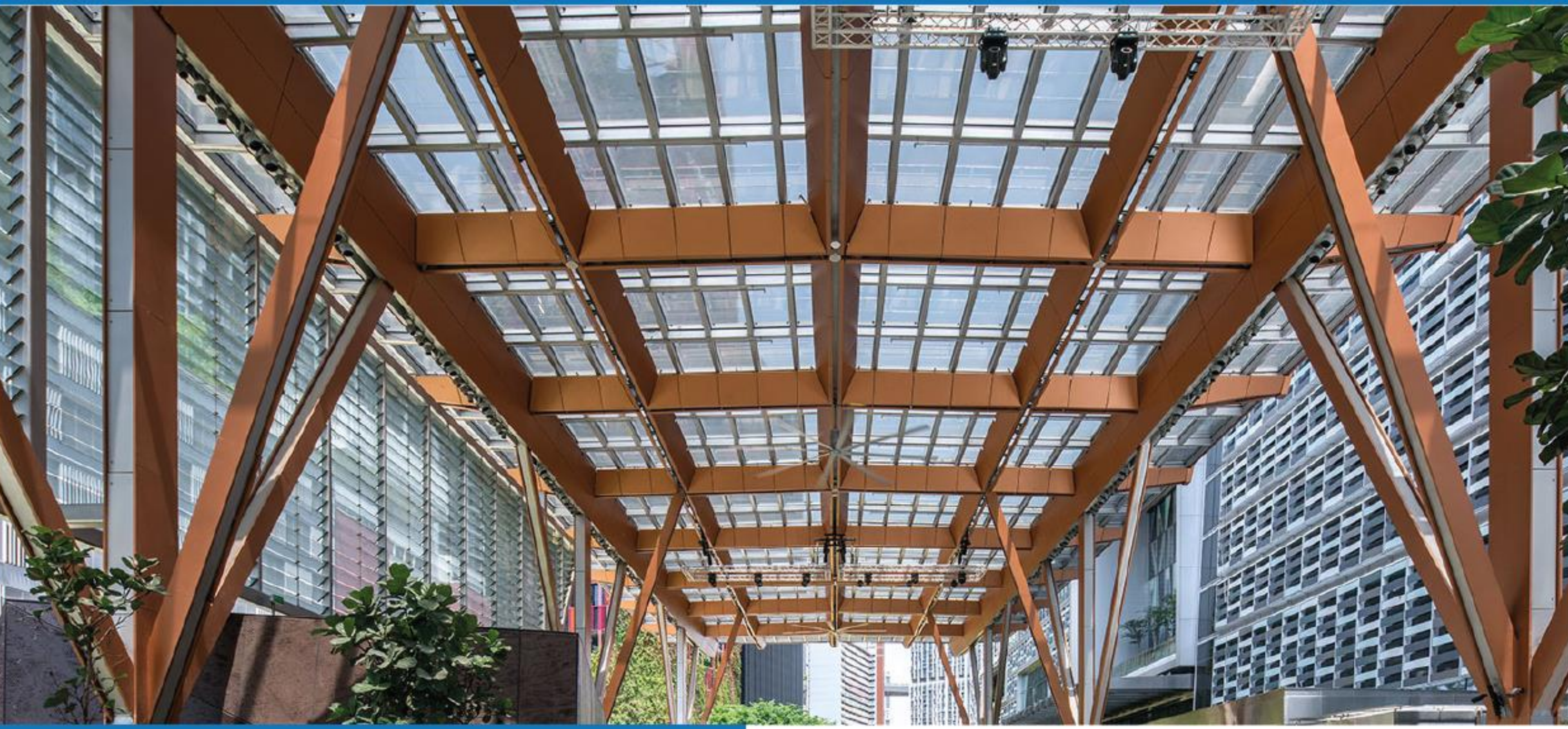

Bringing down costs of multifunctional building- integrated photovoltaic (BIPV) solutions and processes along the value chain, enabling widespread nZEBs implementation

BIPV SOLUTIONS IN EUROPE: COMPETITIVENESS STATUS & ROADMAP TOWARDS 2030

– WHITE PAPER

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#BIPVBOOST

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ABBREVIATIONS' LIST:

BAPV	Building Applied Photovoltaics
BE	Belgium
BEM	Building Energy Management
BIPV	Building Integrated Photovoltaics
CH	Switzerland
CIGS	Copper Indium Gallium Selenide
c-Si	Crystalline silicon
DC	Electricity consumption band for household (2500 kWh to 5000 kWh consumed per year)
DE	Germany
EB	Educational Building
ES	Spain
EU	European Union
FIT	Feed-In Tarif
FR	France
GC	Green Certificates
GHG	Green House Gas
IA	Electricity consumption band for non-household (less than 20 MWh consumed per year)
IB	Industrial Building
IC	Electricity consumption band for non-household (500 MWh to 2000 MWh consumed per year)
IT	Italy
MFH	Multi Family House
MIRR	Modified Internal Return Rate
NB	Net-billing
NL	Netherlands
NM	Net-metering
NPB	Not Paid Back
nZEB	Nearly Zero Energy Buildings
OB	Office Building
P	Premium
PBT	Pay Back Time
PERC	Passivated Emitter and Rear Cell
PV	Photovoltaics
SDE	Stimuleringsregeling Duurzame Energieproductie (Sustainable Energy Production Incentive Scheme)
SET Plan	Strategic Energy Technology Plan
SFH	Single Family House
VAT	Value Added Tax
WM	Wholesale Market

INTRODUCTION

MEASURING THE COMPETITIVENESS OF BIPV:

This white paper provides an overview of the level of competitiveness of various BIPV solutions in key Western European markets. The competitiveness can be assessed from various points of view including:

- material-level, by taking into account the material cost of BIPV (€/m²) and comparing it to the material cost of competing solutions such as conventional cladding systems or BAPV systems.
- system-level, by taking into account the system cost (including installation costs, other hardware costs, development costs, …) of BIPV (€/m²) and comparing it to the system cost of competing solutions such as conventional cladding systems or BAPV systems.
- electricity generation unit-level, by taking into account the cost of generating electricity with a BIPV system (€/kWh) and comparing it with the cost of generating electricity with other competing solutions, or with the cost of electricity provided by the grid.
- project-level, by taking into account the total costs and revenues of ownership of a BIPV solution.

Even if the multi-level assessments are all relevant and allow a full grasp of BIPV competitiveness, this document focuses on assessing the last type of competitiveness, i.e. considering the total costs and revenues of ownership, to clearly identify the intrinsic economic attractiveness of BIPV as a building envelope solution. Indeed, this assessment relies on all sub-level assessments, thus allowing for a complete analysis. In this evaluation, an innovative approach, based on an "extra cost" assessment, is applied to consider the role of building components fulfilled by BIPV elements and consequently the avoided expenses for the façades or roof claddings.

This project-level competitiveness assessment is first conducted with current techno-economic parameters. Then, the impact of various improvements (technical and market related as well as internal and external to the BIPVBOOST project) on the competitiveness is presented to evaluate the economic attractiveness of BIPV solutions in Europe by 2025 and 2030.

LINK WITH CURRENT EUROPEAN STRATEGIC OBJECTIVES:

These improvements can be put in a more general perspective of different strategic objectives at European level. In particular, the reduction of CO_2 emissions in the building sector is a key topic of many strategies developed by governments. Indeed, the building sector is the highest energy consumer in the European Union (40% of the total energy demand and 36% of the total CO_2 yearly emissions) [1]. Many of these strategies thus particularly relevant for the BIPV sector. In particular, the recent long-term strategic vision presented by the European Commission in November 2018 to reduce GHG (greenhouse gas) emissions and to achieve climate neutrality by 2050 can be cited as example. It ambitions to:

- Maximise the benefits of energy efficiency, including zero emissions buildings.
- Maximise the deployment of renewables and the use of electricity to fully decarbonise Europe's energy supply.
- A competitive EU industry and the circular economy as a key enabler to reduce GHG emissions.

Another example is the revised Energy Performance of Buildings Directive, which entered into force in July 2018. Among other objectives, this aims at accelerating the cost-effective renovation of existing buildings and reach a decarbonised building stock by 2050. One can also mention the Renovation Wave Strategy, published in October 2020 by the European Commission, aiming at "doubling the renovation rate" [4]. Finally, another binding renewable energy target of at least 32% and an energy efficiency target of at least 32.5% by 2030 can also be mentioned as strategic objectives relevant to the BIPV sector.

LINK WITH OPERATIONAL EUROPEAN OBJECTIVES:

Defining strategic objectives goes hand in hand with defining a consistent and relevant cost-reduction roadmap for the European BIPV sector. The European Commission has already specified clear objectives to be achieved by the (BI)PV industry, in the framework of the Strategic Energy Technology Plan (SET Plan), published in December 2015 [2].

These SET Plan's objectives cover multiple aspects of PV technologies and aim at "re-build(ing) EU technological leadership and bring(ing) down the levelized cost of electricity". The means to achieve this ambition can be summarised, in the case of classical PV (and BIPV) technologies, as follows:

Key Performance Indicators' details				**Reference value**	**Objective (BIPVBOOST & SET PLAN)**			
Selected KPI	*Change*	*Unit*	*Trend*	*2015*	*2020*	*2022*	*2025*	*2030*
Module efficiency	Relative	[%]	↗	N/A	**+20%**	N/A	N/A	**+35%**
Module cost	Relative	[%]	↘	N/A	N/A	**-50%**	N/A	N/A
End-user system cost	Relative	[%]	↘	N/A	**-20%**	**-10%**	N/A	**-50%**
Module lifetime	Absolute	[years]	↗	N/A	**30**	**30**	**35**	**35**
Performance ratio	Relative	[%]	↗	N/A	N/A	**+5%**	N/A	N/A
Extra cost of BIPV	Relative	[%]	↘	Application dependent*	-50% **-50% to -76%**	N/A	N/A	-75% **-82% to -111%**

*Roof integrated modules = 80-120 €/m²; Roof tiles & membranes = 130-200 €/m²; Semi-transparent facade = 150-350 €/m²; Opaque façade = 130-250 €/m².

RESEARCH TRENDS

Finally, improving the competitiveness of BIPV solutions is also a topic investigated in the framework of many research projects. BIPVBOOST can of course be mentioned as an example but other H2020 projects such as PVSites, BESmart or PVadapt can also be highlighted.

REFERENCE CASES

Reference cases have been defined, in order to use a common basis for cost comparisons and competitiveness evaluations. These reference cases and their characteristics aim at being representative of what can be witnessed in the field. Their characteristics are presented in the next pages. An outline of these reference cases is also presented in the figures below. These have been mainly defined based on the experience of BIPVBOOST's partners and the information collected through other deliverables using the building typology, the cladding typology and the technological systems as differentiation parameters.

Figure 1 Outline of the studied reference cases

NB: Colours are not representative of the actual colour of the BIPV systems and are merely related to the graphic interface of the BIM Solar software.

