further aspects could be considered to describe and create a market segmentation that covers not only technological aspects but also financial and project development aspects as represented in Figure 3.3. This would constitute a "customer cluster" as it takes into the detailed occupant's profile. Indeed, as the range of possibilities (business models) to value one's generated electricity will widen, it will become even more relevant to determine which type of technology-based clusters (as defined above) are more suited technically and financially speaking in the case of on-site self-consumption, in the case of collective self-consumption for multifamily houses or in the case of collective self-consumption for multiple buildings. For example, in the case of a single family house (building typology), with glass-glass system (cladding typology), with a full roof application (technological system), it can be assumed that in most cases the house owner is also the house occupant and therefore the person who will both invest in the BIPV system but also benefit from savings on the electricity bill and remuneration for the electricity fed-back to the grid. This remuneration can happen under various forms depending on the country (FiT, net-metering, net-billing, …). In this first example the business model to be applied is straightforward because it involves few stakeholders as the house owner is also the house occupant. In the case of an office building (building typology), with a glass-glass system (cladding technology), with a façade cladding (technological system) it is very common that the building owner is not occupying the building but renting it. In addition, a facility management company can also be involved. The person who invests in the BIPV system no longer benefits from remuneration for the fed-back electricity or from savings on the electricity bill but could compensate this by increasing the rents. Because of the increased number of stakeholders in this case and to their different interests the project development phase as well as the definition of a business model is complexified, and it is relevant to include those elements into the market segmentation. Indeed, these further aspects can contribute to a more precise, practice-based and detailed market segmentation which can allow to highlight the most attractive segments not only from a technical point of view but with a bottom-up approach.

This segmentation approach appears particularly valuable as, until today, the BIPV market has mostly been a push market, where many competitors proposing a wide range of different products have been trying to convince end-users (architects, building owners and developers) of the attractiveness of their respective technical solutions. Rather than being designed from the beginning to fulfill an identified need, these products have seen their characteristics being framed by technical limitations, which are afterwards adapted in function of actual needs or requirements of end-users, as much as possible. Furthermore, these products have most of the time been marketed as stand-alone products, rather than being bundled within larger, more attractive solutions. By developing customer segments, the needs of end-users can be more precisely identified, as mentioned. Hence allowing to design appropriate products to cover these needs. It can also permit to identify the most attractive customer segments, based on various factors such as the scale and urgency of the identified, the easiness to answer to them, or the revenue opportunity. Ultimately, it could as well lead to an increased specialization of BIPV actors in terms of technology, shapes and aesthetics. Which could contribute to reach enough economies of scale, thus reducing production costs.

Finally, one should bear in mind that this market segmentation is bound to evolve. Indeed, as the regulation will certainly change to take into account the effects of market disruptors like BIPV, both from a construction and distributed PV point of view, new business models will appear, and market demand will adapt. For example, as “prosumers” will have new possibilities to value their PV electricity production, installations on multifamily buildings, which are today technically feasible but economically non-attractive or difficult to put in place, on multiple markets, might become more common. Hence, some products currently mainly installed on tertiary buildings, such as solar PV cladding façade elements, will have their applications increasingly extended to the building envelope of multifamily houses as well.

Note that these customer segments and the associated opportunities will be further investigated within the BIPVBOOST project as part of Task 9.4 “Analysis of business cases to support market uptake strategy”.

3.3 PV technologies in BIPV

The two graphs presented here below demonstrate that no technology is truly dominating the BIPV market, which is in great contrast with the situation of the regular PV market, where crystalline silicon-based modules outrageously dominate the whole market, on all segments. [3] Even more for BIPV than for mainstream PV applications, the choice of one technology over the other, e.g. thin-film or crystalline silicon, is made in function of the type of application, as well as the performance and aesthetical requirements.

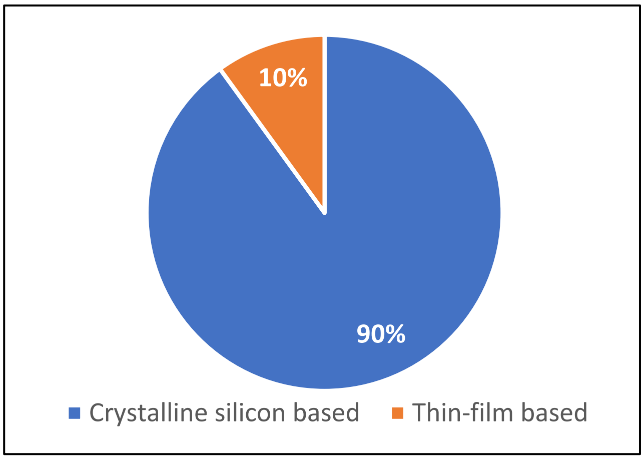


Figure 3.4 Split of PV technologies among BIPV products for roof applications [1]

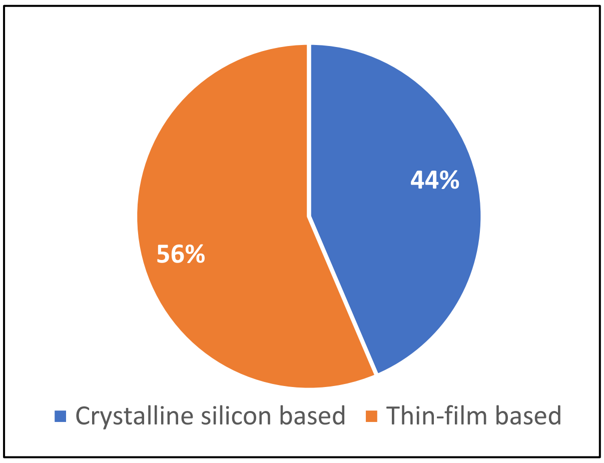


Figure 3.5 Split of PV technologies among BIPV products for façade applications [1]

In the segment of roof applications, crystalline silicon-based solutions lead the market, as shown on the graph above similarly to the PV market. This can be explained by multiple factors. For example, as some BIPV roof-systems rely on regular PV modules, e.g. coupled with in-roof mounting systems, the choice of cSi is the easiest, taking into account the wide offering and the cost advantage. In addition, considering in most cases the limited visibility of roof installations for the public, i.e. from ground level, aesthetical requirements might be less of a concern. Also, transparency is not always required, except in the case of skylights, and performances might become the main objective, hence favoring the use of cSi technology. Furthermore, most BIPV roof systems (except in the case of skylights) allow the installation of a ventilation space. This reduces the problem of performance losses due to temperature's increase, which then limits the relative technological advantage of thin-film PV technologies.

Regarding façades, the situation is much more balanced, and thin-film products slightly dominate. The potential explanatory factors are:

- The more appealing aesthetics of thin film products;
- The potential for "homogenous" transparency;
- The better average temperature coefficient, which is important in case of limited or no ventilation, like for curtain walls;
- Lower sensitivity to non-optimal orientations;
- The relative low weight of thin-film technologies compared to cSi;
- The possibility to apply thin film on a variety of materials;
- Performance is secondary concern.

In the following table the characteristics and the results of a SWOT analysis of the four main technologies used today on the BIPV market are summarized. Three of them are thin-film technologies, namely copper indium gallium selenide (CIGS), cadmium telluride (CdTe) and amorphous silicon. Multi- and mono-crystalline silicon are gathered under a single category, their characteristics being extremely similar. The only difference is slightly higher cost and efficiency of mono-Si cells compared to multi-Si. It is important to note that other PV technologies evoked in a previous section have not been included as they represent highly marginal BIPV market shares, at best, and/or not much has been proven in real field conditions except as part of pilot projects. Here are some remarks on the information contained in this table. First, degradation rates vary widely and depend on the intrinsic characteristics of the concerned PV technology. They are defined as normal degradation rates under standard conditions. But it can also vary in function of the quality of manufacturing, the quality of installation of the system as well as the type of environment (e.g. humidity, temperature) [4, 5].

Then, as an indication, average efficiency of typical BIPV modules are provided, based on our European BIPV product database. Although, it is worth pointing that in BIPV, providing a global average of the nominal power output per square meter must be complemented by an integration context, as the power output highly varies in function of the design (shape, color, cell spacing) of the product. This is especially true in the case of tiles (overlapping of elements) and PV glass (spacing of the cells to let the light go through), among others. Then, these efficiency levels are of course lower than regular PV modules. In addition, as evoked in the previous section, latest technological improvements at the level of the cells and modules are applied to BIPV elements with a delay compared to regular PV modules, which also explains the efficiency gap.

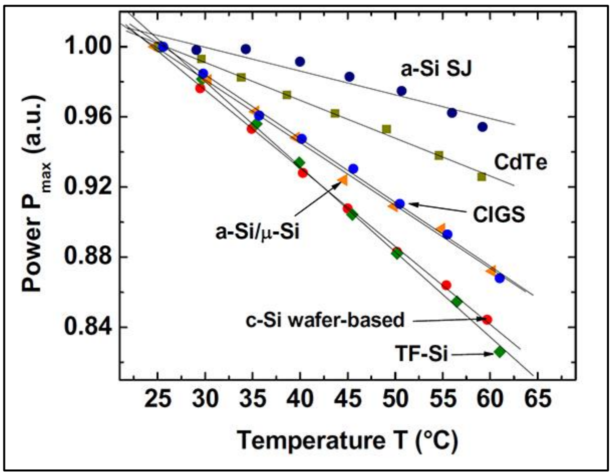


Figure 3.6 Variation of power output with temperature for different solar technologies [25]

The data contained in the column "Main BIPV applications areas" is also based on our BIPV product database and indicates, for each PV technology, the typical customer segment and application area it is applied to.

Temperature coefficients are averages, calculated from the technical datasheets of BIPV products contained in our database, and can vary in function of the design of the BIPV elements, the quality of the materials used as well as the manufacturing treatments. The consequences of rising temperatures on the maximal nominal power output is illustrated on the Figure 3.6 for various technology. Amorphous silicon is the least impacted PV technologies, closely followed by cadmium telluride. CIGS and crystalline silicon stand behind. This aspect is extremely important in the case of BIPV installations as ventilation is not always optimal.

Table 3.1 SWOT analysis of four main technologies

Solar PV Cell Technology	Main Characteristics	Main BIPV Applications Areas	Strengths	Weaknesses	Opportunities	Threats
Crystalline silicon **(Multi & Mono)**	• Average BIPV module efficiency: **10% to 19% in function of technology and opacity** • Average temperature coefficient: **-0,45%/°C (Multi)** and **-0,41%/°C (Mono)** • Average module degradation rate: **0,5%/y (Multi)** and **0,45%/y (Mono)**	• Roof (all segments) • Façade (tertiary buildings) • Accessories (e.g. louver, balustrade…)	• High efficiency • Mature and well understood technology • Limited degradation rate • Reliable product • Broad solar spectrum response	• Highly limited design flexibility • Non-optimal temperature coefficient, which can be problematic if non-ventilated	• Continuous performances increase, at the cell but also module level • Limited cost of cells, due to the high number of potential suppliers	• No immediate threat
Copper Indium Gallium Selenide	• Average BIPV module efficiency: **14% to 16%** • Average temperature coefficient: **-0,35%/°C** • Average module degradation rate: **0,65%/year**	• Roof (residential housing and C&I) • Façade (tertiary buildings)	• Less time- and energy-consuming manufacturing process than cSi • Lightweight • Flexible • Good temperature coefficient • Broad solar spectrum response	• Still limited efficiency for commercial BIPV products • Slightly higher degradation rate than cSi products • Sub-optimal degradation rate	• Can be applied on various surfaces • Potential efficiency improvements • Transparency potential • Better aesthetics than cSi	• Indium and gallium are scarce, which can create pressure on supply and price. • It could also complicate recycling processes considering toxicity. • If regulation related to environmental footprint evolves, it could harm this technology considering high impact of extraction.
Amorphous silicon	• Average BIPV module efficiency: **2% to 9% in function of opacity** • Average temperature coefficient: **-0.21%/°C** • Average module degradation rate: **0,85%/year**	• Roof (C&I) • Façade (tertiary buildings)	• Low cost • Very good temperature coefficient • Mature technology	• Low efficiency • High degradation rate • Sub-par performances under normal light conditions	• Transparency level can be modified and is well understood • Performs well under diffuse light conditions • Flexibility potential • Better aesthetics than cSi	• Limited potential for future efficiency improvement
Cadmium Telluride	• Average BIPV module efficiency: **14% to 17%** • Average temperature coefficient: **-0.23%/°C** • Average module degradation rate: **0,5%/year**	• Roof (residential) • Façade (tertiary buildings)	• Very good temperature coefficient • Limited degradation rate	• Still limited efficiency for commercial BIPV products • Limited solar spectrum response	• Transparency potential • Potential efficiency improvements • Better aesthetics than cSi	• Highly hazardous cadmium. • Scarcity of telluride and cadmium which could create pressure on supply and price • If regulation related to environmental footprint evolves, it could harm this technology considering its toxicity.

3.4 Development status

Until recently, most BIPV installations were limited to "flagship" projects, such as companies' headquarters or buildings with high aesthetical value. When developing projects of that kind, neither costs nor performances' optimization of the system were major concerns. Aside from the possible aesthetical value, the main argument was the marketing or branding potential of such solution. This argument can be defined as the "green" or sustainable marketing value.

Consequently, the BIPV market is still a niche and currently accounts for a negligible share of both PV and construction markets. Based on our estimations, around 1% of the global PV market concerned BIPV installations in 2017. In Europe, the share of BIPV installations in the annual construction market was at most equal to 2% of the total surface of roofs and façades renovated or newly constructed in 2017. Moreover, even in countries where it has been backed-up by specific policies, such as direct subsidies or advantageous feed-in tariffs, the market of BIPV remains negligible.

Estimating the size of the cumulative BIPV market is an extremely difficult exercise, as the definition of BIPV varies from country to country, has changed over time or might be not restrictive enough in some countries so that installations defined as BIPV should not be categorized as such considering the current standards. In addition, regulatory bodies and national administrations often do not keep track of these installations in the sense that they are recorded as any other distributed PV installation. Hence, we advise to use these estimations with caution and consider them for what they are: presentations of order of magnitude of BIPV markets. That being said, based on a review of various publications, such as the National Survey Reports published by the national representatives participating to the Photovoltaic Program of the International Energy Agency (PVPS-IEA), we estimated the cumulative installed capacity of BIPV in various countries. Some numbers have also been approximated based on direct communication with local representatives of regulatory bodies, the BIPV industry, or PV associations and experts. Results are available on the graph below.

Japan leads the way thanks to its favorable market conditions, such as limited space for ground-mounted systems, high urbanization, high turnover of housing construction, and privileged partnerships between (BI)PV manufacturers and construction companies active in the housing market. Furthermore, this trend has been backed up by advantageous feed-in tariff for distributed PV. Finally, there is a high pressure for sustainable buildings, due to "Zero Energy Buildings" regulation, and for alternative electricity generation sources since 2011's earthquake. [6]

Europe has had a long history of BIPV research and projects. Today, France and Italy are respectively second and third markets in terms of cumulative installed BIPV capacity, thanks to their past BIPV specific policies. This BIPV development principally occurred between 2010 and 2015. Again, these numbers should be taken cautiously as it is difficult to evaluate precisely which share is due to real BIPV products. Indeed, in these two countries the regulation regarding BIPV was too loose and the definitions of BIPV were, at least for a significant period, not precise enough. In France, for example, for a few years two definitions of BIPV co-existed. In Italy, the first definition of BIPV was also unrestrictive, but it was then updated in 2011. By looking at the annual installed BIPV capacity in Italy in Figure 3.8, a major drop can be noticed between 2011 and 2012 which corresponds to the change of definition of BIPV.