Legend:

Technical parameters
Economic and financial parameters

Surface coverage ratio and surface available for the system	**Surface coverage ratio** should be understood as the ratio between the surface that is actually covered by the BIPV modules and the available surface for the system on the roof or the façade. Note that "available for the system" means already excluding areas occupied by windows, chimneys or HVAC devices, for instance). This available surface typically equals **50m²** for a residential roof or around **300m²** for an office façade. The available surfaces can never be entirely made "active", because for example of constraints such as the surface occupied by the frames and fastening systems, or the required spaces between modules to allow air to flow. Thus, the surface coverage ratio can vary from around **0,85** to around **0,9** depending on the presented case in this paper.	**Degradation rate**	The system **degradation rate** corresponds to the average values obtained from recent studies, from **0,4 to 0,5%/year** for cSi based systems and **0,7%/year** for CIGS ones. Note that for cSi technologies, this figure is valid only from the second year of operation. Indeed, during the first year of operation, a phenomenon called light-induced degradation (LID) causes an initial degradation of performance of about **1,8%** [6] [7] [8]. Note that these can be seen as conservative figures, considering the specifications of some recent PV and BIPV products. But as the previously cited studies demonstrate, it is not uncommon that field performances are not aligned with theoretical ones. Most importantly, very few data are available from the field in the case of BIPV installations, whereas there are additional constraints compared to regular PV modules (e.g. limited or no ventilation), due to their role of building component.
Transparency	The **transparency** value that has been considered for the semi-transparent curtain wall is **50%** (value calculated based on the surface of the module occupied by the cells).	**Yield**	Finally, the **yield** of the system is function of the technology used, the location as well as the type of application and was calculated for each location using the latest version of the software "BIMSolar" [9].
Module efficiency	The **module efficiency** mainly depends on the PV technology used (mono c-Si, thin-film, …) and the level of transparency. The lowest considered module efficiency is for the semi-transparent modules used in the curtain wall which yield a **10,4%** efficiency at module level. The highest module efficiency is reached for the in-roof mounting system which uses conventional and mono c-Si (PERC)-based modules allowing them to each a **20%** module efficiency. Finally, the CIGS lightweight metal roofing and the mono c-Si (PERC)-based ventilated facades are respectively characterised by module efficiencies of **15,1%** and **17,5%.**	**Tilt and Azimuth**	For all tested buildings, the BIPV system is assumed to be **south oriented**. The **tilt** considered for residential BIPV roof is **30°**, a **flat** roof is considered for the industrial building, while BIPV systems integrated to façade are assumed to be completely **vertically** installed.
Self-consumption rate	**Self-consumption rates** are determined both by the annual electricity consumption of the considered building's occupants as well as by the installed BIPV capacity and its subsequent annual electricity production. In the case of a residential buildings, a **30%** annual self-consumption rate is considered for the single-family house reaching **60%** in the case of a multi-family house. For the office and educational building, it is assumed that **70%** of the annual production is self-consumed, in the case of the industrial building this parameter reaches **90%.**	**Capacity installed**	The **installed capacity** is calculated from the surface available for the system and the system surface power density. When residential systems are considered, the installed capacity is **9 kWp**. Then **46 kWp** and **72 kWp** are respectively installed in the case of a residential and non-residential ventilated façade. Finally, **25 kWp** are integrated to the office building's curtain wall and **180 kWp** to the industrial building's roof.
System lifetime	The total **system lifetime** is assumed to be equal to **30 years.**	**Capacity installed**	The **installed capacity** is calculated from the surface available for the system and the system surface power density. When residential systems are considered, the installed capacity is **9 kWp**. Then **46 kWp** and **72 kWp** are respectively installed in the case of a residential and non-residential ventilated façade. Finally, **25 kWp** are integrated to the office building's curtain wall and **180 kWp** to the industrial building's roof.
System surface power density	The system surface power density depends both on the module efficiency as well as the considered coverage ratio. Its value ranges from **94 Wp/m²** in the case of the semi-transparent curtain wall to **176 Wp/m²** in the case of the in-roof mounting system.		

Total end-user cost (exc. VAT)	The **end-user cost** includes all costs associated to the purchase, delivery and installation of the BIPV system. In the case of residential end-users, the VAT is added to this end-user cost in order to reflect the real expense incurred by the investor. The BIPV system among the studied systems that comes at the lowest end-user cost is the in-roof mounting systems with **208 €/m².** Then, the CIGS-based lightweight metal roofing has an end-user cost of **350 €/m².** Finally, the façade systems are the most expensive with an end-user cost of **462 €/m²** for the mono c-Si (PERC)-based ventilated facades and **797 €/m²** for the mono c-Si (PERC)-based curtain wall.	**Inflation**	**Inflation** is assumed to be similar across Eurozone countries and equal to **1.5%** every year [5]. The same value is used for Switzerland.
		Alternative construction material	The **alternative construction material** is the material that would have been used if the building owner did not opt for a BIPV solution but for a conventional solution. The considered alternative construction materials are **ceramic tiles (45€/m²)** in the case of a residential roof, **metal (60€/m²)** in the case of a ventilated façade and industrial roofs, as well as **insulated glass (150€/m²)** in the case of a warm façade (curtain wall).
Discount rate	The **discount rate** used in the calculations is the after-tax weighted average cost of capital. In the end, computed nominal WACC rates vary between **4,94%** (Germany) and **7,41%** (Italy). Some might consider such figures as optimistic but BIPV installations can be viewed as relatively low-risk projects. Indeed, PV production is foreseeable and well understood, whereas real estate investments are widely recognised as safe. Note that for residential housing cases, the discount rate used equals **2%** and is the same across all considered countries.	**Operations and maintenance costs**	The **operations and maintenance costs**, including cleaning, are assumed to be constant over the useful life of the system, in real value. In 2019, operations and maintenance costs are assumed to equal **2 €/m².year** for roof systems. This is a conservative estimation, based on what can be witnessed on the market for conventional rooftop PV installations. In the case of façade BIPV systems, a yearly operation and maintenance cost of **5 €/m².year** is considered [3].
Depreciation	As a simplifying assumption, asset **depreciation** is assumed to be linear and applied according to theoretical BIPV system useful lifetime.	**Corporate tax rate**	The **corporate tax rate** varies from one country to another, ranging from **8.5%** in Switzerland up to **33.33%** in France [4]. As a simplifying assumption, it is assumed that this tax rate remains constant over the system lifetime.
Electricity consumption band	The **electricity consumption band** of a given building is closely tied to its electricity consumption level and consequently also determines the retail prices at which it can buy its electricity. For residential buildings the **DC consumption band (2500 kWh to 5000 kWh consumed per year)** is considered while office and educational building are assumed to belong to an **IA electricity consumption band (less than 20 MWh consumed per year)**. Finally, for the industrial building the **IC consumption band (500 MWh to 2000 MWh consumed per year)** is considered. Yet, depending on their sector of activity, industrial buildings can have an electricity consumption far more important.	**Total end-user extra cost (exc. VAT)**	The **end-user extra cost** is the share of the total end-user cost that is attributable to the BIPV system. The methodology for the determination of its value is detailed further in this document. The BIPV system with lowest end-user extra cost is the in-roof mounting systems with **91 €/m².** Then, the CIGS-based lightweight metal roofing has an end-user extra cost of **167 €/m².** Finally, the façade systems are the most expensive from an extra cost perspective with an end-user extra cost of **256 €/m²** for the mono c-Si (PERC)-based ventilated facades and **350 €/m²** for the mono c-Si (PERC)-based curtain wall.

MATERIAL AND SYSTEM LEVEL COMPETITIVENESS

The assessment of the material cost competitiveness of BIPV compared to alternative cladding solution demonstrates that there is an important cost gap between regular cladding solutions and BIPV solutions. This is not surprising, as the active part of BIPV requires additional raw materials and processes to be manufactured. Nevertheless, in the case of roofing solutions or ventilated facades, the cheapest BIPV materials can compete with high-end conventional materials such as stone as facade cladding or slate tiles.

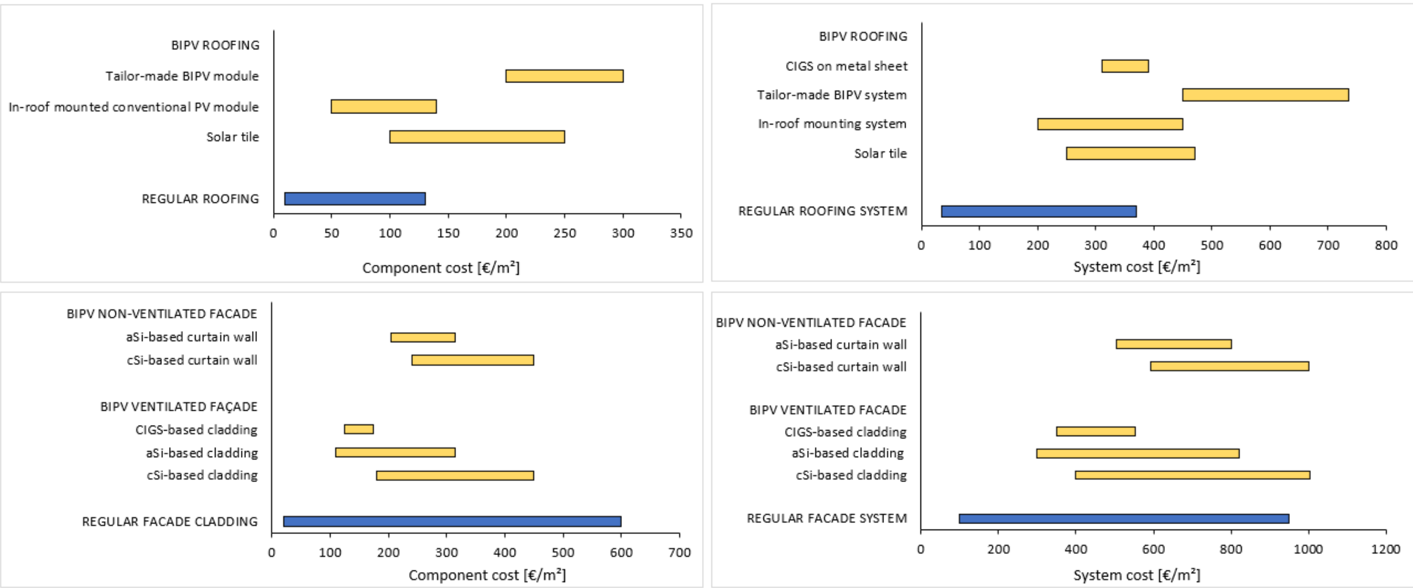


Figure 2 Range of materials/systems costs (respectively left/right), represented as highlighted areas for traditional materials/systems and as colored lines for BIPV materials/systems

Going one step further, an assessment of the competitiveness at the system level, i.e. building envelope solutions, can be conducted. Results show that simple solutions such as in-roof mounting systems can be more competitive than slate tiles, while being able to be on par with other types of tiles, in some cases. Even though, compared to the material-level competitiveness chart, the cost gaps have decreased, and the situation is more homogeneous, active solutions remain undoubtedly more expensive than standard façade cladding solutions. This holds even if the cheapest BIPV cladding without insulation is selected, notwithstanding the case of envelope solutions based on high end stone, which can be considered as an outlier.

Nonetheless, it also appears that active solutions are more competitive, from a system-level cost perspective, than the subsequent application of a PV system on a regular roofing solution, thus strengthening the competitiveness of BIPV solutions. The main advantage comes from the fact the various cost items are not doubled, such as the material but also installation or mounting system.

ELECTRICITY GENERATING UNIT COMPETITIVENESS

The competitiveness of BIPV as an electricity generating unit is assessed by calculating its LCOE and by putting it into perspective with local compensable retail electricity prices *(see following section on revenue for further details on the compensable retail electricity price)*. When examining competitiveness with a dynamic point of view, i.e. on the entire operating lifetime, economic attractiveness can be observed in multiple cases and when considering the extra cost of BIPV only *(see following section for further details on the extra cost approach)*. The capability of BIPV to generate electricity at a competitive cost highly depends on the consumption profile of the investor. Results tend to show that competitiveness of BIPV generated electricity is, in many cases, relatively limited. When residential reference cases are considered (SFH, MFH), the high retail prices allow the BIPV solution to be competitive in all cases, in particular in countries where retail electricity prices are above average. Results are mixed for the educational and the industrial buildings, for which higher consumption bands (respectively IA and IC) and therefore lower prices apply. Consequently, competitiveness is only achieved in the countries with the highest retail electricity prices. But it is interesting to note that competitiveness can still be reached for the educational buildings, in spite of the vertical positioning of the system, which reduces its yield. Finally, when the office building reference cases are considered, the combination of more important end-user extra cost and low production (because of the vertical position on a façade) does not allow the BIPV solutions to compete with compensable retail prices.