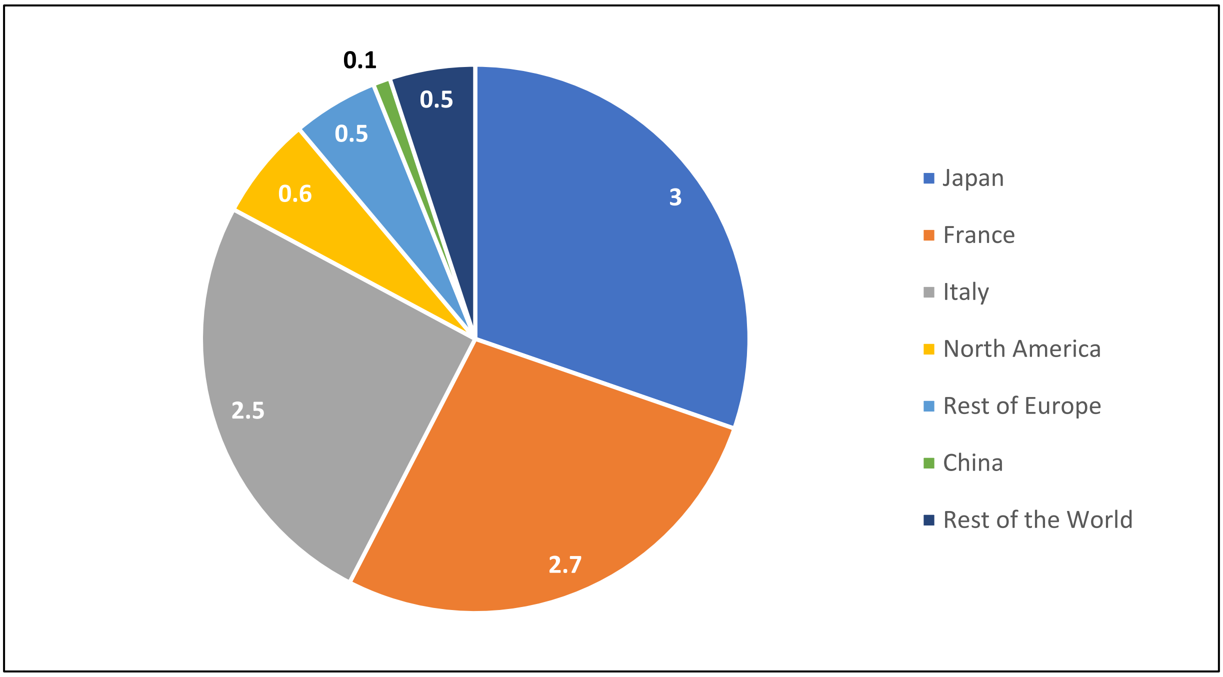


Figure 3.7 Estimated global BIPV cumulative capacity installed by the end in 2018, in GWp (Estimation by Becquerel Institute)

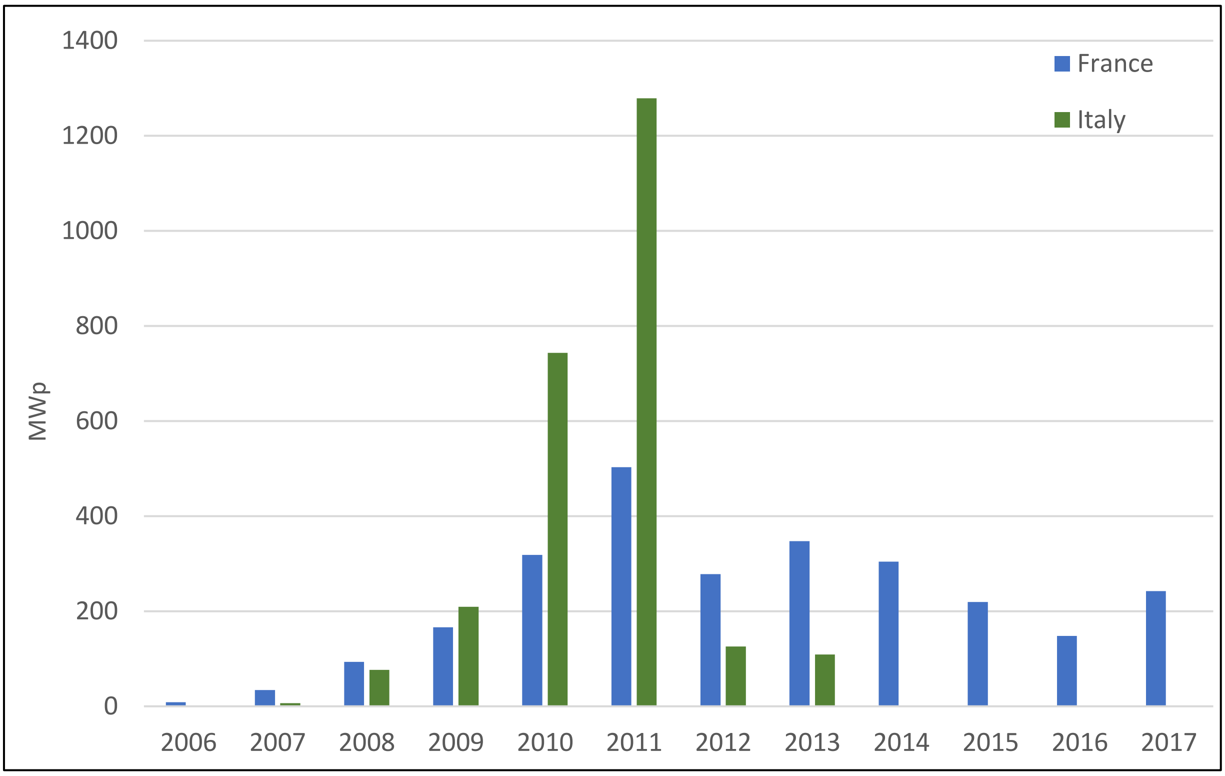


Figure 3.8 Annual BIPV capacity installed (according to the locally applicable "BIPV" definition) in France & Italy (Source: Becquerel Institute, based on the analysis of national databases)

The capacity installed in the rest of Europe is mainly due to projects developed in Austria, Germany, the Netherlands, Spain, Scandinavia, and Switzerland. Switzerland and the Netherlands have today a dynamic BIPV market and industry, even though on the latter there are no BIPV specific policies, contrary to Switzerland. Other European markets are significantly under-developed, even though flagships projects have been developed on tertiary buildings here and there.

USA is another substantial BIPV market. For some BIPV manufacturers, USA is already a bigger market than Europe. Indeed, the potential is important, and it could become a leading BIPV market in the medium-term especially in states like California where there are strong pro-solar mandates and where it will be mandatory from 2020 on for all new buildings under three stories high to have solar installations. [7] China, despite being an important PV market, slightly lags behind and is today a second tier BIPV market. Nonetheless, massive BIPV projects have been developed in the last years, with multiple projects breaking the 1 MWp barrier. [8]

3.5 Market drivers

Various studies have been conducted on that matter, exploring the drivers of the interest for BIPV solutions. One can cite for example reports published in the frame of Horizon 2020 projects Dem4BIPV and PVSITES. [9] [10] These took a supra-national view, investigating the question at the European scale. Other research was conducted at the national level, for example in the Netherlands or more recently in Singapore. [11] [12] [13]

There is currently a phase-out of BIPV specific incentives, as witnessed in France and Italy, but also of incentives for distributed PV in general, mostly in Europe, but Japan is another example. Consequently, business models for (BI)PV rely more and more on optimized self-consumption ratios. Hence, reasons explaining the recent development of BIPV must be found elsewhere.

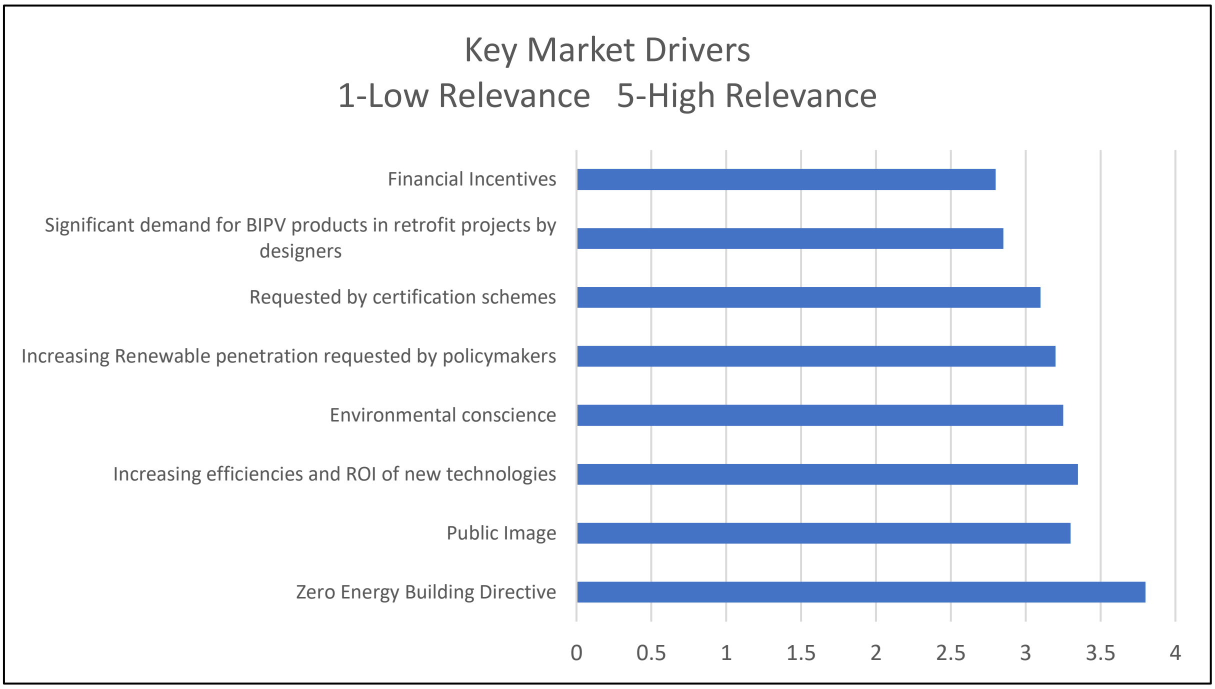


Figure 3.9 Results of a survey conducted in the frame of Dem4BIPV project, investigating BIPV market drivers

Based on these past studies and our understanding of the BIPV market and industry, our analysis is that it is due to the increase of intrinsic attractiveness of this technology and more favorable market conditions. These explanatory drivers can be summarized as follow:

i. Cheaper PV system components;
ii. Systemic innovations leading to improved competitiveness (e.g. higher PV cells efficiency, lower system losses and better reliability of BIPV elements);

iii. Better aesthetics and customization possibilities of BIPV products;
iv. A wide range of product's manufacturers, which stimulates competition;
v. An increasing regulatory pressure to increase the sustainability of buildings;
vi. A "green" and sustainable aspect which is more and more valued by buildings' owners and occupants.

What has historically maintained the price of BIPV products much higher than regular building component was, among others, the cost of PV components. Cost reductions have been constant in the history of the PV sector but recently this trend tremendously accelerated in the last years. As an example, in Figure 3.10 the evolution of one of the main components of BIPV modules (based on crystalline silicon technology), i.e. PV cells is shown. Between early 2016 and March 2019, their average market spot prices have been divided by 3.

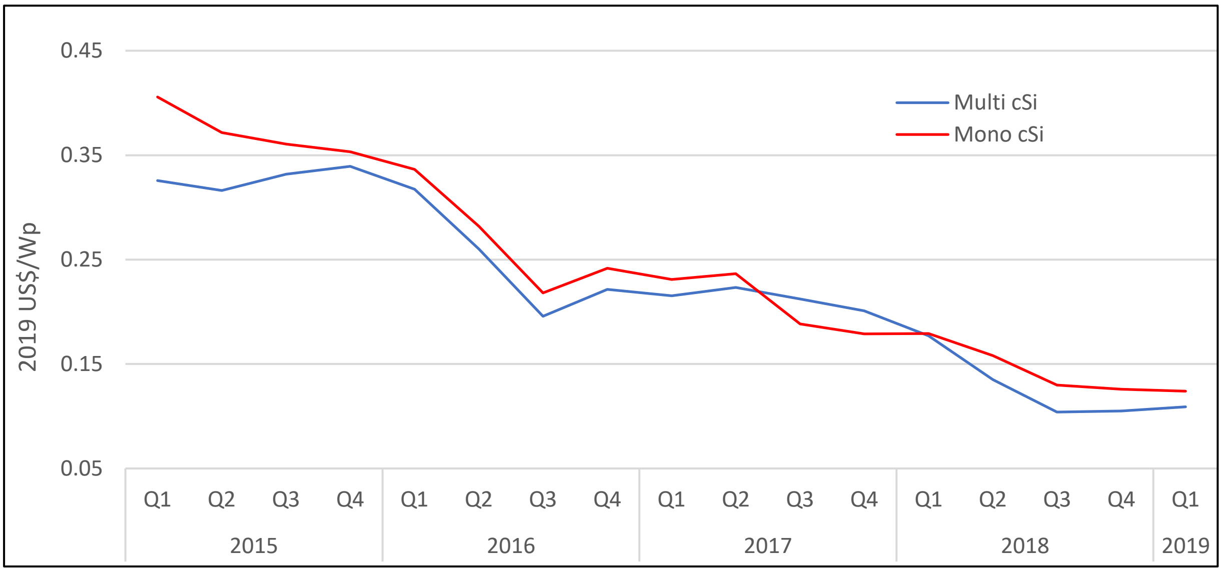


Figure 3.10 Evolution of average market spot prices of crystalline silicon cells, at the end of quarters (Source: Becquerel Institute, based on EnergyTrend and PVInsights)

This creates new opportunities for manufacturers of BIPV elements. In addition to these decrease of costs, technological improvements have been introduced on the market such as, among others, increased efficiency of PV cells, improved coatings, enhanced system performance monitoring and optimization or better mounting systems.

Another driver in BIPV, due to its condition of building component, is its aesthetical aspect. This has been significantly improved in the recent years without harming the cost competitiveness of BIPV solutions. For instance, thanks to an increased use of thin-film technologies like CIGS and CdTe, which are less limitative and more appealing than squared blue crystalline silicon-based cells. In addition, various companies have focused on developing colored films/coatings and glass treatment, applicable to all PV technologies. These films/coatings allow to customize the BIPV elements with various colors, or even a specific printed pattern, without losing to much efficiency. It is common to have 20 to 40% reduction on the STC power and up to 50% losses on the efficiency value. The latter depending of the chosen color and the coating technology. Among recent innovations, PV modules having the same shape and terracotta color as classic tiles or white PV modules can be cited. Also, with these thin-film PV technologies, it is now possible to make the modules transparent and modify the transparency-level in function of customer needs, which widen the range of potential applications for BIPV elements. This is in line with a crucial demand of customers and particularly architects, which is to guarantee design freedom. For this purpose, customization possibilities are needed but might not be a must-have for all manufacturers in the future. Indeed, as for regular construction materials, there are and will be multiple BIPV products from various manufacturers available on the market, each of these having its own technical and aesthetical characteristics. Hence, there will be in any case a wide range of possible choices for architects on the market, without the need for suppliers to invest in products' customization capabilities.

Then, another driver of the development of BIPV is that the market is very competitive, with many actors proposing their own products and/or technology. As displayed in a previous section, for each type of building and application area, multiple solutions exist, with different aesthetics, performances and different PV technologies. In Europe itself, there are more than 100 companies having BIPV products in their portfolio. Most of these companies are exclusively active in BIPV, but a substantial share was initially active in PV, and other industrials are coming from the construction and building sector. This has advantages, such as pressure on price and variety of choice for customers, but also its drawbacks: each company develops its own system, preventing the appearance of standardized products or mounting systems, as well as limiting the potential for economies of scale.

Concerning the effects of the changing buildings-related regulatory environment, even though they are difficult to quantify, they are substantial and certain. They should be considered as key tools for policymakers to initiate a top-down pressure for more renewable energy solutions, e.g. BIPV, into the built environment. In Japan for example, the regulation on "Zero Energy Buildings" clearly contributed to the stimulation of the demand for building applied and integrated photovoltaics, in all segments. In Europe as well, it can be noticed that the closer we are getting to the mandatory date of compliance with Nearly Zero Energy Building for new constructions, the higher the interest and demand for BIPV. In Switzerland for example, the new building energy regulation (MUKEN 2014) imposes for new constructions to have 10W of PV for each square meter of heated area. For multifamily houses, therefore, it means that the façade should be at least cladded partially with BIPV. In addition, these regulatory changes can stimulate the supply-side of the market, thus reinforcing the previously mentioned factors, as demonstrated in the past in Italy or France. Although the viability of this industry without incentives remains to be proved. [6]

Finally, the last significant explanatory factor of the rising attractiveness of BIPV systems is linked to value perception. More and more building owners and occupants are seeing an interest in installing a (BI)PV system because it adds a "green" and sustainable value to the building. In the case of tertiary buildings, this environmental-friendly aspect can also be valued through certifications such as BREEAM or LEED, which are internationally recognized and grant "points" in their evaluation process to on-site electricity generation sources. For owners, this could result in a higher sale- or rent-price. In addition, thanks to its environmentally friendly and original aspect, a chain effect is highly possible. A first BIPV installation in a neighborhood could enhance significantly the chances of a second installation in the same neighborhood.

3.6 Remaining obstacles

Despite the effects of these stimulating factors, barriers to further deployment of BIPV still exist. These remaining obstacles have been summarized in the table below and split in four categories. These are based on discussions with different stakeholders of the BIPV sectors such as manufacturers, installers, architects, consultants, researchers, final customers and real estate developers. Moreover, it partially builds on other studies investigating the same problematic. [9] [10] [11] [12] [13]

Table 3.2 Summary of barriers to the deployment of BIPV solutions (Source: Becquerel Institute)

Structural & Regulatory	Economic	Technical	Socio-Psychological
Lack of collaboration between stakeholders: PV, construction and real estate sectors do not communicate enough	Additional cost of BIPV compared to BAPV and regular construction material which can be discouraging	Lack of field data on degradation level and system performances	Lack of knowledge among professionals of the construction sector
Complex and inappropriate regulatory framework	Lack of possibilities to monetize PV electricity production	Lack of standardized products (e.g. mounting systems)	Lack of awareness among the public
Unstable regulatory environment, such as unexpected modifications and retroactive measures	Lack of valorization of renewables in the built environment	Lack of clearly defined maintenance procedures	Aesthetical possibilities of BIPV elements are still too limiting for some architects
Lack of standards and codes combining PV and building requirements	High up-front cost and long-term payback	Ability of some buildings' structures is insufficient to carry BIPV elements' weight	

Regulatory and socio-psychological barriers mostly influence the confidence of investors and final customers. As a consequence, it directly impacts the amount of time and resources that BIPV manufacturers and installers must spend to settle a contract, also referred to as the customer acquisition cost and financing costs, as well as their ability to secure financing. Typically, these barriers explain why customer acquisition costs and transaction costs are so high in BIPV. Regarding the lack of knowledge of the construction sector, this is partially due to the resistance to change of the sector, but also to the overall lower educational level of its workers. Nonetheless, recent research proved that the average skill-level of workers in the construction sector has been increasing in the last decade, and that this trend should remain. [14] In addition, more than 94% of companies active in the construction sector, in Europe at least, have a workforce of less than 10 people. [15] For such small companies, it is more of a problem

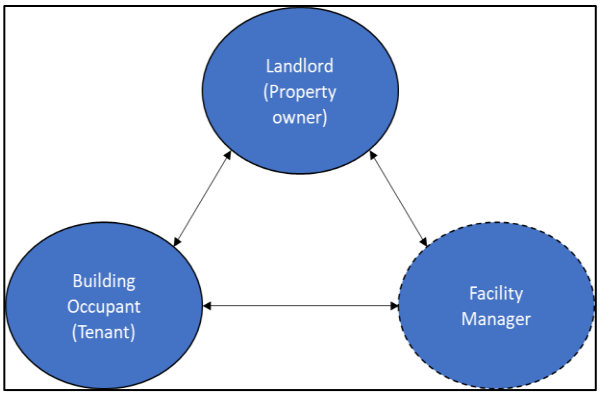


Figure 3.11: The three key stakeholders involved in case of renting of tertiary building

to adapt and stay up to date with latest technological developments, or to recruit new employees with specific expertise. As far as architects are concerned, aesthetical possibilities that are still too limited combined with a lack of appropriate BIPV software that would allow the early integration of BIPV in the design are two main barriers.

Economic barriers, on their side, refer to the profitability of the investment and the possibilities to value BIPV solutions. Except in some specific cases, namely for some residential roofing solutions or simplistic façade cladding, BIPV solutions are substantially more expensive than BAPV systems and regular building components, even though we have seen important progress in the last decade. As price is the primary factor leading the decision-making process, it limits the ability to stimulate demand for BIPV. Then, possibilities to monetize the PV electricity production are limited, and the regulatory environment is still unstable and inappropriate in multiple countries, therefore it is extremely difficult to develop profitable business models. But it also fails at valorizing the extra features linked to BIPV, like building-related functions. This factor is also often negatively influenced by the previous ones, i.e. regulation and standards. Finally, most competitiveness assessment of BIPV do not include both PV- and building-related values. Moreover, there is a general lack of confidence among stakeholders, such as insurance companies. This lack of appropriate regulation is more impactful in some specific cases. For example, if the building is not occupied by its owner, it is difficult to define an attractive business case for a BIPV investment. This is mainly due to the lack of an appropriate regulatory context at a European scale for example and innovative business models. Considering the significant share of the European building stock, which is rented, both in case of residential or professional occupant, it highly limits the demand for BIPV products as long as self-consumption extended to whole rented multifamily buildings is not developed more.

Then, technical barriers mentioned here influence profitability as they directly impact the installation process and its cost. Some of these barriers, namely the lack of standards and the lack of field data, also negatively influence potential investors and final customers, leading to similar consequences as mentioned here above. Furthermore, the lack of standardized products and procedures, such as mounting systems or for cabling and connection, currently limits the future replacement and upgrade potential of BIPV system. Indeed, it could be time- and money-consuming to replace BIPV modules, if, possible at all. Ultimately, it leads to insurance problems and an overestimated risk-perception. Moreover, there is a lack of information on BIPV systems' performances and degradation level under certain configurations. It can also complicate the maintenance processes and the recycling chain. Globally, the lack of harmonized regulatory standards is recognized as a general problem of the construction sector. Harmonization is being promoted by the European Commission as one of the main focus points of the future, which is encouraging. [16] When it comes to harmonization and standardization, a compromise should be found to also take into account the limited aesthetical possibilities for architects.

Another impactful obstacle in the case of BIPV projects is the involvement of many stakeholders, with different expertise and background, as well as different objectives. Fostering collaboration and mutual comprehension is crucial to make a BIPV project a success, eventually ensuring a smooth development process and limiting costs such as transaction costs or the duration of the design phase, for example. Moreover, the lack of cooperation has indirect harmful consequences, such as non-optimal BIPV system's design, potentially leading to sub-part performances. Also, it contributes to maintain socio-psychological barriers, which favor a high difficulty- or risk-perception of BIPV projects, thus artificially inflating some sources of cost, like financing and final installation. Another possible side-effect, occurring in some projects and due to this perception problem is the higher-than-usual insurance costs.

Globally, there are two value chains which should be integrated, one having the electrical and PV expertise and the other the structural and building expertise. Also, experts combining the two expertise are missing. It is also interesting to note that it has been pointed out by collecting the point of view of different stakeholders on market barriers and market drivers, that while the different stakeholders (architects, authorities, manufacturers, engineers and developers) have similar opinions on what the market drivers for BIPV are, their points of view differ when it comes to market obstacles. Indeed, high up-front costs and long-term payback periods are of secondary importance for BIPV manufacturers while it is one of the main barriers for the other stakeholders for example. Similarly, the integration if the BIPV system to the grid is a major concern for architects and designers while it is not for engineers. [13]

3.7 Total addressable market

Perspectives for BIPV market development have always been a topic of interest within the PV sector. In the last decade, building integrated photovoltaic applications have often been considered as the next possible growth path for PV, but this never materialized to significative deployment.

In this section, we will try to give an overview of what is the potential size of the BIPV market in seven European countries that are involved in the BIPVBOOST project. This can be done using two different methodologies that we developed. Firstly, a “supply-side” method is applied, based on the BIPV “suitability” of the existing building stock. This suitability criterion is defined in terms of architectural and solar irradiation characteristics. The second step consists in a “demand-side” analysis, based on the average electricity demand of the same existing building stock. For both methodologies a low and a high scenario are proposed.

3.7.1 Supply-side analysis

The approach developed here below differs from the market forecasts as they present quantified estimation of the theoretical market potential of BIPV. It means that such evaluation is independent from all the existing technical, regulatory or economic constraints that still exist. Hence it does not reflect the current reality of the end-market. But it provides valuable food for thoughts by giving an idea of what BIPV could represent in Europe.

Various studies have been published on the topic of BIPV market potential estimation. [17] [18] These focus on what we call the “supply-side” potential, i.e. what available surface could be provided by the building stock, which can be considered in the case of BIPV as the supplier of electricity. Based on the methodology developed by IEA PVPS Task 7, reassessed in a conference paper in 2016, the technical power potential of BIPV on the existing building stock is estimated. [17] [19] The methodology has been adapted to include supplementary criteria, for example on the occupancy profile or base on the year of construction of the building. This information has been retrieved from the “European Building Stock Observatory”. [20]

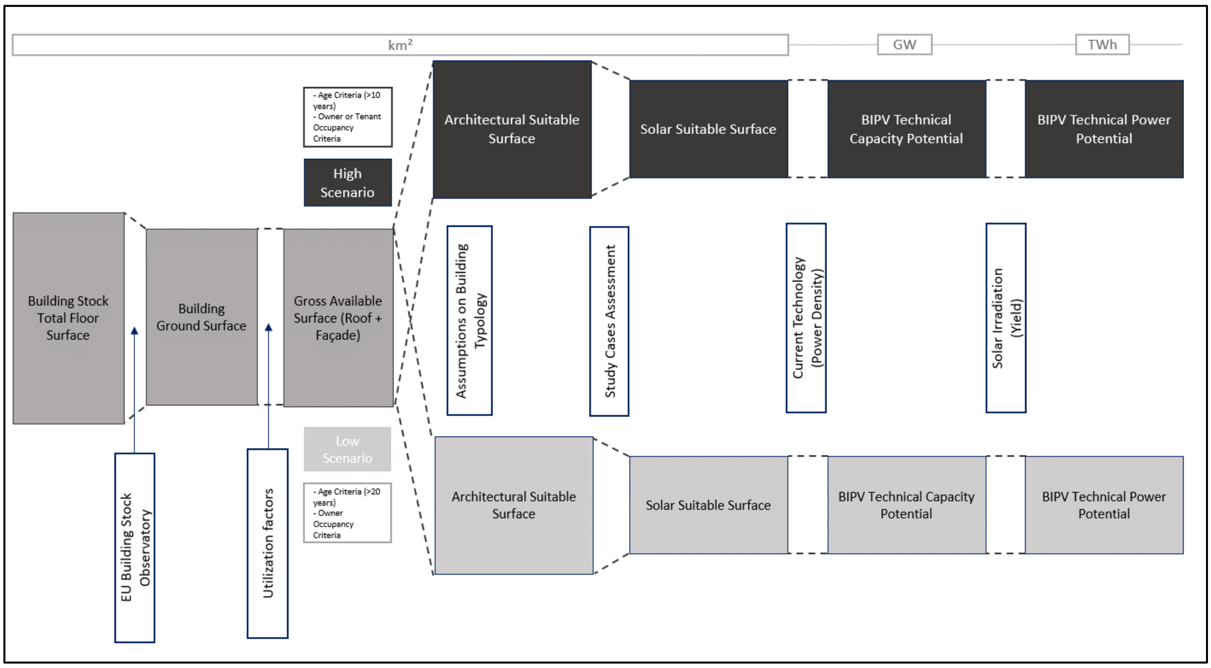


Figure 3.12 Simplified overview of the "supply-side" methodology (Elaboration by Becquerel Institute, based on [17] [19])

The starting point of this methodology is the total building floor surface of a given country including residential and non-residential buildings based on an analysis of the available buildings' datasets (EU Building Stock Observatory). From this total floor surface, the total ground surface can be computed, with some assumptions on building's typology. It is then converted into gross available roof and façade surfaces by using "utilization factors". These factors are different depending on whether the gross roof surface or the gross façade surface is calculated, and they can also depend on the chosen sector (residential or non-residential). The utilization factor used for roofs is considered the same for both sector and assumes an average roof tilt of 30°, while the utilization factor used for façades differs depending on the sector and takes into account the average floor surface and the average floor height.

The computed gross available surface is then refined. A first filtering is applied so that only "architectural" suitable surfaces remain. It means that shading areas, surfaces occupied by other elements like HVAC on roof, or windows on façade, are casted aside. Furthermore, at this stage two scenario are developed. In the first one, defined as the "low scenario", only buildings built more than 20 years ago and occupied by their owner are considered. In the "high scenario", buildings built between 20 and 10 years ago are added and the occupancy-related condition is removed. It is assumed that owners of buildings more recent than 10 years will not consider doing any renovation on the short term.

Then, a second filtering is applied, allowing to keep only the surfaces that are "solar suitable". In other words, only architecturally suitable roof and façade surfaces where the irradiation amounts to at least 80% of the maximum solar irradiation (i.e. at optimum tilt and azimuth for roofs and at optimum azimuths only for façades) that can be reached at this specific location. Note that a hypothetical case with no shading from other buildings or other elements is considered.

Eventually, the architectural and solar suitable façade and roof surfaces resulting from one estimated ground square meter respectively equals 0,10 m² and 0,40 m², approximately (in the case of resulting façade surfaces, the value must then be adapted depending on the assumed number of floors).

Based on typical BIPV power density (15% was considered a representative average efficiency for BIPV systems) and on the resulting surface, what could be the capacity installed can be quantified, would this surface be completely covered with BIPV. The capacity can then be translated into electricity generated using an average yield value. For this purpose, an average yield has been calculated separately for roof and façade applications[2]. The average was based on different geographical locations (north, middle and south of each country), on different tilts in the case of roofs (flat roof and 30° roofs) and on different azimuths in the case of façade (west, east and south orientation). The calculations for theses average yields are resumed in the formulae below and the values for the different countries are given in Table 3.3.

$$Y_{Roof} = \left(\frac{Y_{N;30°;S} + Y_{N;0°;/} + Y_{M;30°;S} + Y_{M;0°;/} + Y_{S;30°;S} + Y_{S;0°;/}}{6}\right)$$

$$Y_{Façade} = \left(\frac{Y_{N;90°;S} + Y_{N;90°;W} + Y_{N;90°;E} + Y_{M;90°;S} + Y_{M;90°;W} + Y_{M;90°;E} + Y_{S;90°;S} + Y_{S;90°;W} + Y_{S;90°;E}}{9}\right)$$

Where

- Y_{Roof} = the yield used for roof applications
- $Y_{Façade}$ = the yield used for façade applications
- $Y_{X1;X2;X3}$ = the yield in the location X1 (N = North, M = Middle, S = South) for the tilt X2 and the azimuth X3 (S = South, W = West, E = East, / = Not applicable)

Table 3.3 Considered yields for the supply-side approach

Country	Belgium	France	Germany	Italy	Netherlands	Spain	Switzerland
$Y_{façade}$ [kWh/kWp]	848	1030	904	1255	860	1296	942
Y_{roof} [kWh/kWp]	533	627	580	748	558	775	568

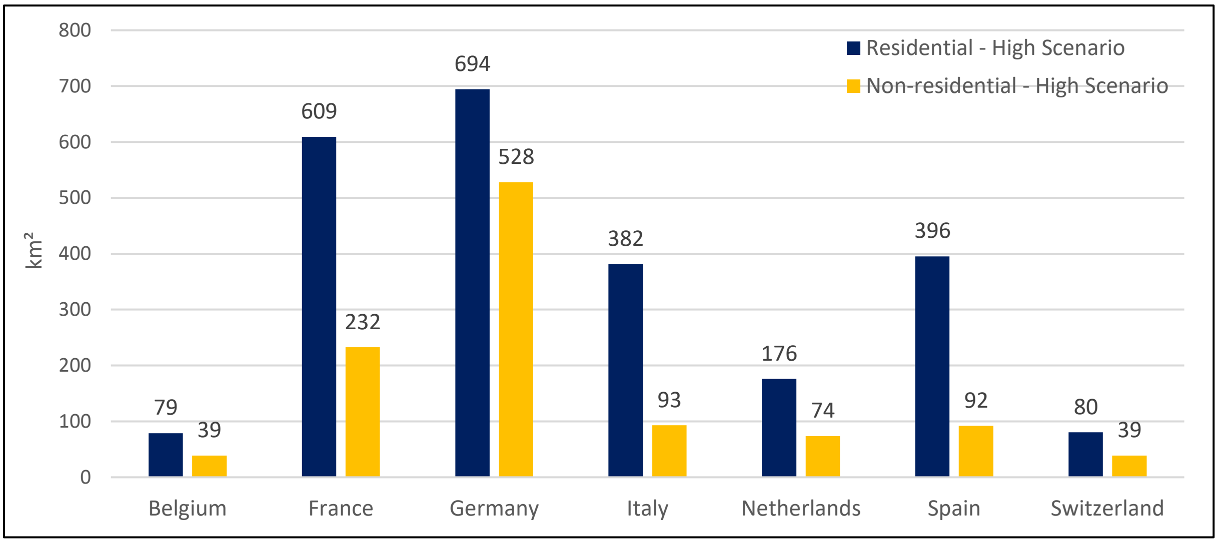


Figure 3.13 Total suitable surface for BIPV in various European countries in the high scenario (Elaboration: Becquerel Institute)

As it can be seen on the Figure 3.13 and Figure 3.14, the potential available space to install BIPV is important, even in small countries, like Belgium or Switzerland. Difference between countries can be mainly explained by differences in building stock's characteristics. For example, Spanish and Italian total

[2] The software BIMSolar has been used for yield calculations

suitable surfaces, especially on roofs, are significantly smaller than German or French ones because of the characteristics of the residential segment. Indeed, in these southern countries, multifamily buildings are much more numerous than single-family houses. Hence, in such configuration, the roof surface per inhabitant is much smaller. Average available façade area is also impacted, though to a lesser extent. In addition, roof and façade spaces in Spain and Italy are also often occupied by cooling systems, unlike France (at least for the Northern half) and Germany, where heating system devices do not require to be placed on the building envelope. In addition, the “supply-side” approach has demonstrated that the theoretical potential for BIPV deployment in Europe is significant.

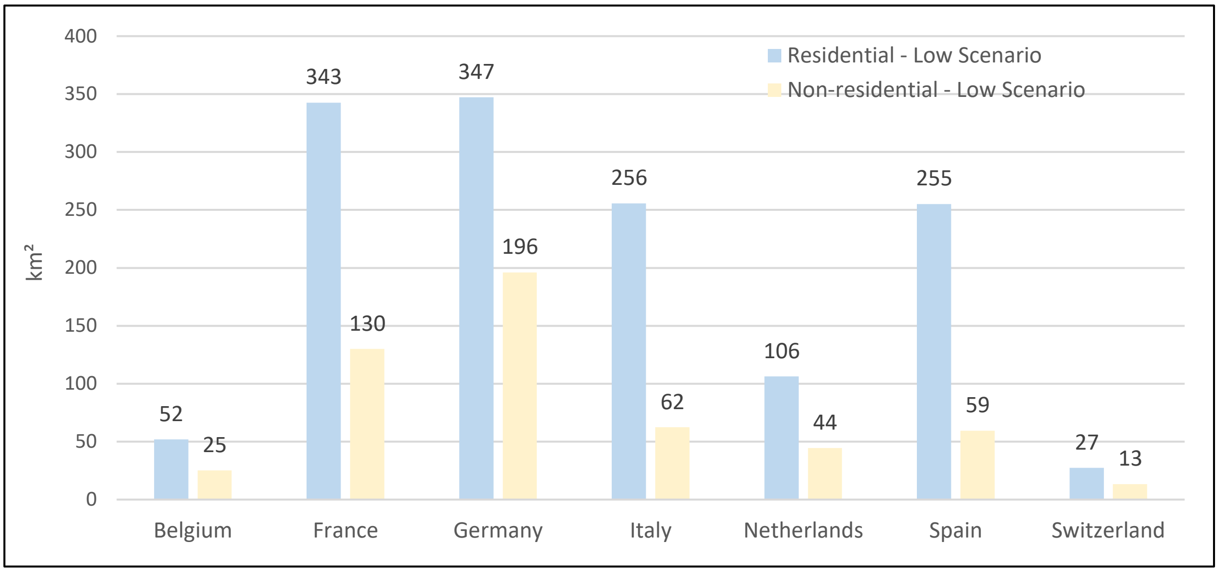


Figure 3.14 Total suitable surface for BIPV in various European countries in the low scenario (Elaboration: Becquerel Institute)

Speaking of nominal installed BIPV capacity, these suitable surfaces could represent 335 GWp for the residential sector and 136 GWp for the non-residential sector in the high scenario. The most striking differences between both scenarios can be seen for Switzerland and Germany. This can be explained by the fact that in those two countries, the shares of buildings occupied by their owners (respectively 32% and 53%) are one of the lowest of the seven considered countries, thus increasing the gap between the low and high scenario.