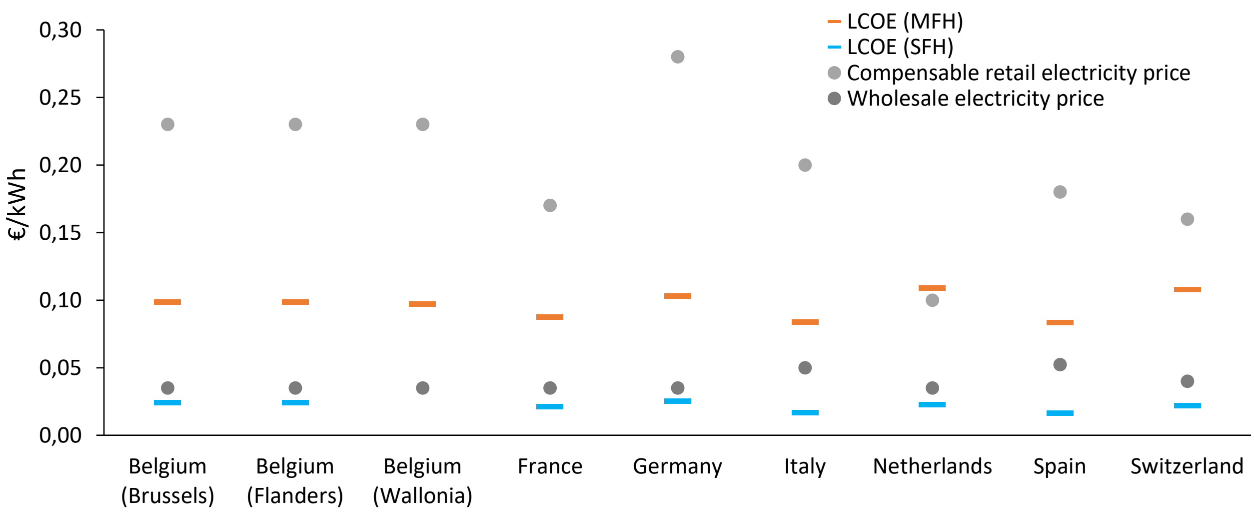


Figure 3 Comparison between the LCOE reached for the SFH and MFH reference cases, the compensable retail electricity price for the DC consumption band and the wholesale electricity price

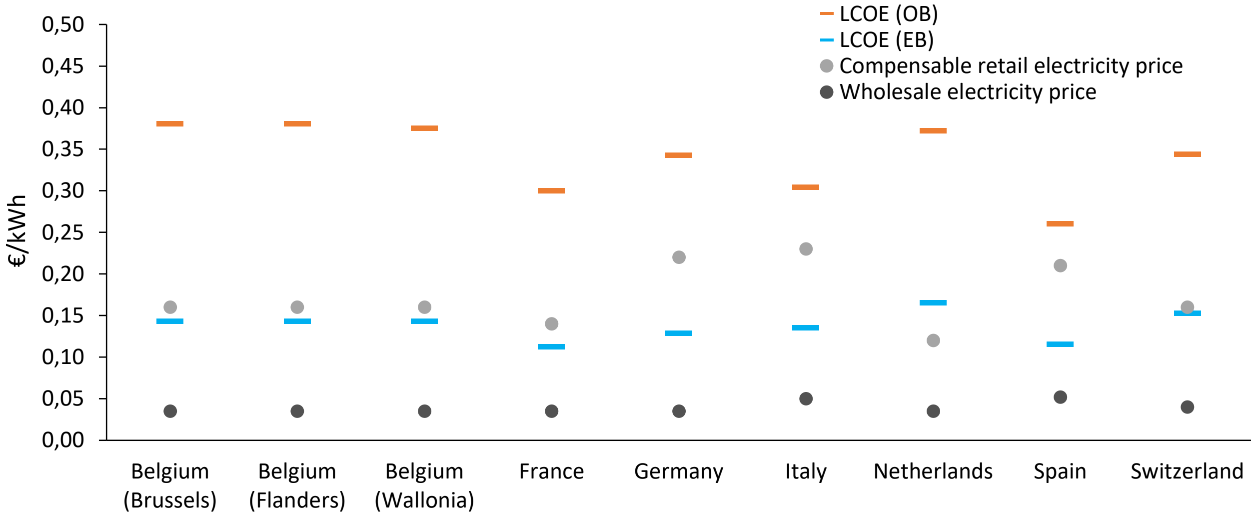


Figure 4 Comparison between the LCOE reached for the OB and EB reference cases, the compensable retail electricity price for the IA consumption band and the wholesale electricity price

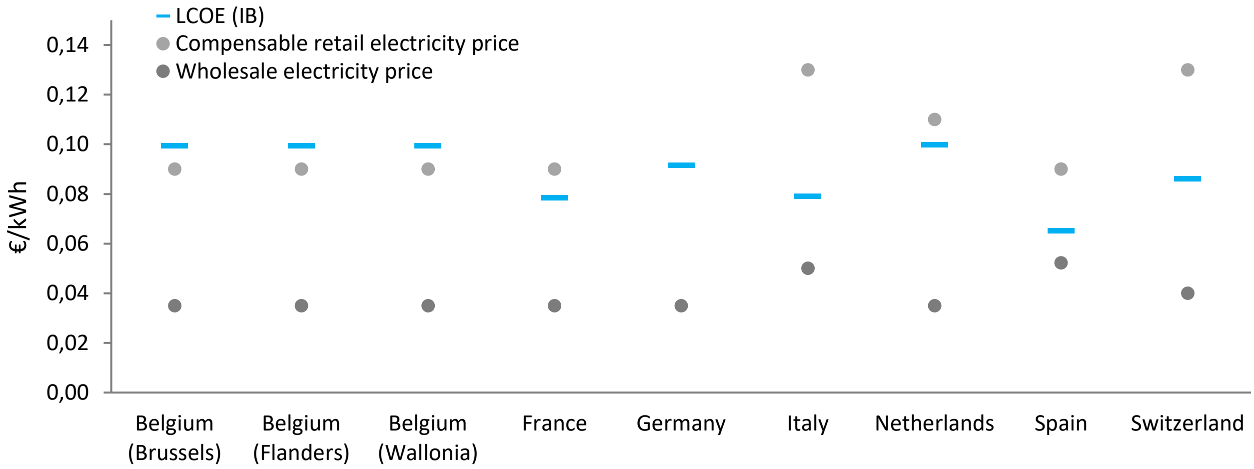


Figure 5 Comparison between the LCOE reached for the IB reference case, the compensable retail electricity price for the IC consumption band and the wholesale electricity price

COMPETITIVENESS BASED ON TOTAL COSTS & REVENUES OF OWNERSHIP

In this competitiveness assessment, a holistic evaluation is conducted. For that purpose, an analysis of the yearly cash-flows associated with the BIPV project is first carried, allowing to estimate all costs and revenues, on its whole lifetime. Then, the net present value of all these yearly cash-flows is calculated, in order to obtain a metric in € of 2021. The final metric obtained is also normalized in €/m², which is a metric more commonly used in the construction sector, and permits to compare solutions and projects. If positive, it means that the BIPV project is economically attractive, as its owner/user earns money for every m² installed. On the contrary, if this number is negative, investing in such system is not economically attractive as it will cost more money than it will be able to earn during the lifetime of the system. Eventually, this holistic competitiveness assessment can help answering this question: is it worth investing in such electricity generating construction material, compared to a conventional building component (from a pure economic point of view)?

REVENUES

To accurately estimate the competitiveness of a building integrated photovoltaics installation, the revenues it can generate must be identified and calculated.

ELECTRICITY REVENUES

Revenues from electricity can be split into those generated from the savings on the electricity expenses and those generated from the electricity fed-back to the grid. Regarding the electricity bill savings, it is important to note that only the variable part of each kWh saved can be considered as a revenue. Indeed, in all countries, a certain share of the invoiced amount for electricity consumption is fixed, independently of the actual amount of electricity consumed over the considered period. The magnitude of this fixed part of the electricity bill depends on the structure of the electricity price, itself influenced by the service provider, the type of contract, the capacity of the connection, the consumption band or the local DSO, among others.

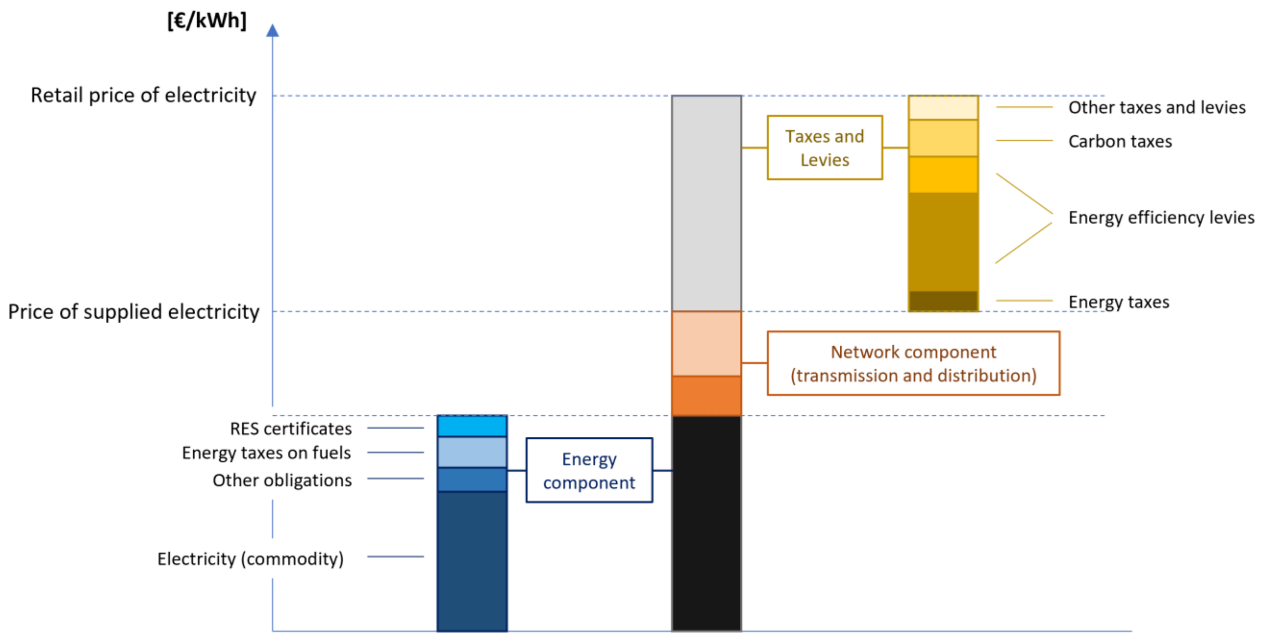


Figure 6 Schematic example of the typical structure of retail electricity price in Europe

Eventually, the electricity price considered in the savings' calculation is called the compensable retail electricity price. To accurately define it, a detailed understanding of the breakdown of retail electricity price is necessary, for each country and consumption band. First, the structure, schematically represented on Figure 6, must be defined and the share of each of the three main components, i.e. commodity, network costs as well as taxes and levies, must be quantified. Then, within each of these components, the variable/fixed ratio must be identified as well. This will allow to define a "compensability ratio", equal to the variable share, for each of the components, specific to a country and a consumption band. This is no simple exercise because many factors can play a role, as mentioned already. Hence, values used in the calculations are averages, based on various recent datasets and publications. It is assumed that possible variations, e.g. in function of the DSO or selected utility company, are of limited magnitude, so that it will not heavily impact the competitiveness evaluation.

The considered retail electricity prices are assumed to vary in function of the type of final user, as electricity consumption levels differ. These consumption levels are called "bands". In the reference cases analysed, three of them are considered (DC, IA and IC).

INCENTIVES

Even if it is a decreasing trend, additional direct and indirect incentives are still granted to individuals or organisations investing in (BI)PV systems, in some countries. These incentives can take the form of investment premiums or advantageous fiscal regimes. Information on the appropriate incentives to add can be found in D9.2 "Update on Regulatory Framework for BIPV" [10].