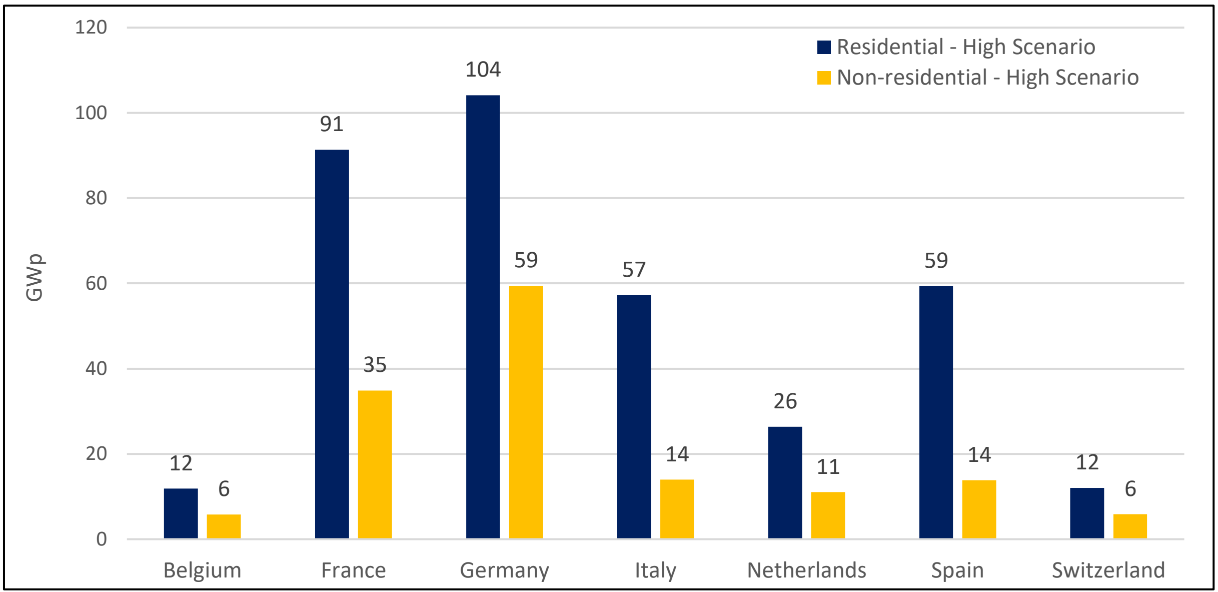


Figure 3.15 Potential of BIPV capacity in target European markets in the high scenario (Elaboration: Becquerel Institute)

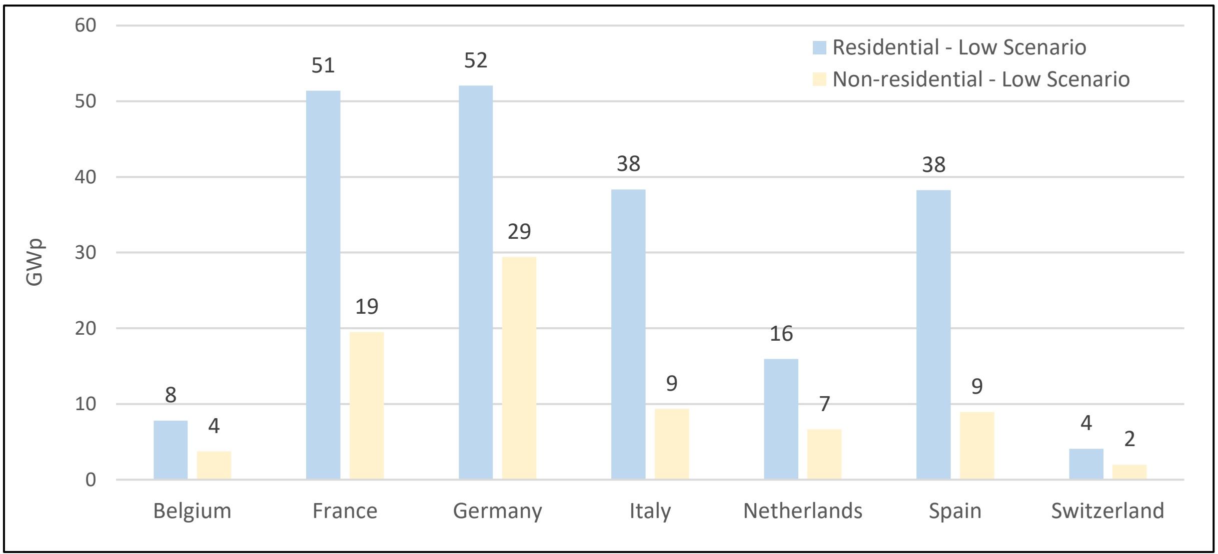


Figure 3.16 Potential of BIPV capacity in target European markets in the low scenario (Elaboration: Becquerel Institute)

To illustrate differences among countries and take into account the capabilities and dynamics of the construction sector, the yearly average rates of renovation and of new constructions are applied to the computed supply-side potential. It thus provides an estimation of the potential annual market for BIPV solutions. The resulting numbers, presented on Figure 3.17 and 3.18, are still promising, despite being obviously much less impressive than the estimations shown on Figure 3.15 and 3.16. It can be seen that the conditions of the construction sector have a significant impact, and that the number of buildings and their associated surfaces are not the only key factors. For example, France, which has a dynamic construction sector thanks to favorable fiscal conditions shows a much higher annual BIPV potential; whereas it is noticeable that the Italian and Spanish construction market is hindered by gloomy economic situation. Belgium and the Netherlands are confronted to a comparable situation as Italy, though of a lesser magnitude. Their construction sectors are very conservative and cost-sensitive, hence less dynamic and rather reluctant to change, which limits the annual potential. The estimated annual potential could even be improved if the construction sector is somehow stimulated and/or the regulatory framework adapted.

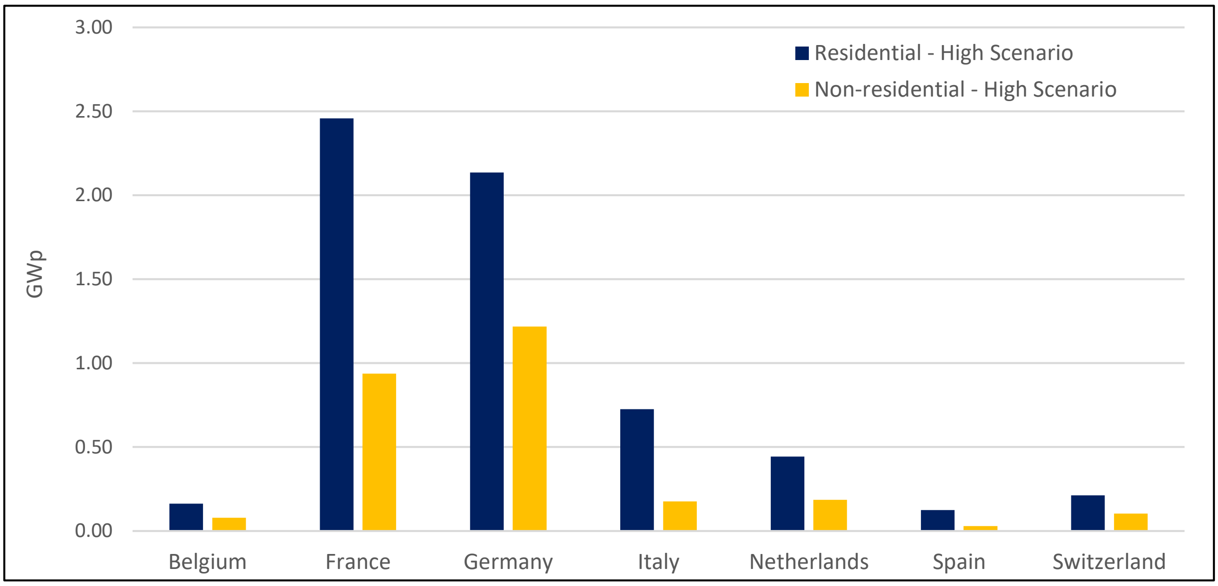


Figure 3.17 Annual potential market of BIPV capacity in target European markets in the high scenario (Elaboration: Becquerel Institute)

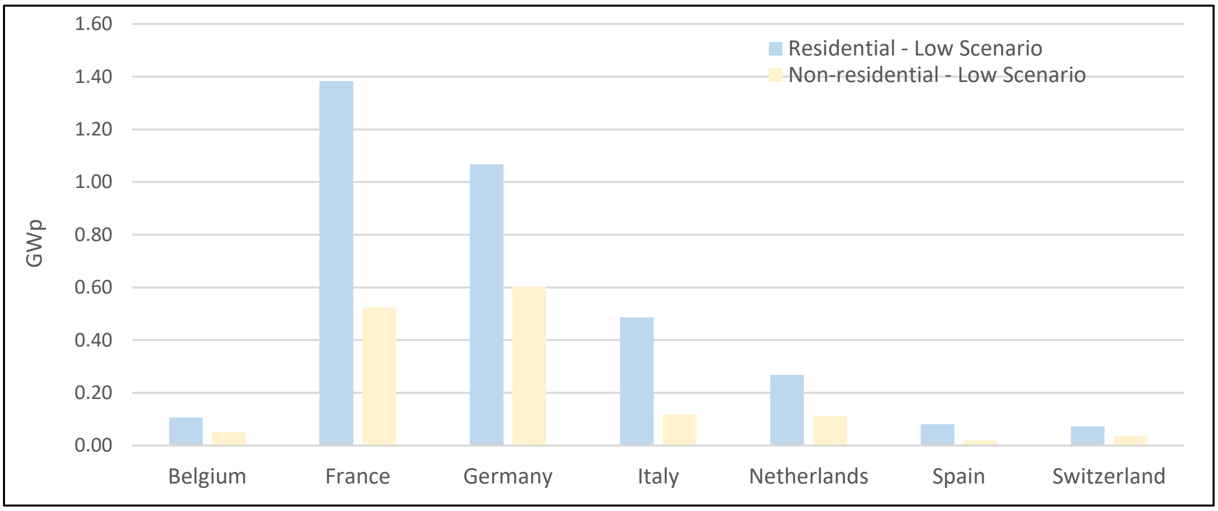


Figure 3.18 Annual potential market of BIPV capacity in target European markets in the low scenario (Elaboration: Becquerel Institute)

Figure 3.19 and 3.20 show the potential electricity that could be generated by covering these suitable areas with BIPV elements. Amounts are significant, and we see that thanks to more generous solar irradiation, Spain and Italy catch up with France or Germany.

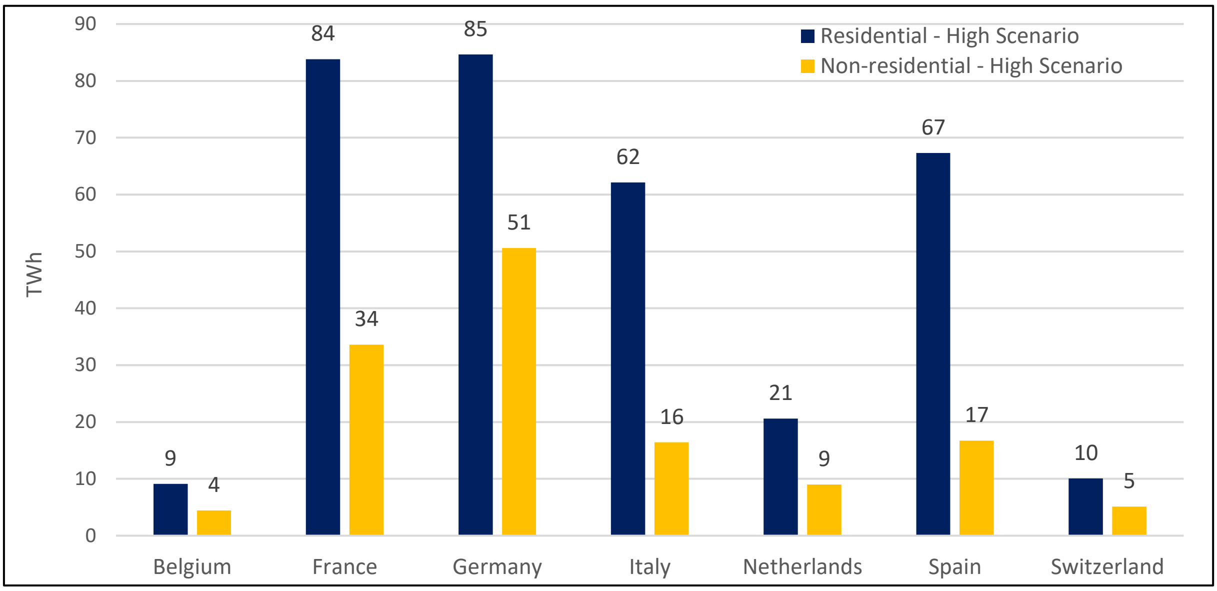


Figure 3.19 Potential of BIPV generated electricity in target European markets in the high scenario (Elaboration: Becquerel Institute)

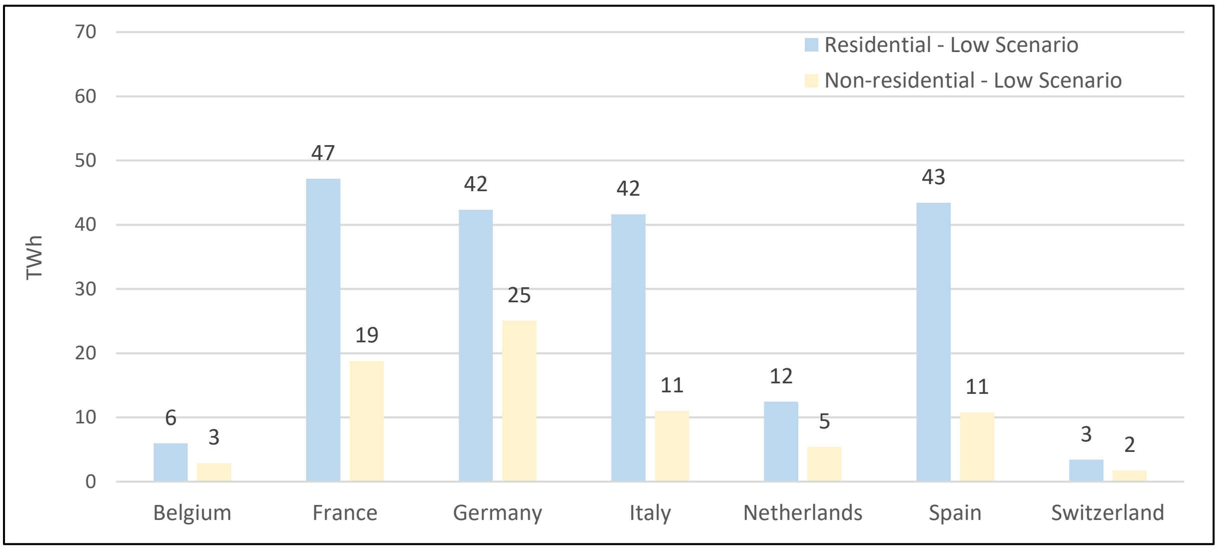


Figure 3.20 Potential of BIPV generated electricity in target European markets in the low scenario (Elaboration: Becquerel Institute)

Finally, in relative terms, this production would be enough to cover 25%, on average in the high scenario (13% in the low scenario), of the total annual electricity consumption of the country (not only linked to the building sector) as seen on the chart below.

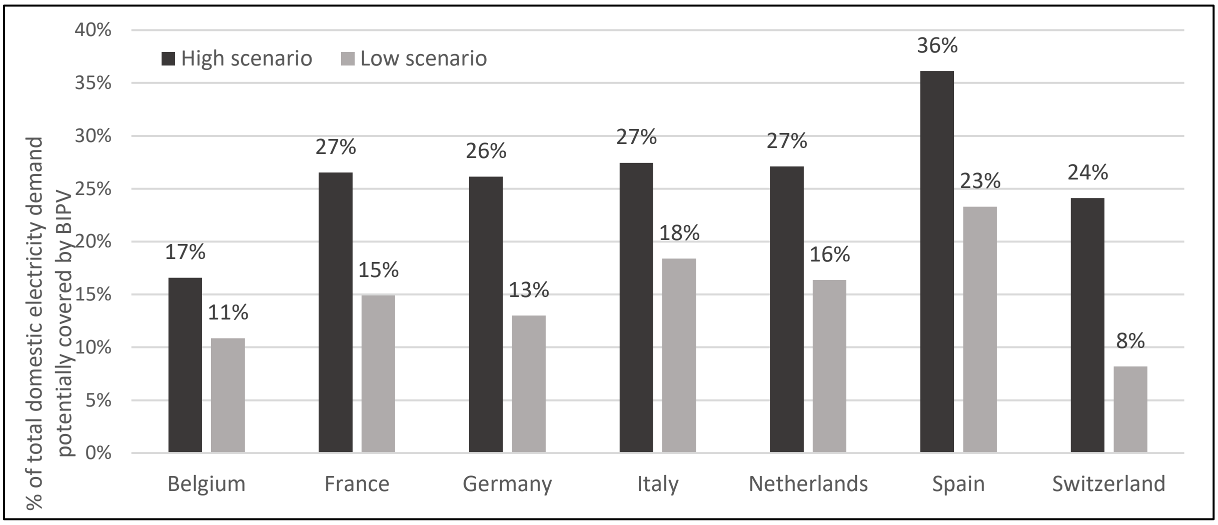


Figure 3.21 Technical potential of BIPV to cover electricity demand in European countries (Elaboration: Becquerel Institute)

3.7.2 Demand-side analysis

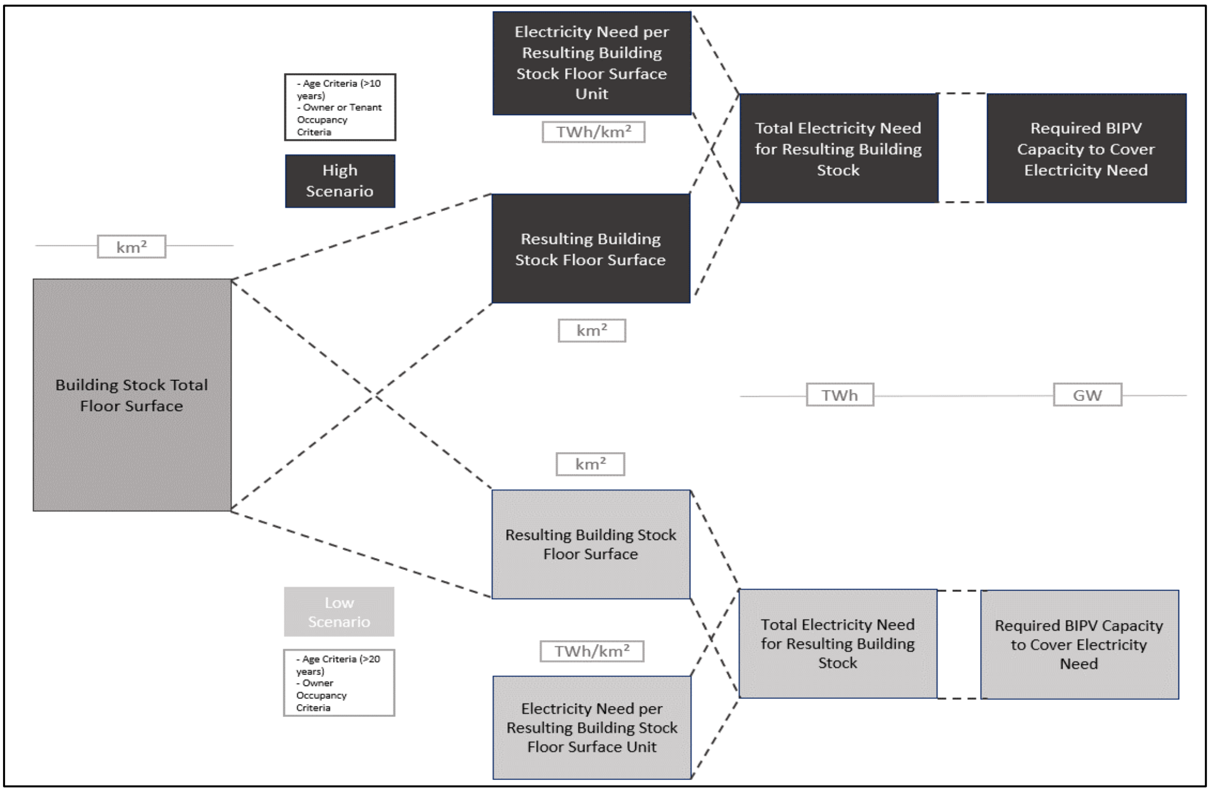


Figure 3.22 Simplified overview of the "demand-side" methodology (Elaboration: Becquerel Institute)

The general idea of the demand-side approach is to consider the average electricity consumption of buildings and to determine which installed BIPV capacity would be needed to cover this final electricity demand.