OTHER REVENUES

Values included in the previous calculation are the ones that can be quantified, hence being directly relevant for the investor and the occupant or owner of the building. But other values linked to the ownership or utilisation of a BIPV system exist and have been already investigated by some researchers [11]. One can for example mention the aesthetical value, as BIPV products are construction elements which can have different shapes and colours. More importantly, the "green" status attached to the BIPV system is often evoked as a source of value creation [12] But it is extremely difficult to estimate, if only possible, and varies in function of the purpose of the building and the activities of its owner. It could, among others, permit the owner of the building to charge a higher rent to the tenant or simply to include a sustainable aspect in its communication and marketing strategy. This can lead to a reduction of the vacancy rate. In addition, a premium could be charged at time of building's sale, justified by the reduced operating expenses made possible by BIPV [13].

Finally, what could also be added to the total savings are the extra energy bill savings allowed by an increase of energy efficiency. For example, some BIPV products could include a layer dedicated to thermal insulation. Also, by providing shading, the BIPV system can reduce the need for cooling of the building. Overall, improvements of the U value or the G value thanks to the BIPV material can play an economic role, especially in the case of a renovation. However, as studies on the matter demonstrated, these effects are not easy to evaluate. They vary from one BIPV product to another, depend on the previously installed or alternative construction materials, the location as well as on the configuration of the system [14] [15] [16].

"EXTRA COST" APPROACH

Building integrated photovoltaics, in addition to producing electricity, have the unique ability to fulfil the functionalities of a building component. Hence, BIPV makes the investment in alternative construction materials unnecessary, thereby offsetting the cost of these conventional, alternative materials. This ability and associated avoided expenses should be considered in the calculations.

To do so, the end-user's typical cost structure needs to be analysed. Indeed, not only is it needed to know the share of each cost item in the total end-user cost (BIPV element, labour, certifications, …), it is also necessary to know which share of each cost item is due to the BIPV system as a building envelope solution, i.e. the fixed costs, and which part is linked to the BIPV system as an electric generating unit, i.e. the extra costs. The split of each cost item into fixed cost and extra cost can be straightforward for some cost items such as those related to the electricity generator functionality (cables, inverter, electrical design, electrical installation, …) which are easily associated with extra costs. On the contrary, for cost items such as structural planning, transport, the assumption is made that they would be the same, would the installation serve a construction purpose only. Finally, some costs are partly associated to the construction function and partially to the electricity generation function. It is the case for the BIPV module, the certification and permitting costs, or the administrative and legal costs which are influenced by both functions. The procedure for these partially extra costs is to assume that the share related to the energy generating function is 50%, as a more precise split could hardly be applied, except in the case of the BIPV module. In that case, a proxy is used to define the fixed cost. This proxy is defined as the value, i.e. the material

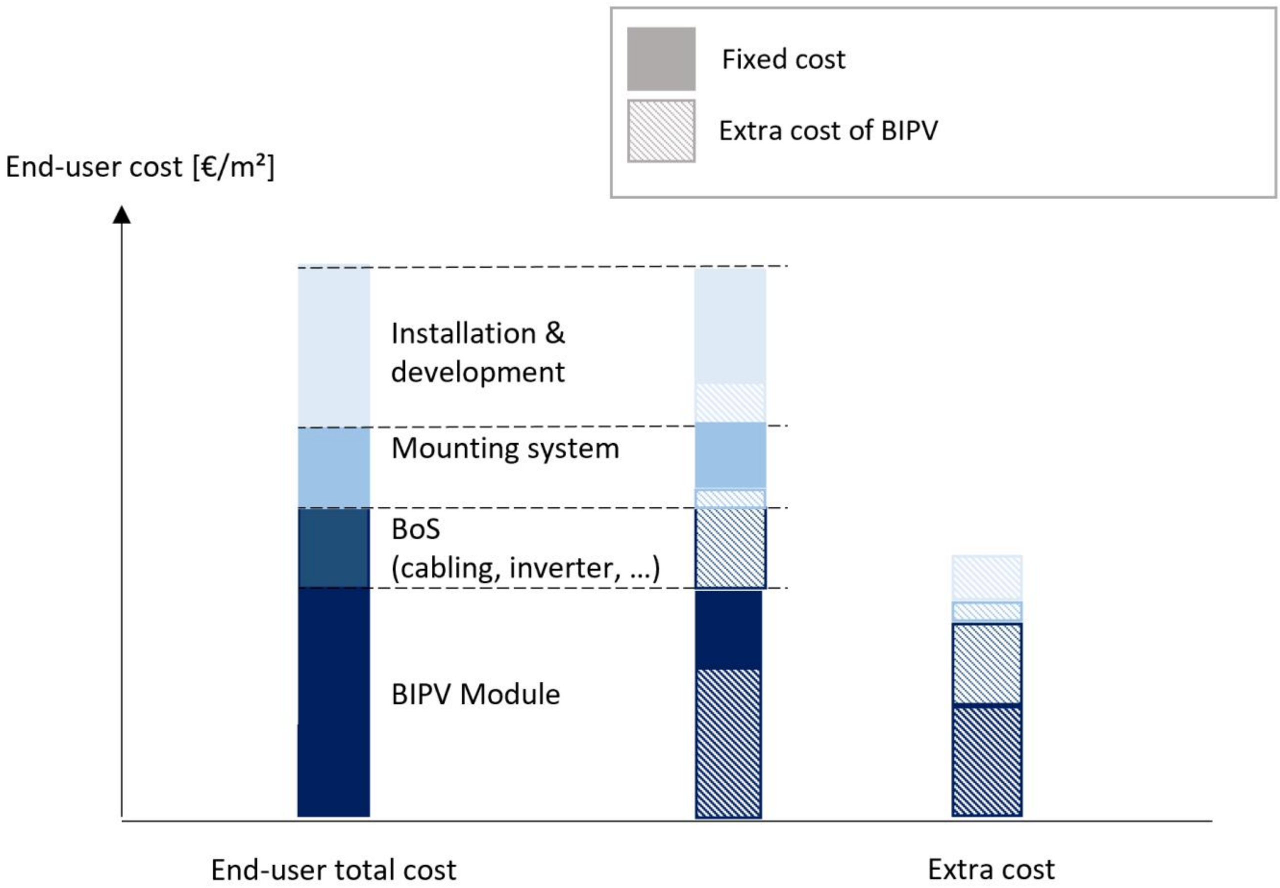


Figure 7 Illustrative explanation of the extra cost approach

cost, of competing mainstream building components. This added value is called “offset cost of conventional construction material”. In order to consider a relevant proxy, it is important to consider a building component having, as much as possible, similar characteristics in terms of aesthetics, quality and functional contribution to the building envelope. In other words, it should belong to what we define as the same “product range”. In the end, it can be drawn from the assessment that BIPV systems represent an extra cost of almost 50% for BIPV roofs and of 40% to 60% for BIPV façades, compared to a conventional building envelope solution. Applying this extra cost approach is also theoretically possible for operation and maintenance costs, however this is not included in this paper, since the operation and maintenance cost for a conventional system can highly vary from one case to another (among others depending on the surrounding environment, or the weather conditions) and can therefore hardly be defined in terms of typical costs for the considered reference cases. Finally, note that the additional cost due to BIPV can represent an even higher share than the results presented above. Indeed, for the purpose of maintaining aesthetic consistency on the entire building envelope, architects or building owners can decide to adapt, not only the façade or roof areas where BIPV will be installed, but also the remaining areas to achieve a harmonized appearance. For example, a glass façade will have a more similar appearance to BIPV glass-glass elements than cheaper cladding materials. Therefore, BIPV can have an impact on the rest of the non-BIPV surfaces because architects and building owners are committed to respect a global aesthetic coherency. In addition, as the cost structure has an impact on the extra cost estimate, the share attributed to each cost item has an influence on the competitiveness results given by this extra cost approach. Therefore, only a detailed case by case assessment of this cost structure can lead to a precise and relevant decision-making process on whether to invest in a given BIPV project or not.

COMPETITIVENESS

To estimate the competitiveness of BIPV system, a holistic approach is taken, as explained in the introduction of the previous subsection. All positive and negative cash flows are simulated, on a yearly basis, according to the previously listed parameters and assumptions. They are then summarized in a profit and loss statement, which allows to subsequently quantify the yearly "free cash flows" via the cash flow statement. Based on the free cash flows, the net present value of the BIPV project is calculated, by discounting all these free cash flows back to the initial year of investment:

$$NPV_{Project} = \sum_{n=0}^{N} \frac{Free\ Cash\ Flow_n}{(1 + WACC_{nom})^n} = -I + \sum_{n=1}^{N} \frac{Free\ Cash\ Flow_n}{(1 + WACC_{nom})^n}$$

Where

- N is the total number of periods, i.e. years, during which the system will be operated.
- $WACC_{nom}$ is the nominal weighted average cost of capital.
- $Free\ Cash\ Flow_n$ of the BIPV project going to the organization who made the investment (also assumed to benefit from electricity revenues), in year n.
- *I* is the initial investment considered under the extra cost approach.

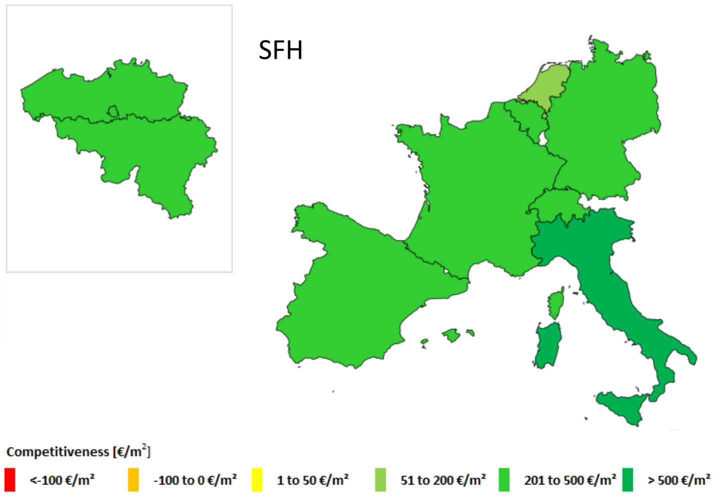
Finally, the competitiveness of the BIPV project, in €/m², is obtained by dividing the NPV of the project by the surface occupied by the system. The competitiveness is expressed in €/m² as it is an easily understandable metric, widely used in the construction and BIPV sectors. It also is a more suitable metric to compare projects.

$$Competitiveness = \frac{NPV_{Project}}{A}$$

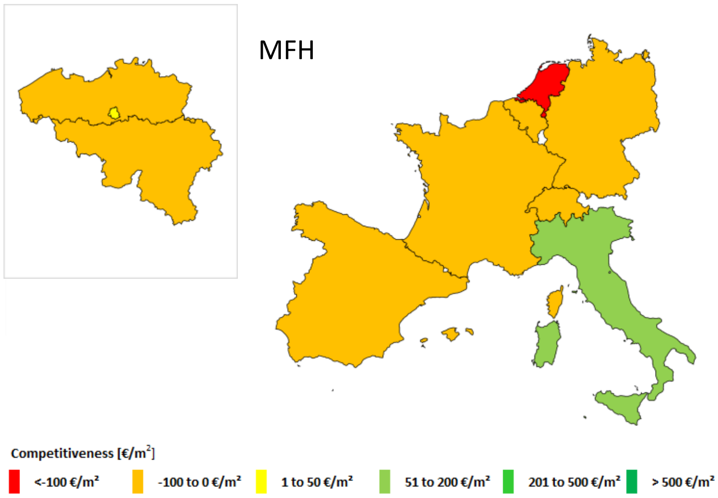
Where A is the available surface for the system. If positive, it means that the BIPV project is economically attractive, as its owner/user earns money for every m² installed. On the contrary, if this number is negative, investing in such system is not economically attractive as it will cost more money than it will be able to earn during the lifetime of the system. Eventually, this holistic competitiveness assessment can help answering this question: is it worth investing in such electricity generating construction material, compared to a conventional building component (from a pure economic point of view)?

CURRENT COMPETITIVENESS STATUS OF BIPV SOLUTIONS IN KEY EUROPEAN COUNTRIES

BIPV SOLUTIONS IN RESIDENTIAL BUILDINGS

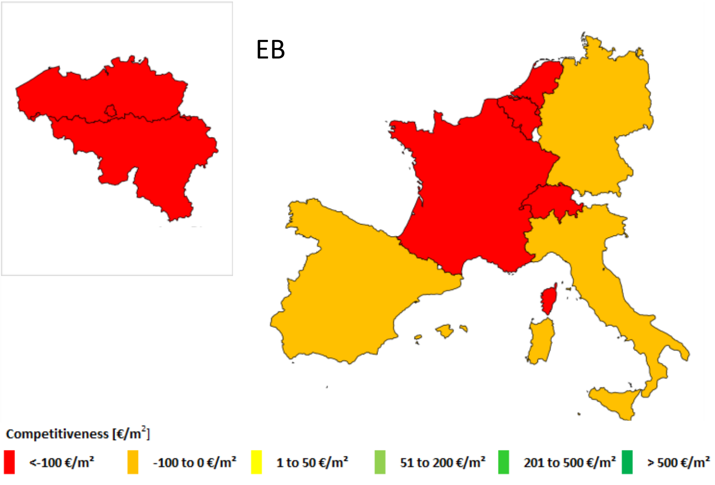


The considered BIPV solution for a single-family house (in-roof mounting system) is competitive across all considered European countries, allowing revenues of couple hundreds of euros per square meter. In particular in Italy, a competitiveness value as high as **877 €/m²** is reached. Other countries in Europe, exhibit decent competitiveness with values around **300 €/m²**.

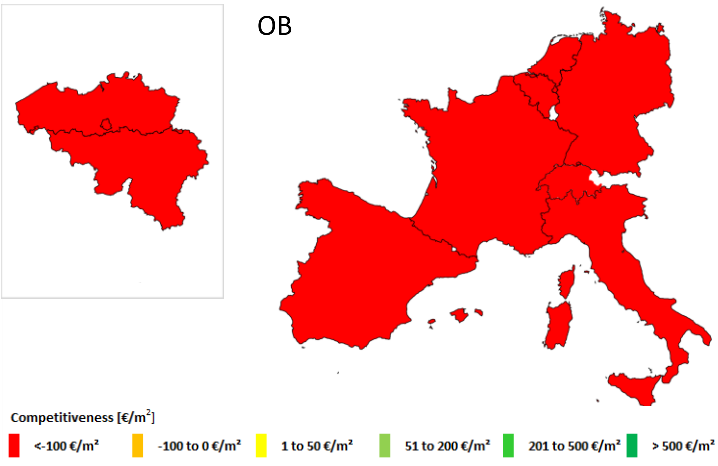


The competitiveness of the considered BIPV façade solution for a multi-family house is currently viable only in Italy and in the centre (Brussels) of Belgium with respective competitiveness values of **143 €/m²** and **44 €/m²**. However, concerning other countries their competitiveness is rather weak with values going from **-17 €/m²** for Germany to **-235 €/m²** for the Netherlands.

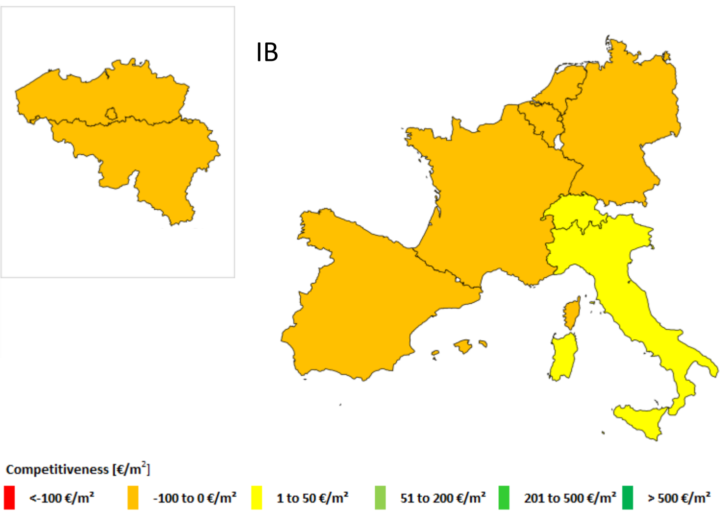
BIPV SOLUTIONS IN NON-RESIDENTIAL BUILDINGS



The competitiveness of the considered BIPV façade solution for an educational building in Europe is currently weak with values going from **-5 €/m^2** for Italy to **-204 €/m^2** for the Netherlands. Thus, educational buildings, when a façade-integrated BIPV system is considered, represent a less competitive sector for BIPV than residential buildings.



The BIPV curtain wall solution considered for an office building suffers from higher extra costs and lower system power density compared to the other studied systems as well a less optimal irradiation conditions. This explains why the competitiveness threshold is currently never reached in Europe, with values around **-300 €/m^2.**



The competitiveness of the considered BIPV roofing solution for an industrial building in Europe is the only viable one concerning non-residential buildings. Better competitiveness results are made possible mainly thanks to the fact that the BIPV system, contrary to the two other non-residential buildings, is integrated to a roof thus resulting in better yields. Switzerland and Italy exhibit respectively competitiveness values of **29 €/m^2** and **4 €/m^2**. While BIPV competitiveness' values in other countries vary between **-19 €/m^2** and **-83 €/m^2.** This can be mainly explained by the fact that electricity prices for industrial actors is quite low.

COST TARGETS

In this section, what we define as "cost targets" are presented. These targets are specific to each reference case, and to each combination of country and business model studied in the competitiveness assessment, presented in the previous sections. These cost targets can be understood as what efforts, purely in terms of BIPV extra cost decreases for the end-user, would be needed to achieve economic competitiveness. It can contribute to help BIPV stakeholders along the value chain, who can have an influence on various cost items (on-site labour, transport, manufacturing, …), to define coherent cost objectives. Note that for the SFH reference case, the competitiveness threshold is reached with current end-user extra cost values in all countries, so no graph is presented.

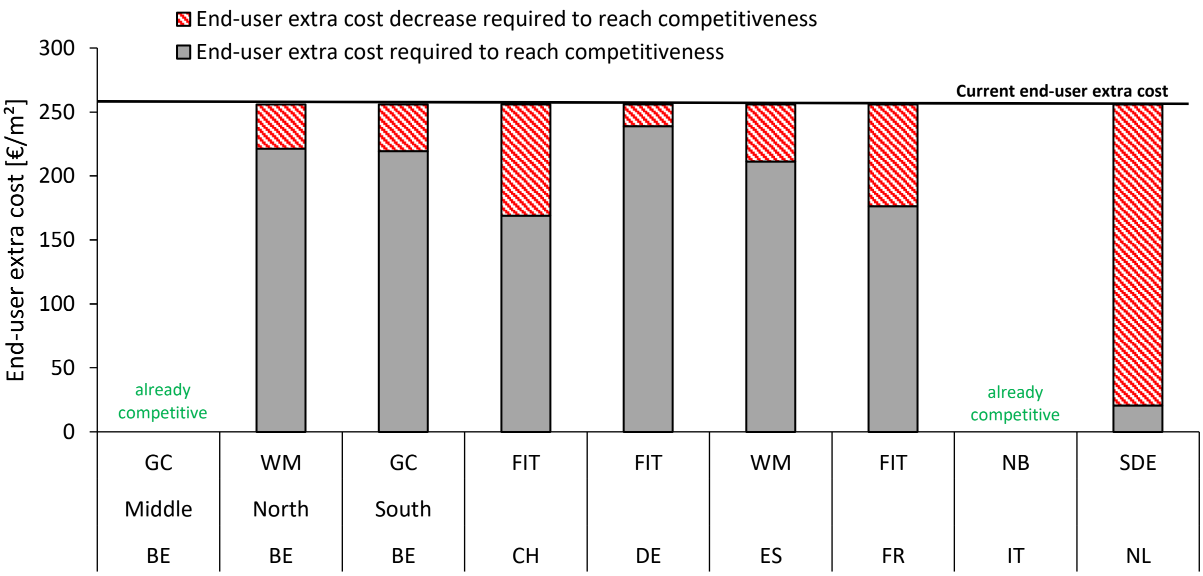


Figure 8 Extra cost targets for the MFH reference case

The end-user extra cost targets for the MFH reference cases which did not reach the competitiveness threshold with current end-user extra cost values are realistically achievable with the exception of the Netherlands. Therefore, the reduction of the CAPEX can be identified as a clear lever to focus on to achieve competitiveness for the MFH reference case and such type of BIPV façade solution.

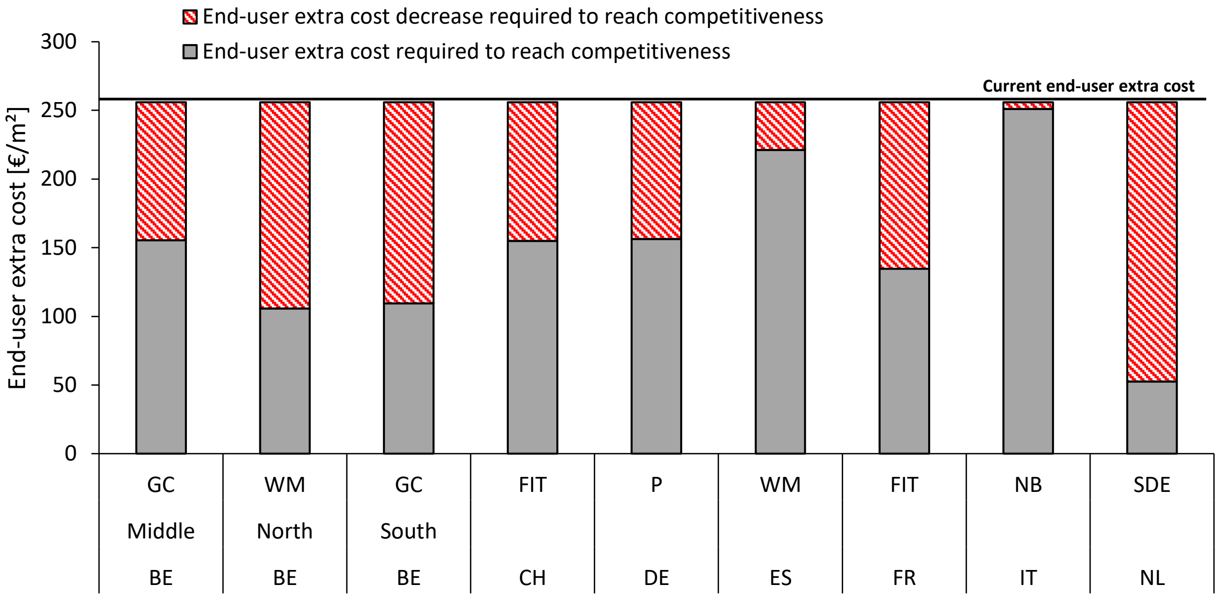


Figure 9 Extra cost targets for the EB reference case

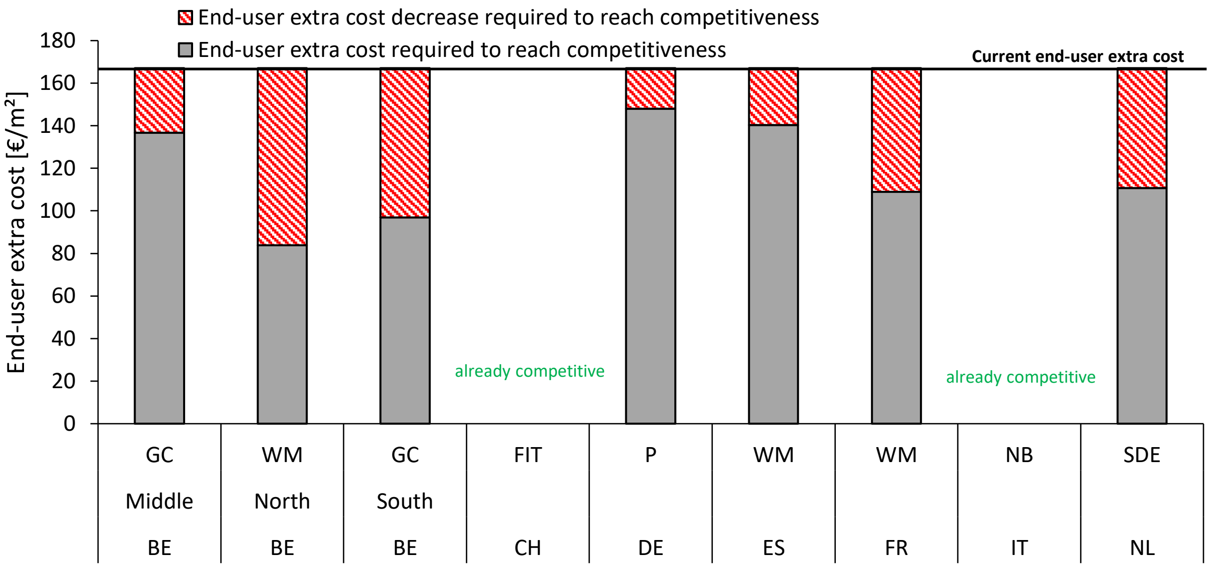


Figure 10 Extra cost targets for the IB reference case

For the educational building, as well as the industrial building reference cases, it can be noted that the end-user extra cost targets are reachable except for the Netherlands for the educational building reference case, and for the regions of Flanders and Wallonia in Belgium for the industrial building. Overall, these extra cost targets are more ambitious than in the case of an MFH, representing a bigger challenge.