The starting point of this methodology is the total building stock of a country. It is then reduced to buildings that follow specific criteria (age and occupancy) as presented for the supply-side approach. The age criterion consists in keeping only the buildings that were built more than ten years ago in the high scenario and more than twenty years ago in the low scenario. The occupancy criterion gathers only buildings that are occupied by their owners in the low scenario while also including tenants-occupied building in the high scenario. Therefore, the building stock as a whole is studied, without considering each building's singularity such as the ability to welcome a BIPV installation. Nevertheless, it is estimated in this approach, as a simplification assumption, that any buildings' envelope could cover its own electricity needs. Once this suitable building stock has been decomposed, the corresponding floor surface is deduced. Based on this surface and on the average electricity consumption per floor surface unit, the total electricity demand of the determined buildings can be calculated. Using an average system yield value for each country, the capacity required to cover the electricity demand can be further computed.

To determine which yield value to use, the hypothesis has been made that BIPV roof installations account for 60% of the total BIPV capacity installed in the residential sector, and 40% in the non-residential sector, the rest being façade installations. To take that into account, a technical average has been calculated for roof installations by considering yields resulting from flat and 30° roofs as well as a geographical average on yields from different locations in each country (South, Middle and North) and by different azimuths. The same process has been used for façade installations. Then a weighted average has been determined with the 40 to 60 proportion. The calculation process for the residential and non-residential yields is detailed below and the yield for each country are summarized in Table 3.5.

$$Y_{Res} = 0{,}4 * \left(\frac{Y_{N;90°;S} + Y_{N;90°;W} + Y_{N;90°;E} + Y_{M;90°;S} + Y_{M;90°;W} + Y_{M;90°;E} + +Y_{S;90°;S} + Y_{S;90°;W} + Y_{S;90°;E}}{9}\right)$$
$$+0{,}6 * \left(\frac{Y_{N;30°;S} + Y_{N;0°;/} + Y_{M;30°;S} + Y_{M;0°;/} + Y_{S;30°;S} + Y_{S;0°;/}}{6}\right)$$

$$Y_{Non-Res} = 0{,}6 * \left(\frac{Y_{N;90°;S} + Y_{N;90°;W} + Y_{N;90°;E} + Y_{M;90°;S} + Y_{M;90°;W} + Y_{M;90°;E} + +Y_{S;90°;S} + Y_{S;90°;W} + Y_{S;90°;E}}{9}\right)$$
$$+0{,}4 * \left(\frac{Y_{N;30°;S} + Y_{N;0°;/} + Y_{M;30°;S} + Y_{M;0°;/} + Y_{S;30°;S} + Y_{S;0°;/}}{6}\right)$$

Where

- Y_{Res} = the yield used for the residential sector
- $Y_{Non\text{-}Res}$ = the yield used for the non-residential sector
- $Y_{X1;\,X2;\,X3}$ = the yield in the location X1 (N = North, M = Middle, S = South) for the tilt X2 and the azimuth XA (S = South, W = West, E = East, / = not applicable)

Table 3.4 Considered yields for the demand-side approach

Country	Belgium	France	Germany	Italy	Netherlands	Spain	Switzerland
Y_{res} [kWh/kW]	722	869	775	1052	740	1088	793
$Y_{non\text{-}res}$ [kWh/kW]	659	789	710	951	680	984	718

Figure 3.23 and 3.24 give the results of these calculations. It can be viewed as a “stock” of potential demand. However, these figures must be moderated by the fact that all this market potential cannot be tapped that easily. Apart from the problematic regulatory conditions evoked in the previous lines, other aspects come into play. Most importantly the capability to actually reach the target customers and install these solutions. To do so, collaboration with the construction sector is crucial, and knowing the constraints linked to it, in every country, is crucial.

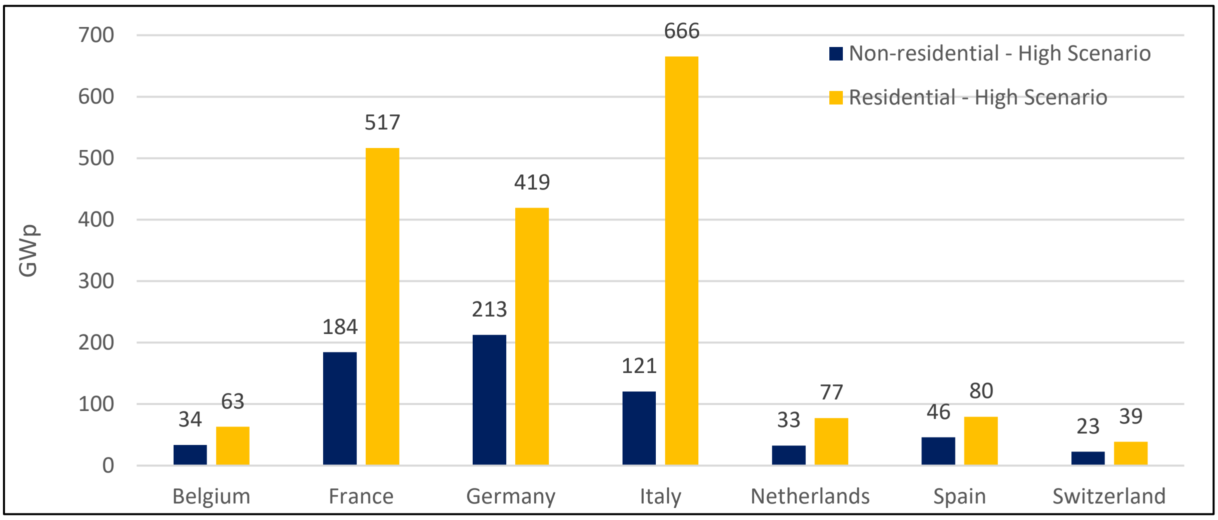


Figure 3.23 Stock of "demand" for BIPV in the residential and non-residential sector in key European countries, by 2019 for the high scenario

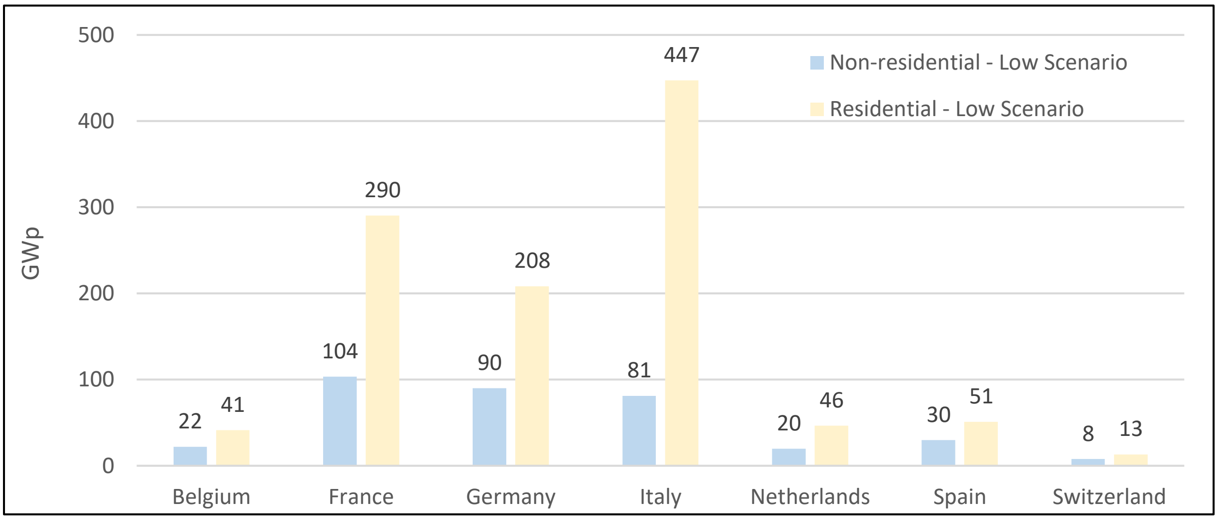


Figure 3.24 Stock of "demand" for BIPV in the residential and non-residential sector in key European countries, by 2019 for the low scenario

Then, the annual market potential has been calculated, following the same methodology as developed in the supply side approach.

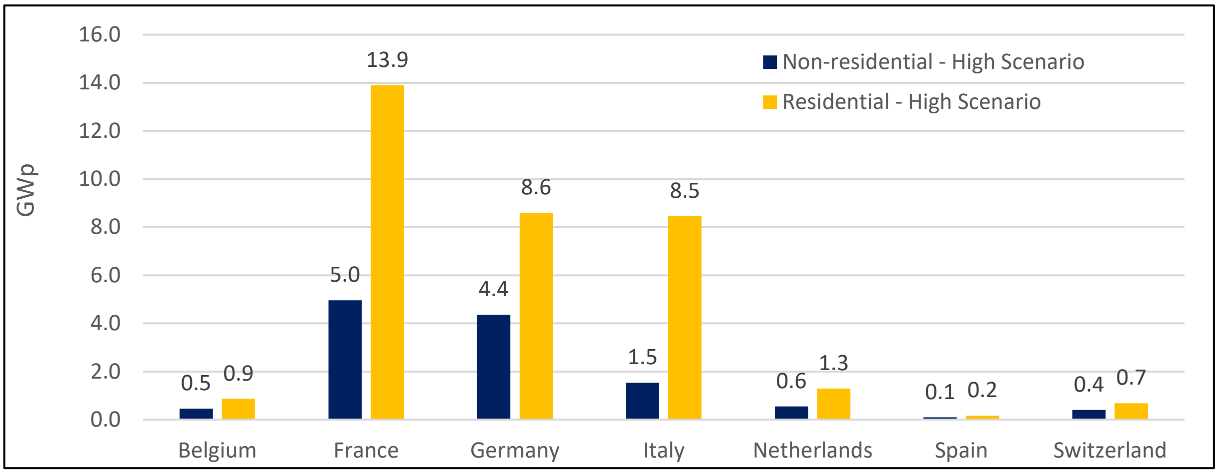


Figure 3.25 Annual market potential for BIPV in the residential and non-residential sector in key European countries, by 2019 in the high scenario

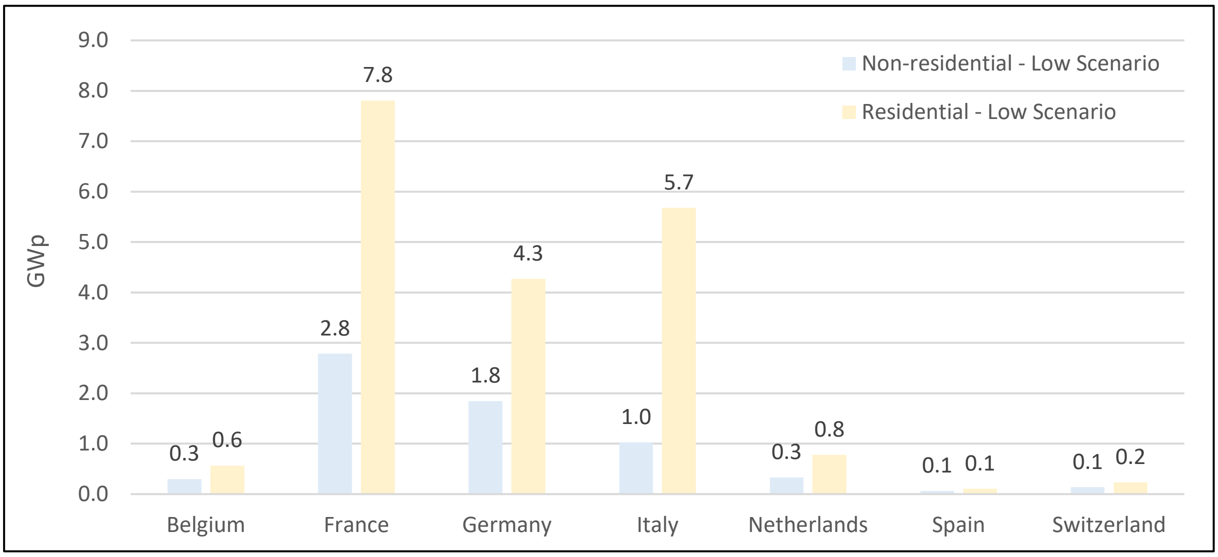


Figure 3.26 Annual market potential for BIPV in the residential and non-residential sector in key European countries, by 2019 in the low scenario

The resulting numbers, presented on Figure 3.25 and Figure 3.26, are still promising, despite being much less impressive than the estimations shown on Figure 3.23 and 3.24. The same remarks as for the supply-side can apply. Indeed, it can be noted that the conditions of the construction sector have a significant impact, and that the number of buildings, the total floor area or the electricity demand of non-residential buildings are not the only key factors. The dynamic construction market in France, or on the contrary the constrained Italian and Spanish construction market are again noticeable. The quite low figures for Spain, compared to other countries of similar size, can be explained by a combination of multiple unfavorable factors. Indeed, as far as the age criteria is concerned, Spain has the highest shares of the buildings built after 2000 and after 2010, which are not taken into account in the low scenario and only partially taken into account in the high scenario. In addition, high yields can be reached in Spain, diminishing the capacity needed to meet the electricity demand. Moreover, low renovation and construction rates are the reason for the little annual potential values, as already highlighted.

3.8 Comparison and interpretation of results

Figures 3.27 and 3.28 below give the potential capacity resulting from both approaches for the residential and non-residential sectors. Global results will be first commented.