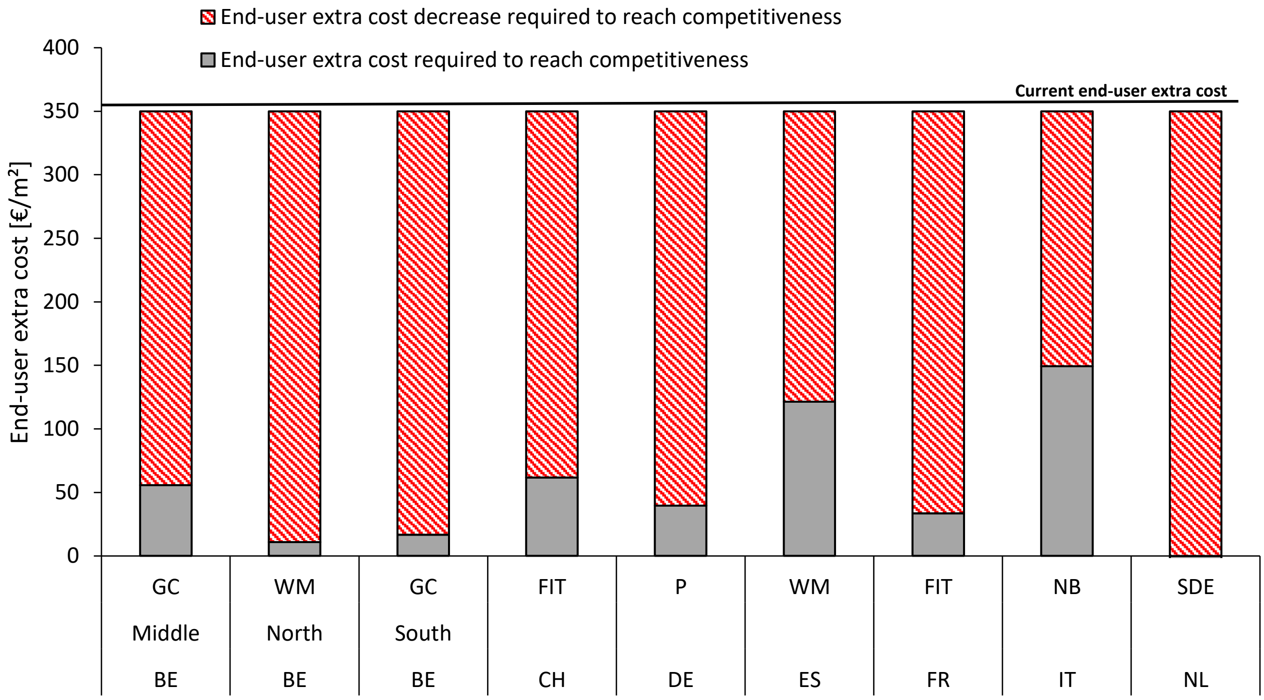


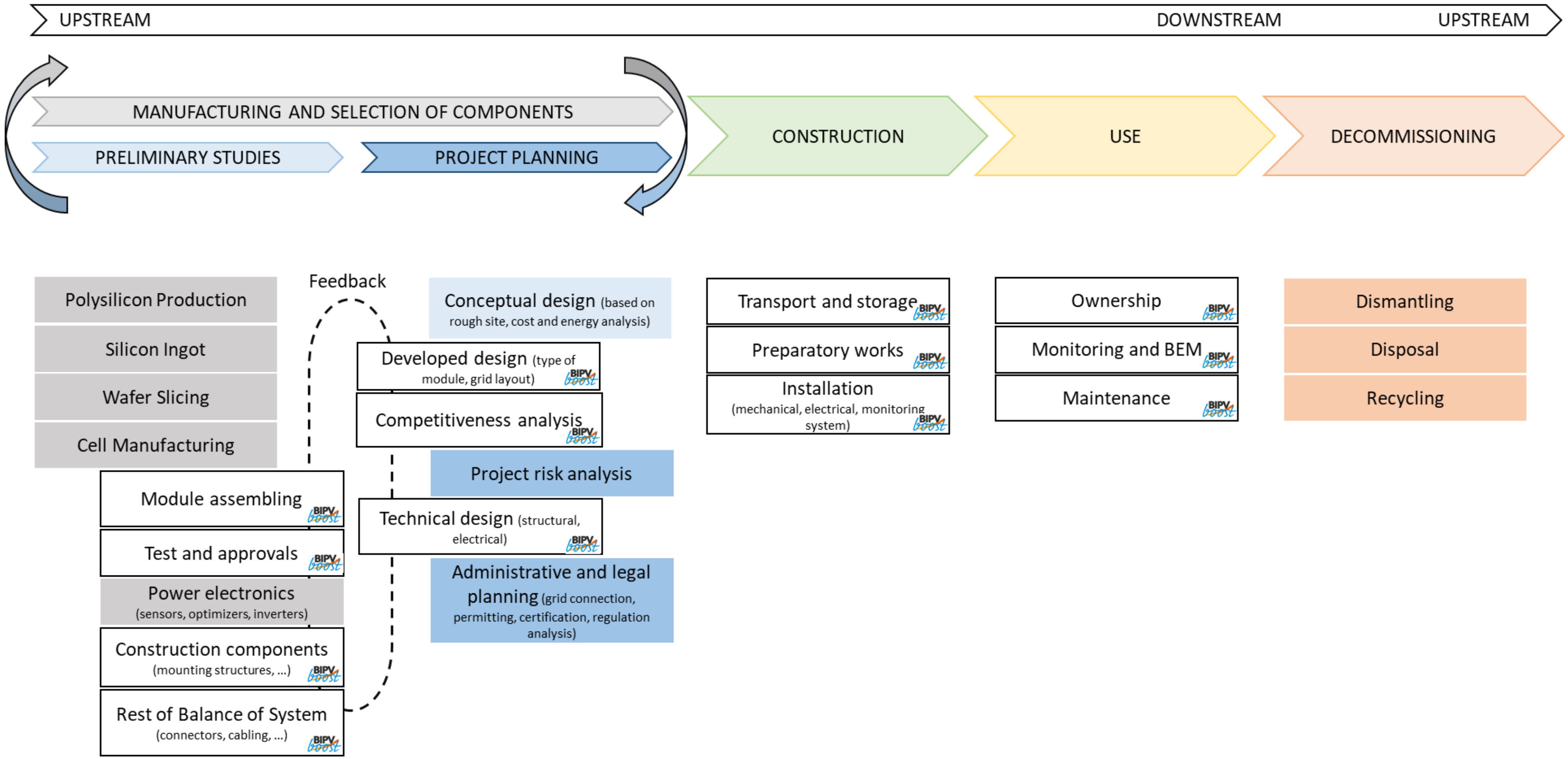
Figure 11 Extra cost targets for the OB reference case

Concerning the office building reference cases, no end-user extra cost target seems realistically reachable. The fact that these targets are extremely far from the current end-user cost can be explained by, on one hand, the higher end-user cost of BIPV curtain walls, and on the other hand, the limited conversion efficiency values of modules under such configuration, (10,4%), due to their semi-transparent characteristic. In comparison, the other reference cases studying a BIPV system integrated to a façade are exhibiting a module efficiency of around 17% leading to an almost doubled electricity production for a same system surface and all other factors (orientation, irradiation) being equal. These targets can therefore hardly be interpreted as real targets for manufacturers or other stakeholders. These results also demonstrate that potential cost reductions absolutely need to be combined with technical improvements in order to reach competitiveness.

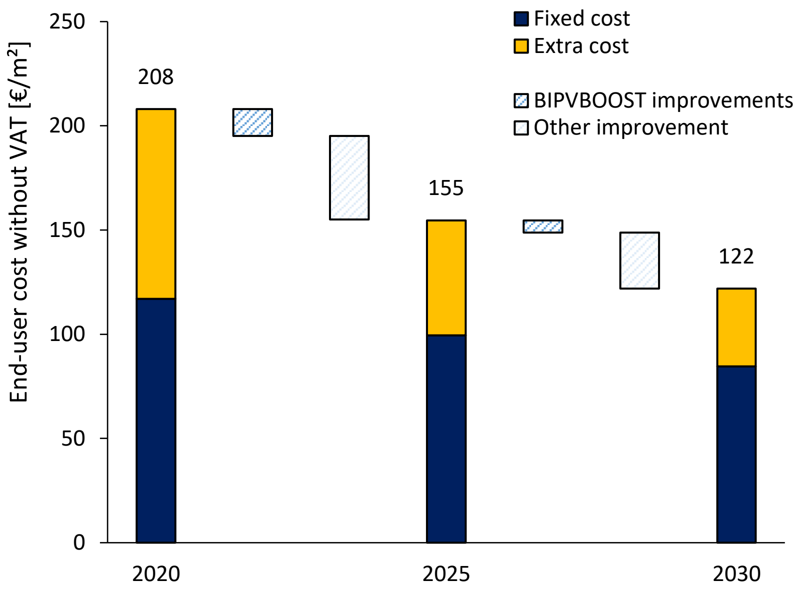
COST REDUCTION ROADMAP

The end-user extra cost reduction potential is important as such reduction can arise from all steps of the BIPV value chain (cf. figure below) from the module assembling to the installation costs and thanks to both technological innovations as well as market maturation. These end-user cost reductions are presented in pages 23 and 24. Nevertheless, other aspects are also the subject of innovations such as the module efficiency, the system lifetime or the operation and maintenance costs. All these improvements will arise either directly from the BIPV sector (in particular in the frame of BIPV-dedicated research projects such as BIPVBOOST) but also from the PV or the construction sectors.

Table 1 BIPV value chain *(framed value chain steps marked with the BIPVBOOST logo are worked on in the BIPVBOOST project)*

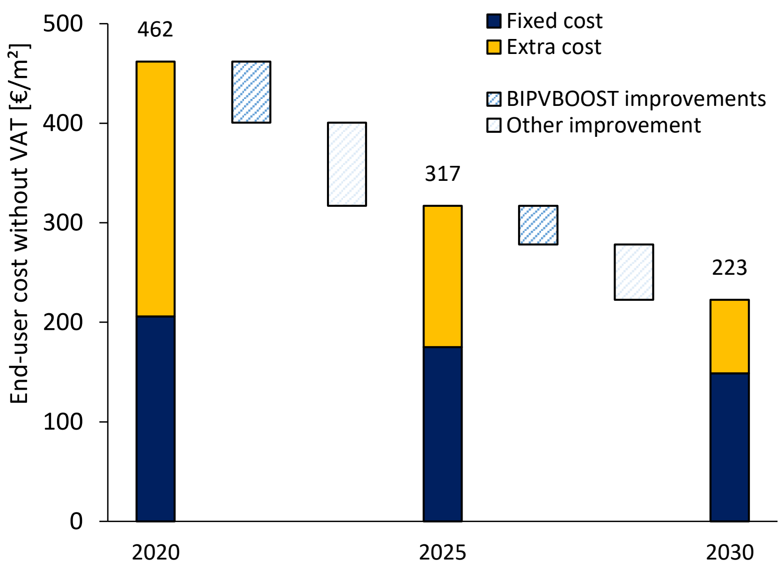


In-roof mounting system (mono c-Si PERC)



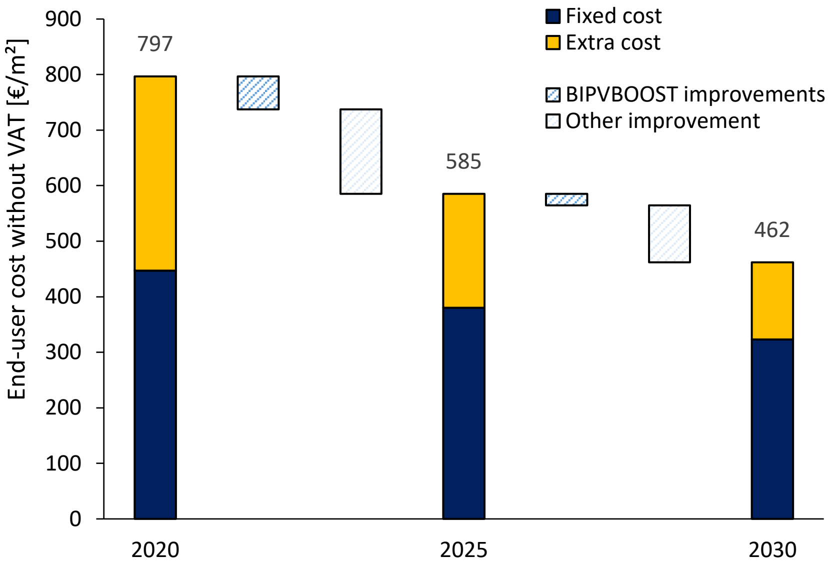
The end-user cost reductions should mainly come from various market maturation improvements and from technical innovations (e.g., automatic and flexible BIPV production lines for c-Si cells developed in the BIPVBOOST project). These improvements should allow a total end-user cost reduction of 53 €/m² by 2025 and an additional cost reduction of 33 €/m² by 2030. Eventually, there is a potential of reaching an **end-user BIPV extra cost of 37 €/m² by 2030**.

Rainscreen façade (mono c-Si PERC)



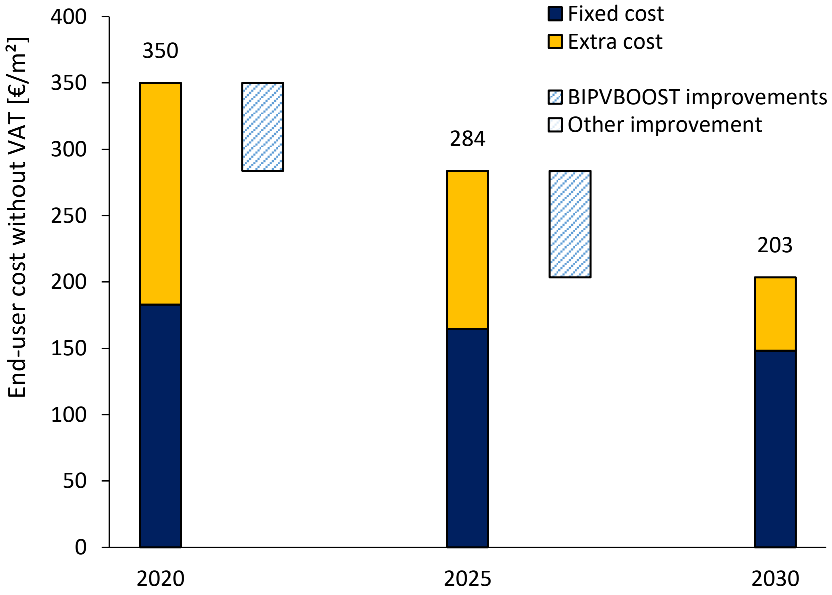
For mono c-Si PERC-based rainscreen façades, the end-user cost reductions are foreseen to near-equitably come from market maturation improvements and technical innovations (e.g., glass façades based on upgraded plug-and-play substructures and automatic and flexible BIPV production lines for c-Si cells both developed in the BIPVBOOST project). These improvements should allow a total end-user cost reduction of 145 €/m² by 2025 and an additional cost reduction of 94 €/m² by 2030. Eventually, there is a potential of reaching an **end-user BIPV extra cost of 74 €/m² by 2030**.

Curtain wall (mono c-Si PERC)



Concerning curtain walls, the end-user cost reductions should come both from market maturation improvements and technical innovations (e.g., automatic and flexible BIPV production lines for c-Si cells both developed in the BIPVBOOST project). These improvements should allow a total end-user cost reduction of 212 €/m² by 2025 and an additional cost reduction of 123 €/m² by 2030. Eventually, there is a potential of reaching an **end-user BIPV extra cost of 139 €/m² by 2030**.

Lightweight metal roofing (CIGS)



Concerning CIGS-based lightweight metal roofing, the considered cost reductions will arise from the BIPVBOOST project[1] (development of a roof system based on lightweight CIGS on metal). This improvement will allow a total end-user cost reduction of 66 €/m² by 2025 and an additional cost reduction of 81 €/m² by 2030. Eventually, there is a potential of reaching an **end-user BIPV extra cost of 55 €/m² by 2030**.

[1] The development of a roof system based on lightweight CIGS on metal which will take place in the BIPVBOOST project is already a concatenate of both various improvements that are internal or external to the BIPVBOOST project (both technical innovations and market maturation) and taking place at different steps of the BIPV value chain.

RESULTS AND HOW TO INTERPRET THEM

For each country, the business model applicable at the time of publication of this document, according to the local regulation, for this specific segment of installed nominal power and which yields the best competitiveness is selected. It is referred to as the "classic" business model. A summary of used abbreviations is provided in table 2.6.

Table 2 Summary of used abbreviations for business models

Business Model Abbreviation	Business model complete name
FIT	Feed-in tariff
GC	Green Certificates
NB	Net-billing
NM	Net-metering
P	Premium
SDE	"Stimuleringsregeling Duurzame Energieproductie" (Sustainable Energy Production Incentive Scheme)
WM	Wholesale market price

SELECTED INDICATORS

Competitiveness

[€/m²]

- The competitiveness is the net present value of the yearly cash flows normalised with the surface covered by the system.
- Even though they have the same unit, the competitiveness should **not be mistaken for the end-user cost.**
- To interpret the competitiveness, its value must be **compared to the competitiveness of a project without BIPV which is 0 €/m²** (no extra cost and no revenues)
- A **positive competitiveness** means that the BIPV project is economically attractive compared to a conventional building envelope solution, as its owner/user earns money for every m² installed. On the contrary, a **negative competitiveness** indicates that investing in such system is not economically attractive as it will cost more money than it will allow to earn on the lifetime of the system.

Modified Internal Return Rate

[%]

- The Modified Internal Return Rate (MIRR) is the discount rate for which the net present value equals 0.
- This metric is preferred compared to the IRR, which can lead to inconsistent results, as more than one solution is possible, and as it implicitly assumes that project cash flows are reinvested in new projects at a rate equalling the computed IRR [17].
- To interpret the MIRR, its value must be **compared to the discount rate** used in each case.
- A **MIRR greater than the used discount rate** underlines the competitiveness of the case. On the contrary, a **MIRR smaller than the discount rates** indicate that the investment is not attractive.

NB :

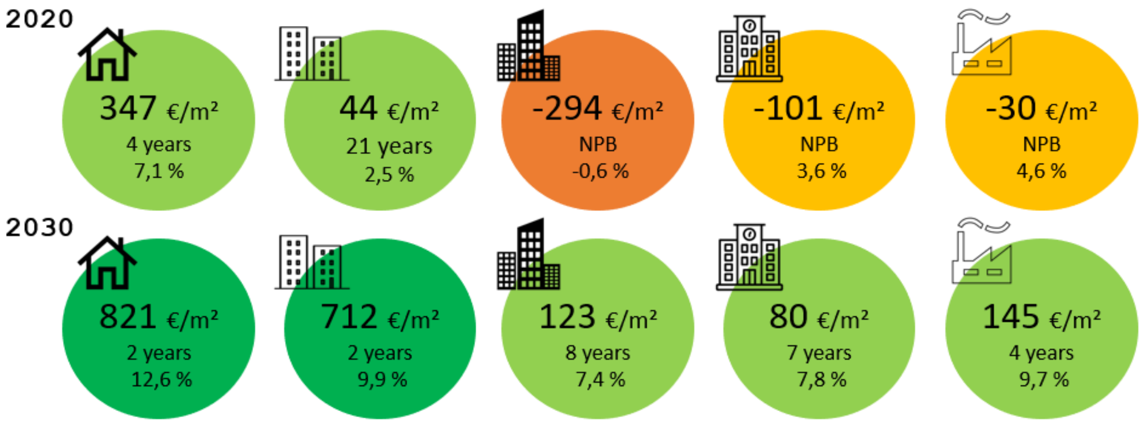
When not indicated otherwise, presented economic values are **nominal values**, i.e. in € of the year they concern.

COUNTRY FACTSHEETS

In the following pages, the current and estimated future competitiveness status of the different studied reference cases are presented for each country. Insights on the electricity prices and current local regulatory environment applicable in this country are presented as well, along with some comments analysing the presented results.

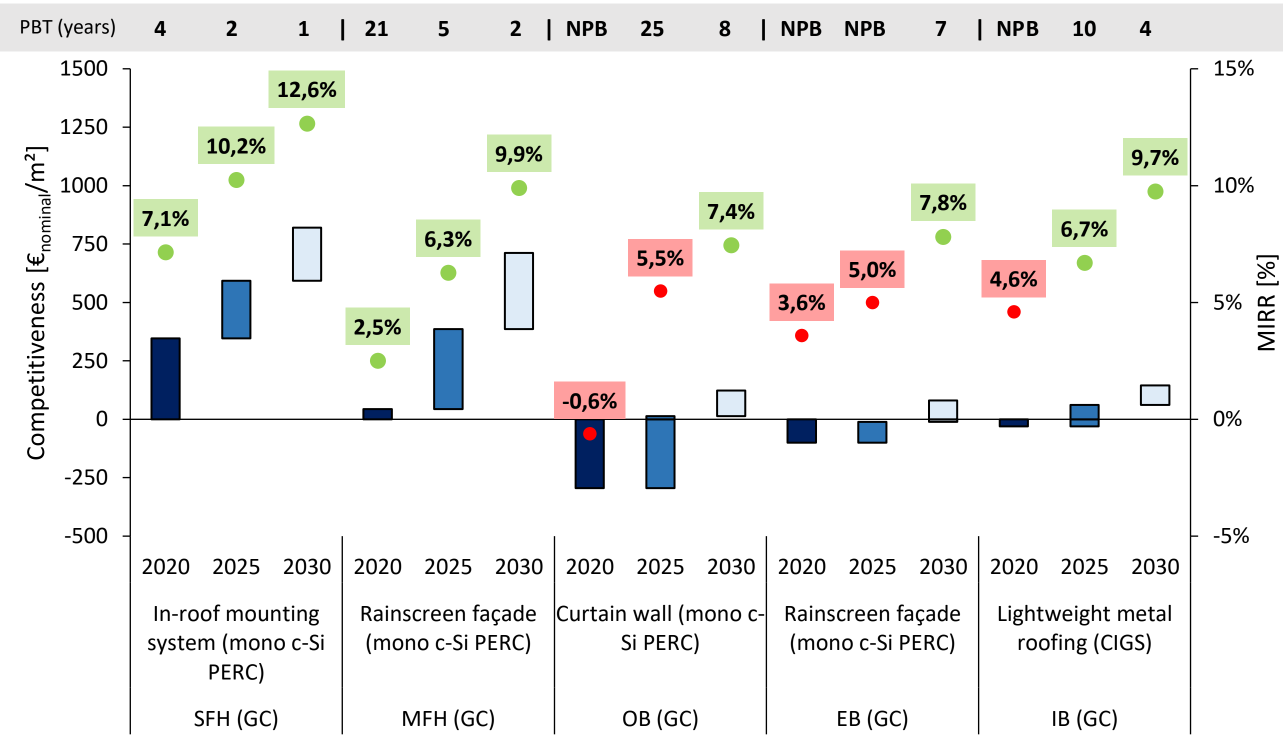
It is worth noting that the competitiveness results for 2020, 2025 and 2030 are all based on the same business model, for comparability purpose. However, it is highly uncertain that all support schemes will remain identical over the next decade. The reason why no assumptions have been made on the possible evolution of these regulatory variables, nor on the potential variation of electricity prices, is to avoid blurring the interpretation of conclusions. Competitiveness results estimated at 2025 and 2030 horizons strictly aim at showing to what extent the cost efficiency increases (efficiency increase combined with end-user cost decrease) of the studied BIPV systems can contribute to increase their competitiveness. Thus, the values should not be interpreted as the competitiveness levels that will be achieved at that time horizon, since any support scheme modification (transition from one support scheme to another, removal of a support scheme or incentive, or the significant reduction of the support amount such as the feed-in tariff value) or significant electricity price variation could have a significant impact on the presented results. Eventually, this permits a strict evaluation of the impact on competitiveness of variables (end-user cost and system performances) that can be directly influenced by actors of the BIPV sector.