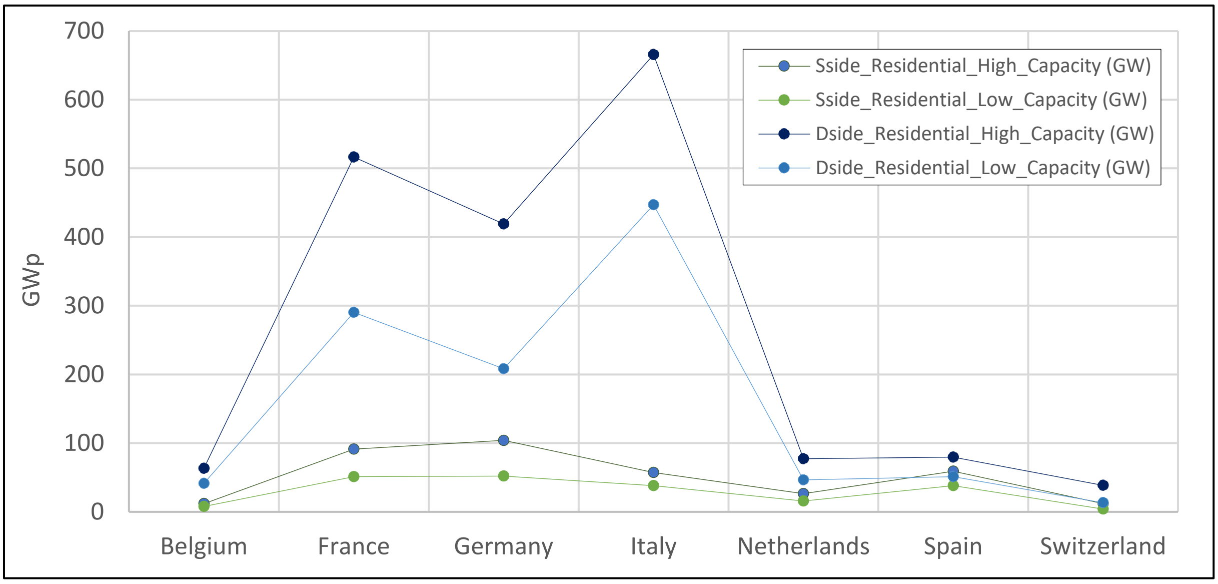


Figure 3.27 Comparison of demand-side and supply-side capacity potential results for the residential sector

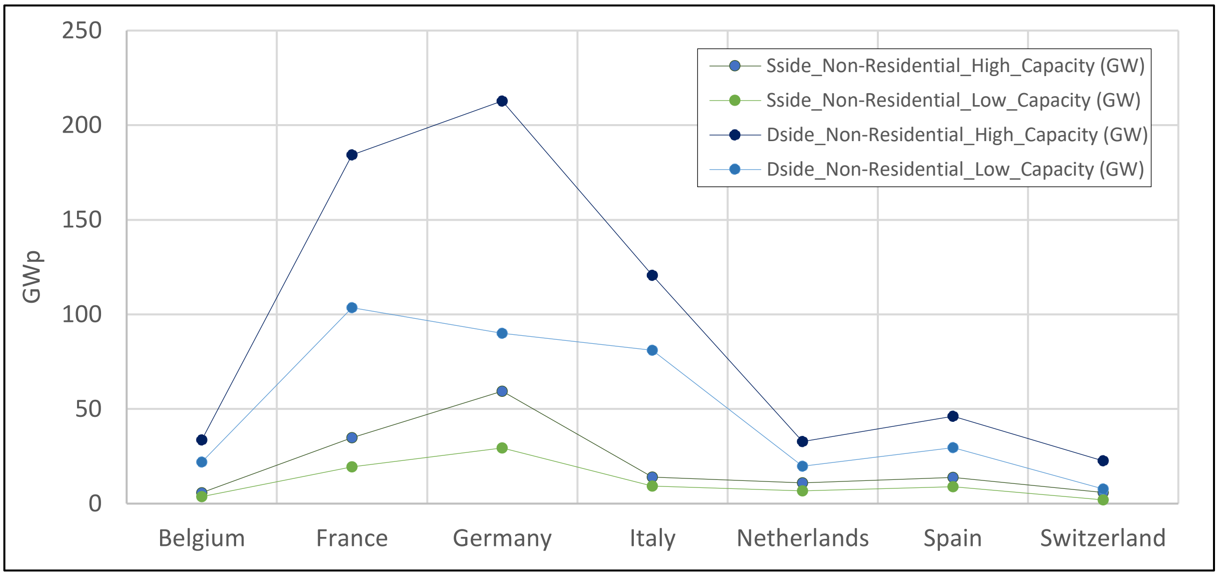


Figure 3.28 Comparison of demand-side and supply-side capacity potential results for the non-residential sector

For both residential and non-residential sectors, in countries where the capacity potential is relatively smaller such as Belgium, the Netherlands and Switzerland, the two different approaches give very similar results. On the contrary for Italy, Germany and France, the gap between the supply-side methodology and the demand-side approach is substantial, for both scenarios. Indeed, in Italy, the characteristics of the building stock reduces the suitable surface's supply while the electricity consumption of buildings is among the three highest in the European Union. As far as Germany and to a lesser extent France are concerned, the rather generous "supply-side" capacity is outranked by the high electricity consumption of buildings, thus it is not enough to cover the electricity needs. Nevertheless, in countries such as Belgium, Netherlands, Spain and Switzerland, the values are quite comparable. Therefore, by increasing

BIPV performances, leading to a higher supply potential, or by decreasing electricity consumption in the buildings thanks to improvements in terms of energy efficiency, the gap could be closed for those countries. BIPV solutions could then fully cover the electricity needs of buildings, both for residential and non-residential sectors.

Note that the supply-side defines a limit for BIPV capacity, as once all the available and suitable space has been covered, no more BIPV installations can be added. Nevertheless, its value can slightly increase if new buildings are added to the building stock or if technical performances such as conversion efficiency of modules are increased. The total addressable market for France and Italy can be put into perspective with the BIPV capacity that was already installed in those two countries. Around 2.500 MW and 2.700 MW represented the cumulative installed BIPV capacities in 2017 in respectively Italy and France. This numbers barely represent 2 to 4% of the national total addressable BIPV market (71.000 MW for Italy and 126.000 MW for France) given by the supply-side approach. Therefore, there is still much room for BIPV market in Europe to develop. Even if to some extent, a part of the identified “BIPV total addressable market” could be captured by (lightweight) BAPV installations, when it comes to roof surfaces, especially in case of retrofit.

Then, it is worth highlighting that the demand-side approach considers the electricity consumption of any building independently from its suitability (the defined solar and architectural suitability) for BIPV, as mentioned already. This simplifying assumption allows to consider the building stock as a whole and its consumption. Moreover, the demand-side approach currently gives a too unfavorable estimation of the total addressable market, which could be re-evaluated upwards in case of a more flexible regulatory framework. Indeed, today the demand-side approach is limited to the consumption of buildings only, as in most cases self-consumption of PV electricity must be done on site. Which tremendously restricts the possibilities to valuate PV electricity, inciting investor to limit the installed capacity in function of building’s occupant electricity demand rather than based on the available surface. Ideally, under a more appropriate and flexible regulatory framework, allowing for example collective self-consumption, the consumption considered in the demand-side approach would be almost equal to the total consumption of the country. Nevertheless, the regulatory environment for PV and BIPV in Europe should evolve in the medium-term, increasing the attractiveness of distributed PV and BIPV solutions by improving the ability to value generated electricity and thus, the results given by the demand side approach will be relevant and in line with the regulatory context.

Finally, when comparing both analyses, the supply-side can be considered as the true bottleneck when estimating the total addressable market for BIPV. Indeed, not only are the numbers summarized on Figures 3.27 and 3.28 showing that in any case the estimated “supply-side” capacity is always outranked by the calculated “demand-side” capacity, but the suitable surfaces on buildings’ envelopes can logically be treated as the limiting factor when it comes to BIPV deployment. Still, the identified addressable market remains significant, ranging from 6 GW in Switzerland up to 81 GW in Germany in the low scenario.

3.9 Market outlook

After having presented the total addressable market for seven European countries, in the previous sections, this part aims at giving global BIPV market forecasts in the short-term, i.e. the next three years.

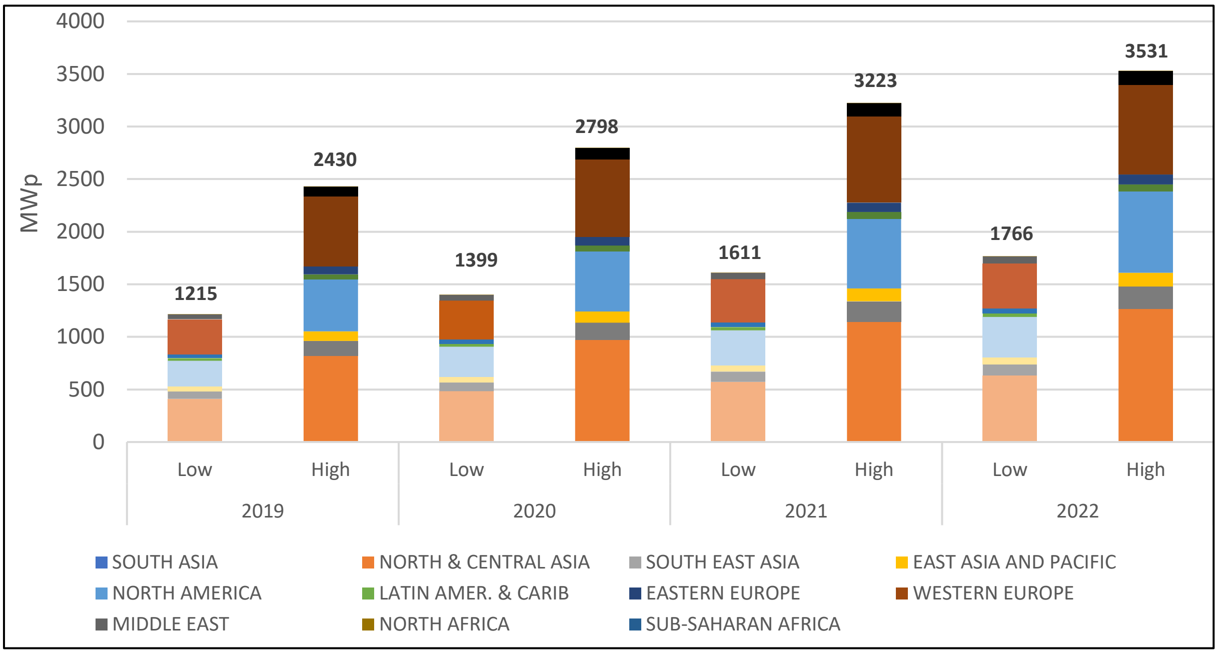


Figure 3.29 Forecasted global BIPV market in terms of installed capacity, under two scenarios [21]

Low scenario can be seen as a "business-as-usual" one, while the high scenario is an "improved conditions" scenario. That it is to say, such growth rates can only be achieved if a substantial number of the obstacles defined previously are overcome. For example, if the regulatory environment adapts, regarding distributed PV systems but also construction and buildings, and if BIPV stakeholders improve their cooperation, it could lead to the development of new, value-maximizing business models, ultimately rising the attractiveness of BIPV. In the case where market conditions would improve even more, for example if acceptance and knowledge of the public rise thanks to more commitments of policymakers, backed-up by significant technological improvements, optimizations and cost reductions along the BIPV value chain, and with a revival of the construction industry, market growth rates could potentially be even higher. Indeed, under such conditions, part of the European BAPV market could shift to BIPV solutions. This market segment represents great opportunities as it has historically been an important segment in Europe and is foreseen to remain dynamic, with multi-GW's at the European scale. [22] Although, such optimistic vision cannot be envisaged in the short-term. It is estimated that such paradigm shift could not occur before 2025, considering the aforementioned obstacles. Considering today's market environment, BIPV deployment is more likely to follow the low scenario curve, in the short-term.

Looking at the global trends, it is forecasted that by 2022, the leading regions in the BIPV sector in the world will be North & Central Asia (including China and Japan), Western Europe as well as North America.

For the same reasons evoked in a previous section about the estimation of the cumulative BIPV market, forecasting BIPV markets is a difficult exercise. Hence, as shown on Figure 3.30, forecasts can highly vary from one research or consultancy organization to another. Looking retrospectively, projections by various consulting companies, which have been vastly used by actors of the industry, can be considered as having been overestimated. It demonstrates that projected market figures must be considered cautiously.

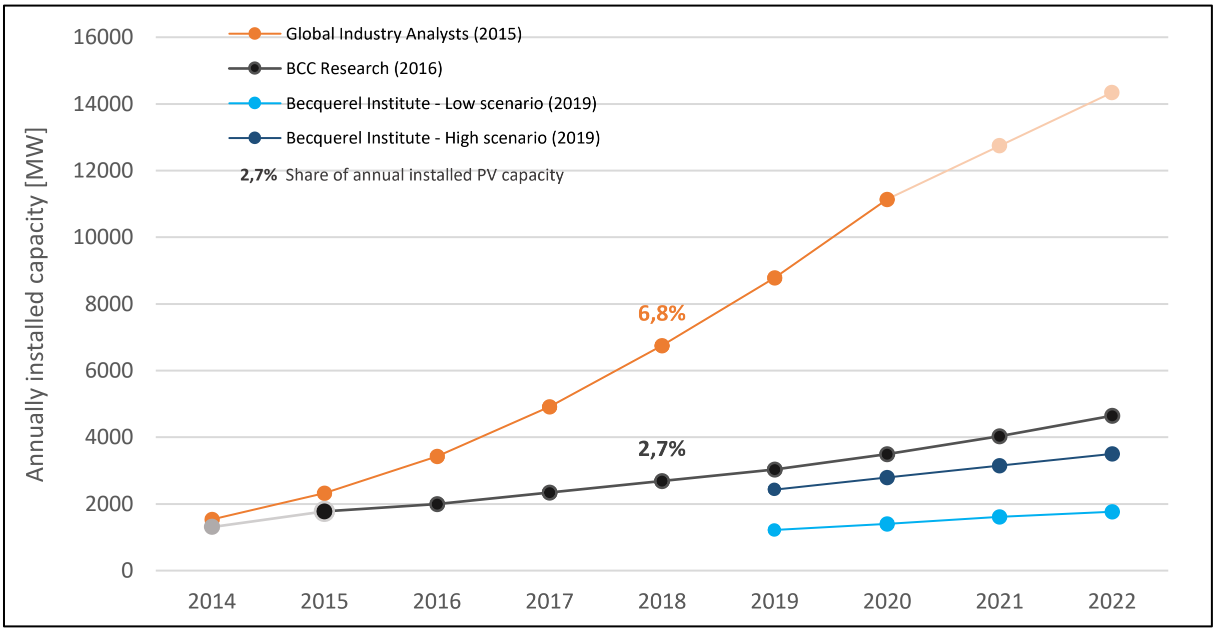


Figure 3.30 Projections of the annual BIPV capacity installed worldwide, from different organizations

The different forecasts give results that differ significantly. Although, the difference in terms of market share of the PV capacity installed annually worldwide remains marginal with shares ranging from 2,7% to 6,8% in 2018 and so are the forecasts compared to the total addressable market presented before.

4 STAKEHOLDER ANALYSIS

The stakeholder analysis conducted here aims at giving a comprehensive overview of the stakeholders involved in BIPV, directly or indirectly, at different steps of product's or project's lifetime. The stakeholder analysis will be divided into three main steps, themselves split in various subsections:

1) An exhaustive inventory presentation and a classification of the different stakeholders
2) A presentation of BIPV stakeholder in project development process
3) The definition of the challenges and needs that these stakeholders face.

This global analysis will be conducted thanks to a literature review and the extensive experience of partners of the BIPVBOOST consortium.

4.1 Inventory and classification of stakeholders

This section aims at presenting an exhaustive inventory of stakeholders in the BIPV market and at classifying them based on their place in the BIPV value chain in a first place and based on their interest in and power on the BIPV market in a second place.

Multiple stakeholders take part at some point in the BIPV value chain and can be categorized based on their respective position in this chain. **First level stakeholders** are directly in touch with the owner and/or the final user of the BIPV system, whereas **third level stakeholders** have the least links with the final customer and further away in the value chain. **Second level stakeholders** are positioned in between. These stakeholders are also defined by a 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 part of both the solar PV and the construction sector. This categorization is shown in the infographic below.

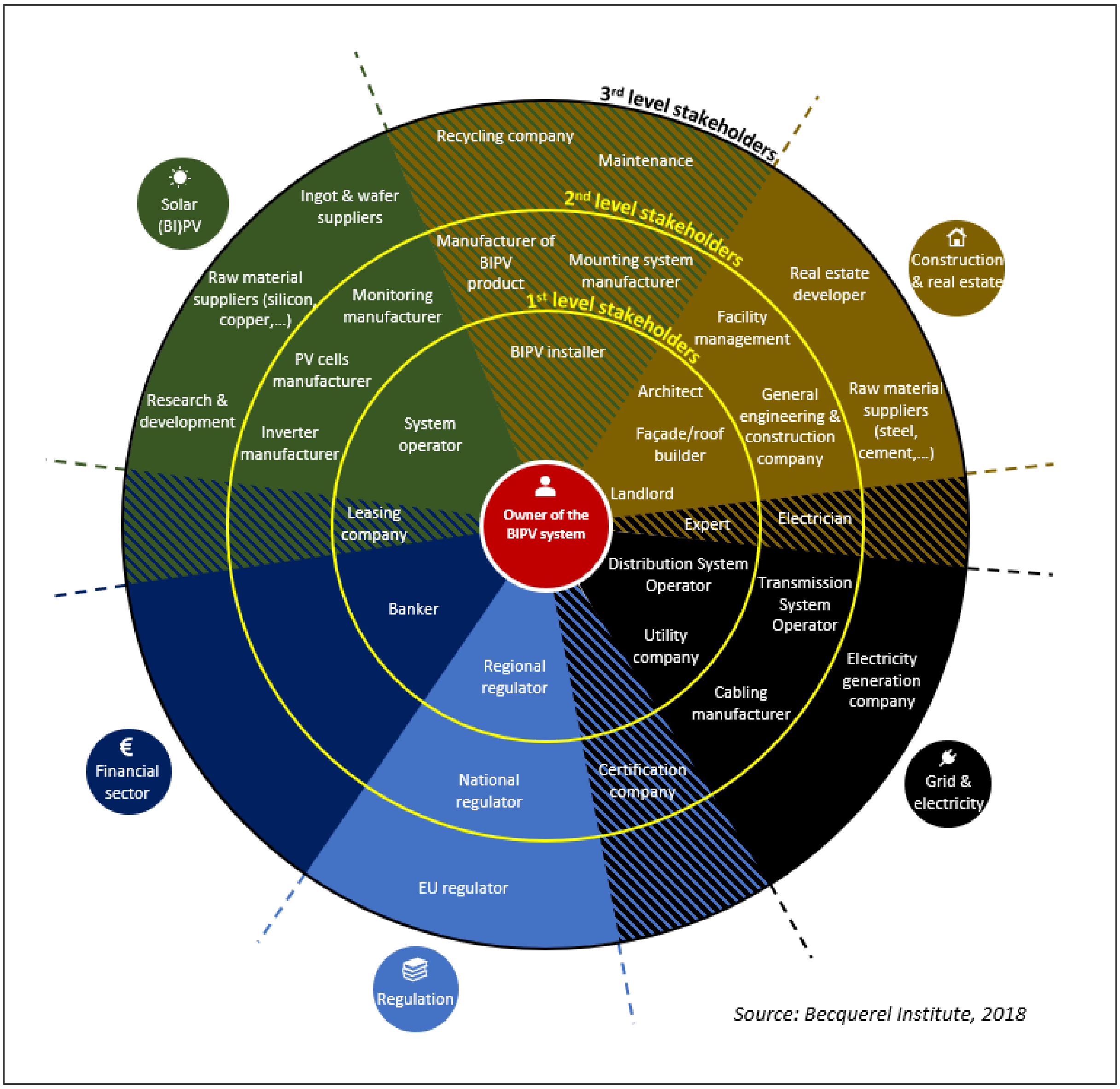


Figure 4.1 BIPV stakeholders' map - "From manufacturing to operations" (Source: Becquerel Institute)

Note 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 manufacturer or via a partner, if the financing is done by debt and/or equity, if the investor is the final user or not, etc.

In order to simplify the following charts and schemes, the stakeholders represented on the maps have been gathered in different categories based on an influence/interest approach which evaluates the interest in and the influence of the different stakeholders on the BIPV market.

- **Policymakers**: regional regulator, national regulator, EU regulator, certification company);
- **Project investors and financers** (leasing company, banker);
- **General contractors** (real estate developer);
- **Architects and designers;**
- **Building owner** (landlord, owner);

- **Facility managers;**
- **Grid operators** (DSO, TSO, cabling manufacturers, electricity generation company, utility company);
- **BIPV components manufacturers and suppliers** (monitoring manufacturers, inverter manufacturers, PV cells manufacturers, ingot and wafer suppliers, raw material suppliers, research and development);
- **BIPV system installers** (system operator, BIPV system installer);
- **Construction companies** (façade or roof builder, general engineering and construction company, raw material supplier, electrician);
- **Experts on both PV and construction aspects;**
- **Recycling companies;**
- **Operation & maintenance companies;**
- **Occupants of the building.**

It can be distinguished from this analysis, which of them are primary stakeholders and which of them are secondary stakeholders. Primary stakeholders are characterized by a high influence on the project. Even if their interest in the project can be regardless high or low, the success of BIPV market lies directly in their hands as their reluctance towards the project could lead to its failure. Consequently, secondary stakeholders are not directly linked to the success of BIPV market, but their involvement will lead to bigger success, and to better future development possibilities.

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.

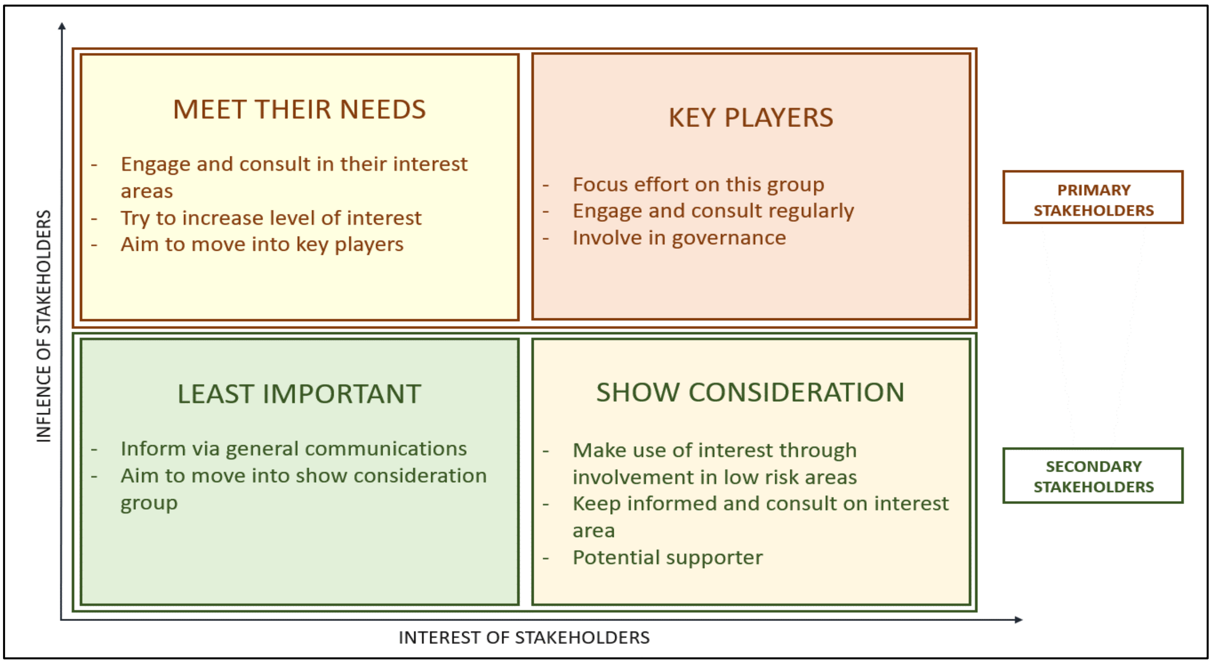


Figure 4.2 Engagement strategies for primary and secondary stakeholders (Elaboration by Becquerel Institute based on PVSITES' publication [10])

The stakeholders that were identified in the map above have been positioned in the power/interest matrix in Figure 4.3.

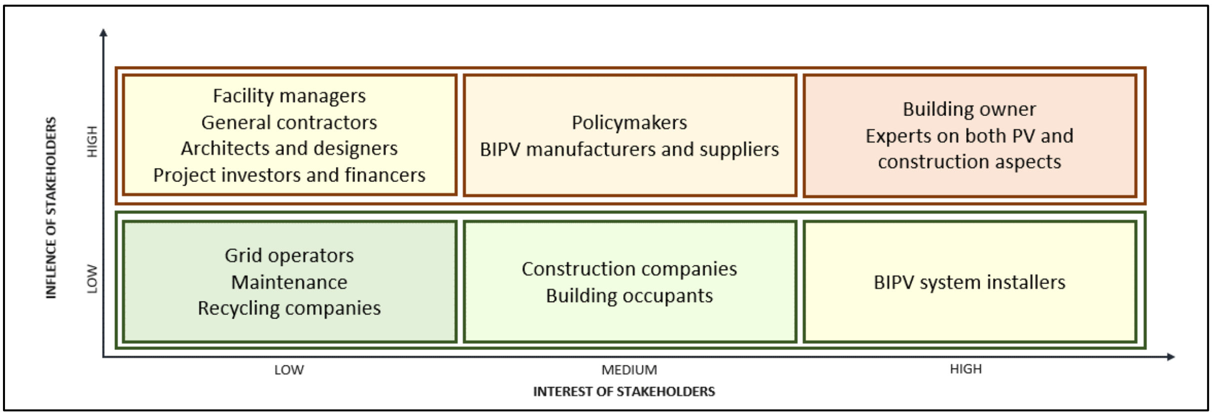


Figure 4.3 Power/interest matrix for primary and secondary stakeholders (Elaboration by Becquerel Institute based on PVSITES's publication [10])

Depending on the category of a stakeholder, different approaches and engagement strategies, gathered in the following figure, should be taken.

Their interest in a project is directly linked to the benefits they can generate by taking part in it. BIPV manufacturers can benefit from direct sale of products, investors and financers receive return on investment, charge interests and can extend their investment portfolio. Architects and designers can see the opportunity to obtain more clients and a better reputation by developing green projects. General contractors can increase their market share and can ease planning permission processes thanks to the green aspect and projects can be eligible for some taw allowances and other incentives. Then, policymakers can increase renewable energy penetration, contribute to the decarbonization of the economy and comply with binding objectives. Building owners can make savings on their electricity bill, if they occupy it, increase the value of their property and its associated applicable rents and enhance their sustainable image. [2], [23, 24]

Architects and designers, general contractors, facility managers, policy makers, building owners, project investors and financers and the BIPV manufacturers and suppliers have been identified as **primary stakeholders**. Indeed, architects have little financial interest in the project (apart potentially from increasing their reputation and their number of clients), but they decide whether and how to integrate BIPV in project's design. The influence of project investors and financers is also quite high as by allowing a credit or not, owners (which have both a high influence and a high interest) can decide whether to invest in a BIPV solution or not, especially since pay-back time for BIPV are still long. As far as policymakers are concerned, their interest is medium, but their influence is high. Indeed, by implementing regulatory frameworks they can put more pressure on renewable energy sources and by introducing financial incentives they can make BIPV more or less attractive. Grid operators, maintenance, recycling companies, construction companies and BIPV system installers were on the other hand identified as **secondary stakeholders** as have limited or no impact in the decision process and in the definition of the business model.

The limits between both categories are not definitive and a secondary stakeholder can become a primary one depending on the context, the situation and the engagement strategies that are implemented towards him.

4.2 Key stakeholders in BIPV project development process

In addition, to demonstrate the complexity of the development process of a BIPV project, we developed the framework displayed hereafter. Main steps of the development process are shown to the left, divided in three phases. Then, side and support activities, partners and component providers are located up and down the main steps, with arrows indicating at which step they interfere.

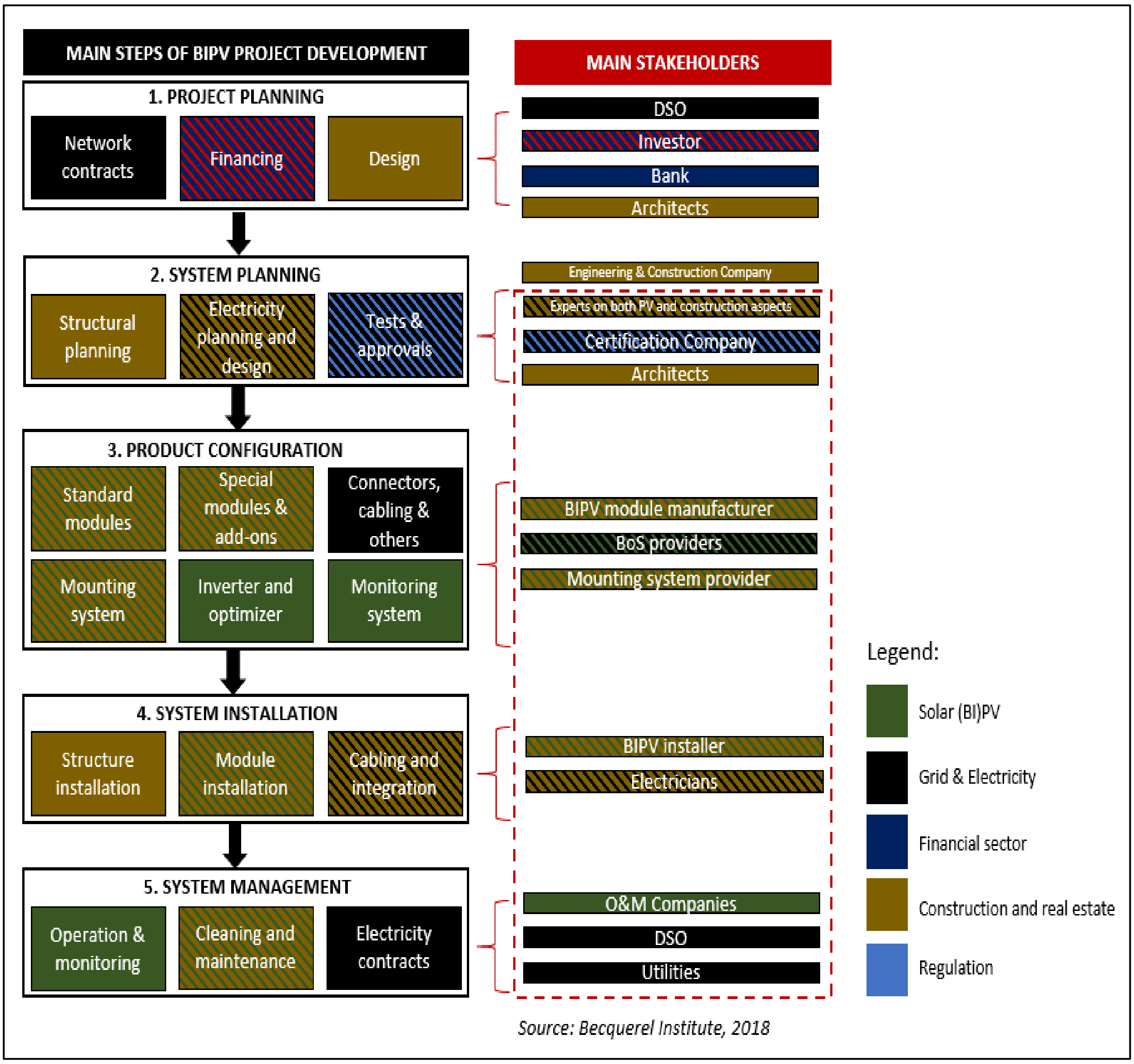


Figure 4.4 Main steps of BIPV project development

What is noticeable on the previous flowchart is that PV experts such as EPC, developers or installers are not imperative, at any step. Such conclusion results from the fact that BIPV is a construction product before being a PV product. Professionals of the construction sector who are anyway involved in construction or renovation projects have the competencies to fill the potential gaps in multiple areas: due diligence, design, placement, electrical maintenance. Moreover, as standardization and ease of installation of BIPV products increase, the specialized skills of the PV experts, are no longer required. PV experts will exclusively by needed in some very specific cases. Also, their expertise could be required when aspects such as the sizing of the PV system, the monitoring of its production or the regulatory framework must be investigated. In addition, the involvement of these « classic » PV experts will be needed in some countries in order to give a certification to the installation, which is mandatory to benefit from the financial incentives and/or the support schemes such as FiT or net-metering.

4.3 Challenges and needs

Remaining obstacles for the BIPV market were addressed in part 3.6 as issues that need to be tackled for the BIPV market to develop properly, but also indirectly for stakeholders to play their role in good conditions. Indeed, the market barriers accentuate and exacerbate the challenges that stakeholders face.

The different challenges that stakeholders along the value chain may face are detailed in the Figure 4.5 and Figure 4.6. The stakeholders have been positioned in order to highlight how they interact with each other. As far as primary stakeholders are concerned, the green diamond represents the four main actors in project development (architects, building owners, system installer and BIPV components manufacturers and suppliers). The yellow diamond gathers the stakeholders that constitute together the frame of the business model applied to the installation. The policy makers are not represented in any of the diamonds as they have an influence on both project development and business model definition. This explains their position on top of the chart. For the secondary stakeholders, they have been represented depending on when they are involved on the duration of system's operational lifetime.

Two main types of challenges can be distinguished and are represented with different colours. Those who are directly linked to the complexity and the characteristics of BIPV, and those who are not directly to BIPV itself but more to its introduction and insertion into a well-working construction sector loop composed of architects, general contractors and building owners.

As far as **the first type of challenge** is concerned, stakeholders must deal with complexity, appearance and cost characteristics that are specific to BIPV. For example, general contractors face higher CAPEX, and extra cost can also make building owners and investors reluctant to invest in BIPV. In addition, architects must try to deal with the current appearance possibilities range of BIPV and enhance the look of the building with the given set of solutions. Therefore, their needs encompass more knowledge, more confidence and communication towards this technology, or new skills. This could be provided by experts which expertise encompasses both aspects of BIPV. Their role would be key especially in the planning phase to insert BIPV correctly in the project design and planning phase, offering support to architects and construction companies, thus facilitating the project. The stakeholders that face this type of challenge had mostly already dealt with similar aspects linked to BAPV for example, therefore the challenges are easier to overcome with the needed time and knowledge acquisition and also if policymakers manage to develop innovative incentives regulations to find the balance between pushing the BIPV penetration without making the technology incentive dependent.

When it comes to **the second type of challenges**, stakeholders face the merging of the construction and the PV sectors for BIPV applications. It thus creates knowledge and processes gaps. Indeed, stakeholders that take part in the installation are required to get a new qualification, or even permit in order for them to be allowed to work on both aspects of BIPV, or a specialist of one or the other aspect has to be called in. This justifies the role of BIPV installers which have not only capabilities in both aspects of BIPV, but more importantly they can be the stakeholders that can bear with the potential risks associated to BIPV, which, until now, none of the PV installers nor building element installers wanted to bear. Architect on their side, will need to focus more on green design and especially energy-efficient design. BIPV can also be associated with fear of investors for extra-investment or of building owners for uncertain outlooks. Thus, training, but also communication and collaboration between both sectors and the building owners from the beginning of the project planning are crucial.

Most of the stakeholders, face challenges that would require similar needs to be fulfilled (more communication, more collaboration, standardization of processes, etc.) to overcome those challenges. Standardization, in terms of product and system design, as well as mounting structure, also reduces risk. If the manufacturer of the BIPV product, the BIPV installer is not available (bankruptcy, change of strategy …) any failure or required update could be taken in charge by another manufacturer. In best case, BIPV products would be “plug and play”. In addition, in case of problem, modules should be possibly updated individually, reducing cost of maintenance as well as risks associated with BIPV systems. But, other stakeholders (mostly architects and building owners) would rather need BIPV to follow the path of growing possibilities instead of standardization. Indeed, if building owners could benefit from a financial point of view from cost reductions linked to standardized products, from an aesthetical point of view, building owners and architects would take more advantage from an enlargement of design possibilities (shape, colour, etc) that will not help economies of scale. Therefore, it is about finding a compromise between customization and standardization as it is important to consider all BIPV stakeholders, especially primary ones, for the sake of the BIPV market.

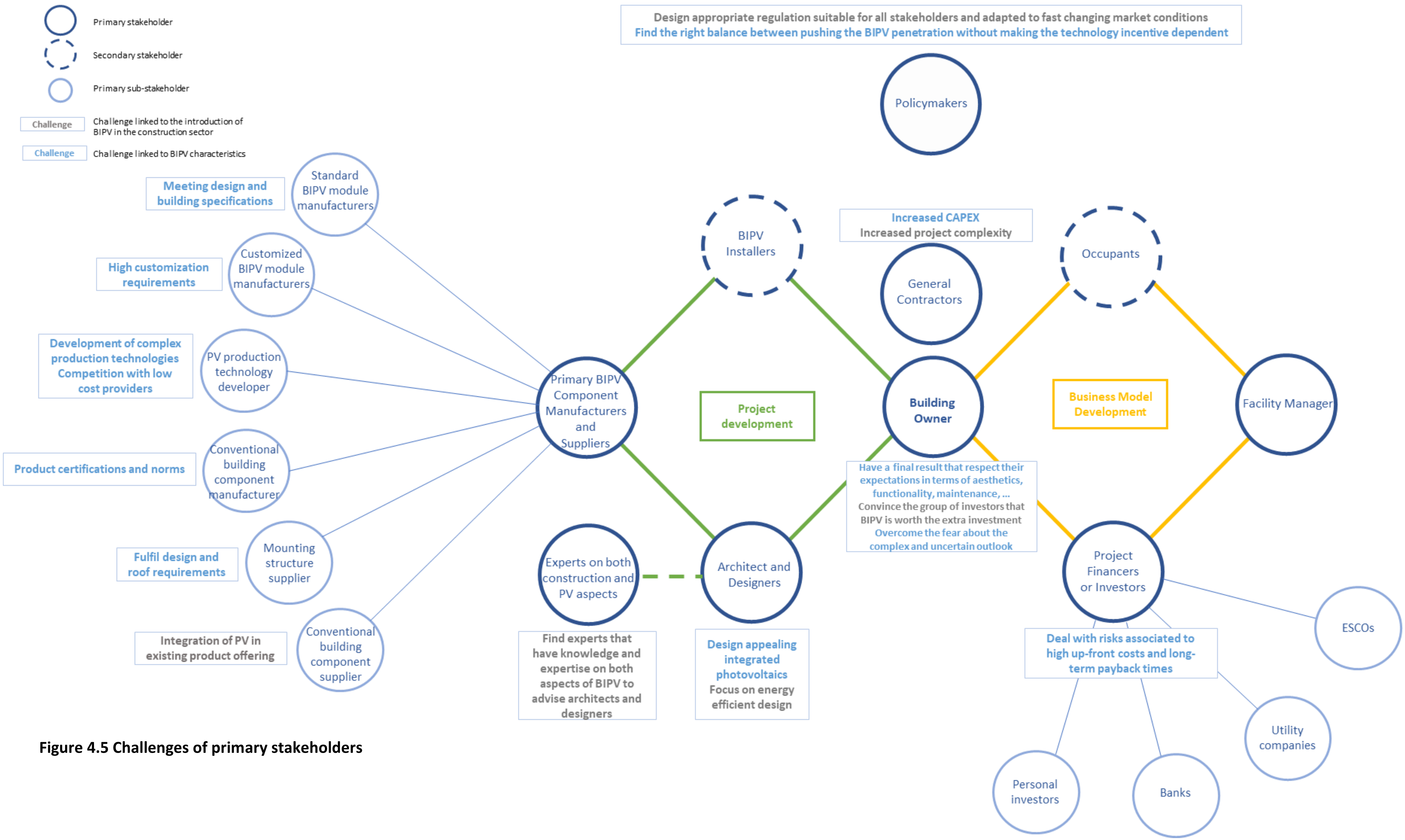


Figure 4.5 Challenges of primary stakeholders

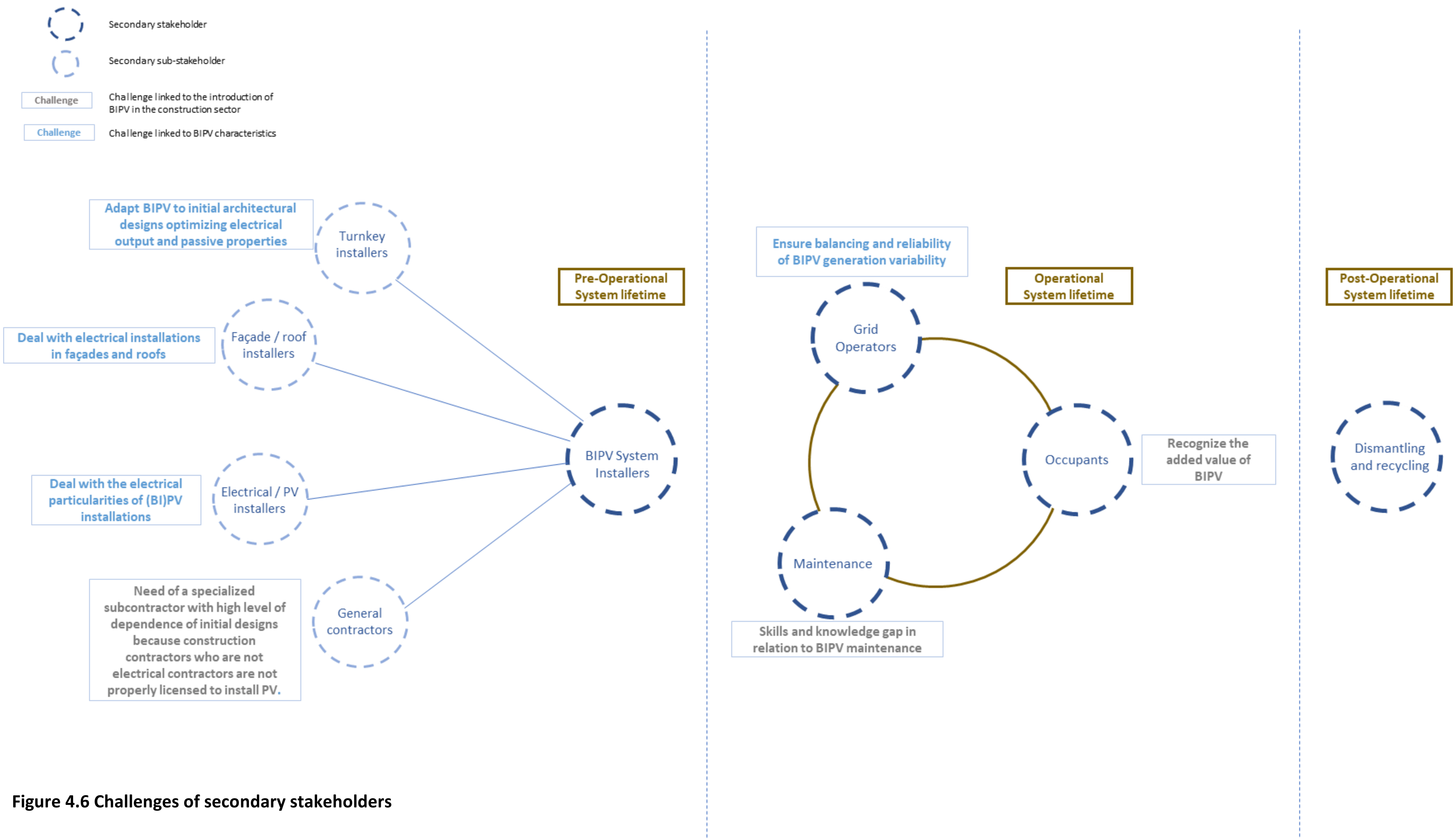


Figure 4.6 Challenges of secondary stakeholders

5 CONCLUSIONS

The analysis conducted in this report showed that the BIPV market is extremely varied, with no leading product, PV technology or application type. It gave a first overview of a segmentation based on both technical and economic aspects, which will be further developed in a following deliverable.

It was identified that until today, the main factors that have been fostering the development of the BIPV market are the price decreases of PV-related components, improved performances as well as an increasing regulatory pressure for more sustainable buildings. This has been accompanied by rising interest for sustainable technologies and an increasing range of aesthetical possibilities for BIPV. Nonetheless, the development of BIPV can still be improved. Aspects such as standardization, enabling easier installation processes and reducing risk perception, can have a tremendous impact, for example. More knowledge and awareness regarding BIPV among the public and the construction sector are also crucial. The need for adapted regulatory frameworks, increasing the possibilities to value the electricity generated by distributed PV systems is another key driver.

Following this analysis of market drivers and obstacles, the total addressable market for BIPV was explored, taking two different approaches, namely from the “supply-side” and from the “demand-side” of the market. It demonstrated that the potential is substantial, and that only a minor share of this addressable market has been achieved so far, even taking the lower estimations and putting them in regards of development numbers in countries where BIPV has been heavily incentivized. Additionally, it was shown that the “supply-side” estimated capacity, evaluating the total addressable market from a technical point of view, would not be sufficient to cover the final electricity demand of buildings. On a country level, even the most conservative evaluations demonstrate that the market could be as high as 6 GW in Switzerland, up to 81 GW in Germany. On total, in the 6 analysed countries, the total addressable market is estimated to stand at approximately 290 GW, taking the low scenario of the “supply-side” approach.

Then, the market forecasts presented in this document were put into perspective with the total addressable market showing that the forecasts, even in the high scenario, remain marginal compared to the total potential for BIPV. This is due to the fact that numerous market barriers still persist, as evoked previously. But should they be overcome, and should the market drivers be leveraged, the high scenario could be reached even in the short-term, and a substantial share of the total addressable market could be reasonably attained in the long-term even if a share of the identified market could also be overtook by BAPV.

Finally, the stakeholder analysis pointed out that collaboration and communication between the BIPV industry and the historical project actors such as building owners, architects and general contractors imperatively needs to be improved. This will permit to reduce the knowledge and skills gap with regards to BIPV system aspects and, consequently, will contribute to overcome most of 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. Furthermore, a global challenge lies in the fact that compromises must be found between standardization for cost reductions on the one hand, and easier processes and customization for more aesthetical possibilities including colour, shape or patterns, on the other hand.

6 REFERENCES

[1] I. Zanetti, P. Bonomo, F. Frontini, E. Saretta, M. van den Donker, G. Verberne, K. Sinapis et W. Folkerts , «Building Integrated Photovoltaics: Product overview for solar buildings skins - Status Report,» chez *33rd EU PVSEC*, Amsterdam, The Netherlands, September 2017.

[2] BIPVBOOST WP1 , «T1.3 Archetypal building situation and definition of the architectural specifications to enlarge market exploitation,» 2019.

[3] Fraunhofer Institute for Solar Energy Systems, ISE, «Photovoltaics Report,» 27 August 2018.

[4] D. C. Jordan et S. R. Kurtz, «Compendium of photovoltaic degradation rates,» *Progress in Photovoltaics: Research and Applications,* February 2016.

[5] D. C. Jordan et S. R. Kurtz, «Robust PV Degradation Methodology and Application,» 2018.

[6] ADEME, «Filière Photovoltaïque Française: Bilan, Perspectives et Stratégie,» Septembre 2015.

[7] I. Penn, «California Will Require Solar Power for New Homes,» *The New York Times,* 2018.

[8] «BIPVcn.org projects' database,» BIPV CN, [En ligne]. Available: http://www.bipvcn.org/project/case/domestic. [Accès le 2019 June 05].

[9] Dem4BIPV Project, Review of the BIPV market and educational needs in the field - Framework and Requirements' Analysis, November 2016.

[10] PVSITES Project, BIPV market and stakeholders analysis and needs, October 2016.

[11] M. van Horrik et et al, Belemmeringen voor BIPV: Opschaling en uitrol in de Nederlandse markt van gebouw geïntegreerde PV systemen, June 2016.

[12] L. van den Hurk et E. Teunissen, Roadmap Building Integrated Photovoltaics: Bouwen aan BIPV, November 2015.

[13] Y. Lu, R. Chang, V. Shabunko et A. Tan Lay Yee, «The implementation of building-integrated photovoltaics in Singapore: drivers versus barriers,» *Energy, Volume 168,* pp. 400-408, 1 February 2019.

[14] European Construction Sector Observatory, «Analytical Report: Improving the human capital basis,» April 2017.

[15] European Builders Confederation, «Annual Report 2017-2018,» 2018.

[16] European Construction Sector Observatory, «Analytical Report: Fostering the international competitiveness of EU construction entreprises,» April 2017.

[17] IEA PVPS Task 7, Potential for Building Integrated Photovoltaics, 2002.

[18] P. R. Defaix et e. al., «Technical potential for photovoltaics on buildings in the EU-27,» *Solar Energy (86),* pp. 2644-2653, 2012.

[19] P. Macé, A. El Gammal et al, «Technical Evaluation of BIPV Power Generation Potential in EU-28,» chez *32nd EU PVSEC*, Munich, Germany, June 2016.

[20] European Commission , «EU Building Stock Observatory,» [En ligne]. Available: https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-performance-of-buildings/eubuildings. [Accès le 28 June 2019].

[21] The PV Market Alliance.

[22] Solar Power Europe, «Global Market Outlook For Solar Power 2019-2023,» 2019.

[23] IEA PVPS Task 15, «Inventory on Existing Business Models, Opportunities and Issues for BIPV,» 2019.

[24] IEA PVPS Task 15, «Development of BIPV business cases,» 2019.

[25] A. Virtuani, D. Pavanello et G. Friesen, «Overview of Temperature Coefficient of Different Thin-Film Photovoltaic Technologies,» chez *25th EU PVSEC*, Spain, 2010.

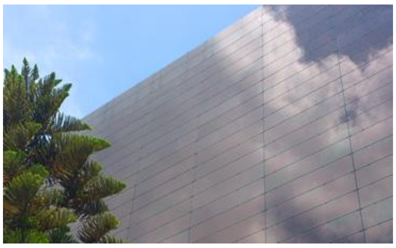
7 APPENDIX

APPENDIX 1: Definition and description of the 11 technological systems (from [2])

- Rainscreen façade: it consists in a load-bearing substructure, air gap and cladding. Usually PV modules are integrated as external coating similarly to non-active building elements. This façade uses the exterior layer breathing like a skin. There is no significant pressure differential between cavity and external environment. Evaporation and drainage in the cavity remove water eventually penetrating between panel joints. In summer heat from the sun is dissipated thanks to the cavity that is naturally ventilated through bottom and top openings. This is the reason why it is also called as “cold façade”. The rainscreen façade is ideal for using solar modules made of crystalline solar cells, with system efficiency enhanced by rear ventilation. Many constructive models and technological solutions are available.

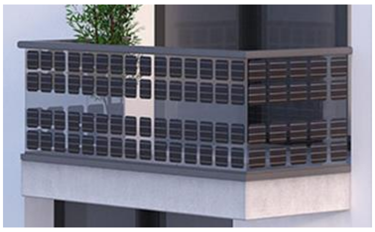
- Curtain wall façade: external not ventilated and continuous building skin system, totally or partially glazed, composed by panels supported by a substructure. A curtain wall system is an outer building envelope system in which the outer walls are non-structural. The curtain wall façade does not carry any dead load weight from the building excluding its own dead load weight: moreover, it transfers horizontal loads (wind, seismic) to the main building structure through connections. A curtain wall is designed to resist air and water infiltration, dividing outdoor and indoor environments, and it is typically designed with extruded aluminium frames (but also steel, woods, etc.) filled with glass. The façade should satisfy all the main requirements such as load-bearing function, acoustic and thermal insulation, light transmission, waterproof, etc.

- Double skin façade: it is a façade building system consisting of two glazed skins separated by an intermediate air cavity. The ventilation of the cavity can be natural or mechanical. The functioning and the effectiveness depend mostly on the climatic conditions, the use, the location, the typology of the building and the HVAC strategy. The air cavity or the distance between the two skin layers can range from 20 cm up to 2 meters. The inner glass is insulated, while the external panes, where the PV modules are normally located, are usually laminated glasses since they should wide stand wind loads. The air gap between the two façades works as thermal and acoustic insulated area.



- Prefabricated/Multifunctional façade: it is a unique and preassembled multifunctional (i.e. thermal, acoustic, weather protection, energy production, …) element installed on the façade, composed by PV cladding, protective layers and substructure

- Accessory façade: transparent or opaque shading devices for façades or railings with the role of “fall protection“ that are necessary for the safety of the building (balconies, parapets or external screens).



- Cold roof: it consists in a load-bearing substructure, air gap and cladding. Pitched/sloped opaque roof is extremely common all over the world: it is known as "discontinuous" roof due to the presence of small element (tiles, slates, etc.) with the main function of water tightness. Of course, it is the part of the building envelope where the PV transfer has had the most success for many reasons such as the typical optimal orientation of pitches, the easiness of installing PV panels. Usually PV modules are integrated as external coating (tiles, shingles, standard modules, etc.) as similar non active building element.

- Skylight: it is a light-transmitting building element that cover all or a part of the roof. They are typically (semi)-transparent. It has the thermal, acoustic, waterproof functions.

- Canopy: it is an overhead building element with open sides. It has the function of weather protection. Often this solution is composed by a laminated (safety)-glazing cladding since the thermal protection is not a requirement.

- Prefabricated/Multifunctional roof: it is a unique and preassembled multifunctional element installed on the roof, composed by PV cladding, protective layers and substructure. Polyvalent components are able to satisfy more than a single technological requirement in a unitized way.

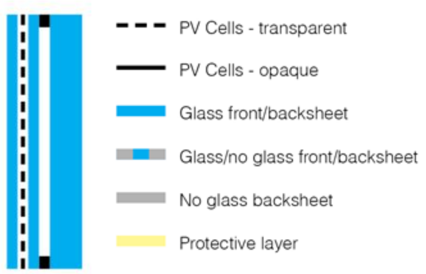
- Walkable floor: PV paver installed on the roof of buildings, while preserving their habitability.

- Accessory roof: transparent or opaque shading devices for roofs mainly on a glazed support aimed to select the solar radiation.

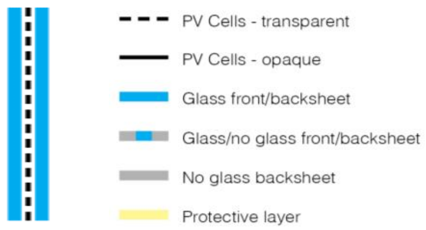
APPENDIX 2: Definition and description of the 5 cladding typologies (from [2])

Five groups based on the building skin cladding type are defined by considering the material used and the thermal insulation property.

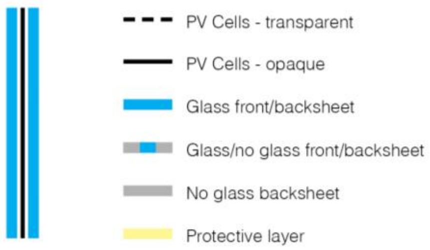
- Group 1 - Glazed transparent solution with thermal properties. This solution is typical for skylights and curtain walls.



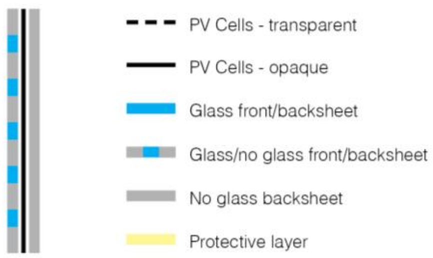
- Group 2 - Glazed transparent solution without specific thermal protection performances. This solution is typical for canopies, external pane of double skins facades and walkable floors.



- Group 3 - Opaque glazed solution without thermal protection. This solution is typical for “cold” roofs and façades and accessories.



- Group 4 - Opaque no glazed solution without thermal protection. This solution is typical for “cold” roofs and façades and accessories.



- Group 5 - Opaque prefab/multifunctional solution. It may have or not the thermal properties. This solution is typical for multifunctional façades and roofs.