BELGIUM – Brussels



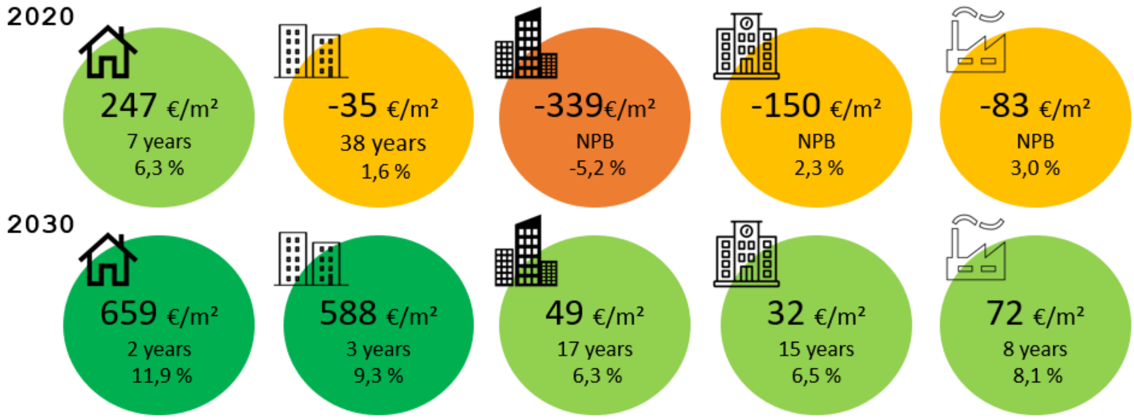
In Brussels, self-consumption is allowed for all studied systems, thus allowing revenues through savings on the electricity bill. (BI)PV installations are entitled to receive **Green Certificates** for each kWh produced. In addition, excess electricity produced is assumed to be resold at the average **wholesale market price**.

Electricity prices for households in Brussels can be considered **high compared to the European average** lying at **28 c€/kWh** (23 c€/kWh of which are compensable). In the same way, electricity prices for small non-household consumers (IA) can also be considered **relatively high compared** to other European countries lying at around **23 c€/kWh** (16 c€/kWh of which are compensable). Industrial consumers belonging to the IC consumption band have access to a retail electricity price of **12 c€/kWh** (9 c€/kWh of which are compensable). [18]



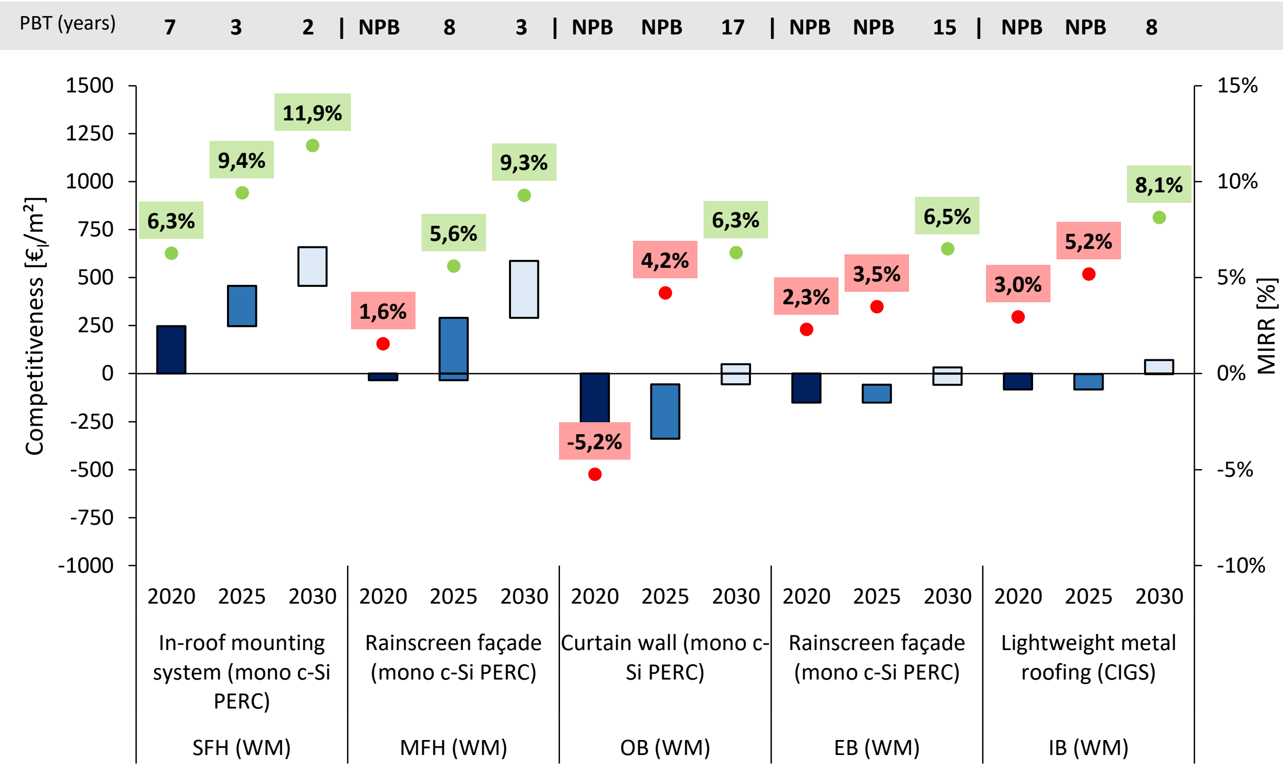
- **In-roof mounting systems** integrated to a **SFH** roof are already competitive in Brussels with a current competitiveness of 347 €/m² corresponding to a pay-back time of 4 years and a MIRR of 7,1%. This is particularly possible thanks to the revenues provided by the Green Certificates and acceptable irradiance conditions obtained on a south oriented roof in this region. The various improvements that will benefit to in-roof mounting BIPV systems should contribute to further increase the profitability by 2030, allowing to reach a competitiveness of 821 €/m².
- The **ventilated MFH façade based on mono c-Si PERC** modules suffers from sub-optimal irradiance conditions being positioned vertically. Nevertheless, thanks to the low discount rate considered (2%), the savings on the electricity bill based on the DC electricity prices and the Green Certificates, the competitiveness is already reached in 2020 with 44 €/m², with the potential to reach more than 700 €/m² by 2030.
- The **ventilated EB façade based on mono c-Si PERC** modules also suffers from sub-optimal irradiance conditions being positioned vertically. Due to a higher discount rate (5,7%) and lower retail electricity prices for the IA consumption band compared to DC band, the competitiveness reached by 2020 is worse than the MFH case. Eventually, the competitiveness threshold should be reached by 2030, allowing a competitiveness of 80 €/m².
- The **OB curtain wall** façade based on **semi-transparent mono c-Si PERC** modules suffers not only from sub-optimal irradiance conditions being positioned vertically, but it also hindered by a reduced energy production due to the semi-transparency of the modules used and their consequent lower efficiency as well as a significantly higher end-user extra cost. All these elements lead to a negative competitiveness in 2020. Nonetheless, this BIPV products' important end-user extra costs also represent an opportunity for possible important cost reductions which should allow the case to become competitive by 2030.
- The **IB, CIGS-based lightweight metal roofing** combines multiple advantages such as being installed on a roof thus allowing better yields and coming at a relatively low end-user extra cost. Despite the important self-consumption rate considered for this case (90%), the low retail electricity prices for the IC consumption band limits the attractiveness of this case. Eventually, this case should only be competitive by 2025, reaching 145 €/m² by 2030.

BELGIUM – Flanders



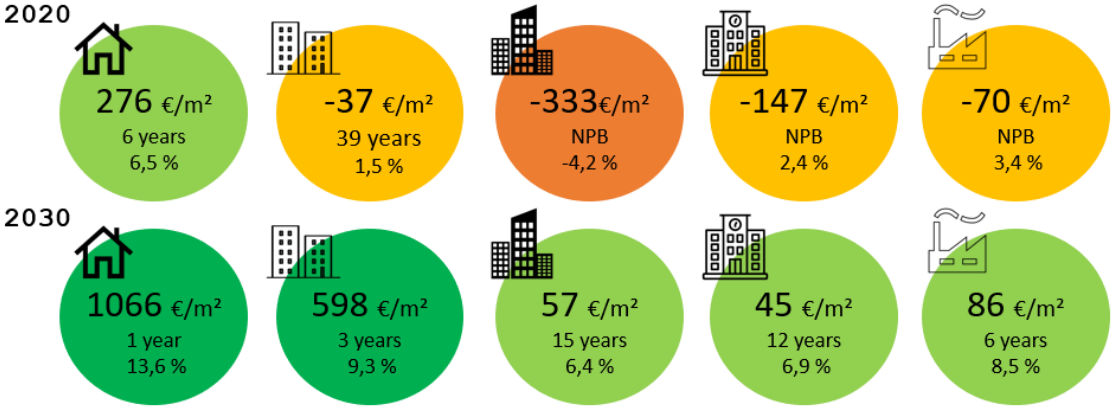
In Flanders, the standard revenues are the savings on the electricity bill. For small rooftop (BI)PV systems (<10kWp) a direct investment aid is applicable as well. It consists in 300 €/kWp for the first 4 kWp installed and 150 €/kWp for the following 2 kWp [4kWp-6kWp] for 2021 (which is the value considered in the calculations here). For systems between 10 kWp and 40 kWp there is no support. For systems bigger than 40 kWp and up to 2 MWp, investment aids will be attributed through a tendering process (the lowest bids only will obtain an investment aid), therefore it is assumed that the BIPV systems greater than 40 kWp considered here will not be competitive enough (in particular since they will possibly compete with ground-mounted PV) and will therefore not receive an investment aid. For all considered systems, excess electricity produced is assumed to be resold at the average **wholesale market price**.

Electricity prices for households in Flanders can be considered **high compared to the European average** lying at **28 c€/kWh** (23 c€/kWh of which are compensable). In the same way, electricity prices for small non-household consumers (IA) can also be considered **relatively high compared** to other European countries lying at around **23 c€/kWh** (16 c€/kWh of which are compensable). Industrial consumers belonging to the IC consumption band have access to a retail electricity price of **12 c€/kWh** (9 c€/kWh of which are compensable). [18]



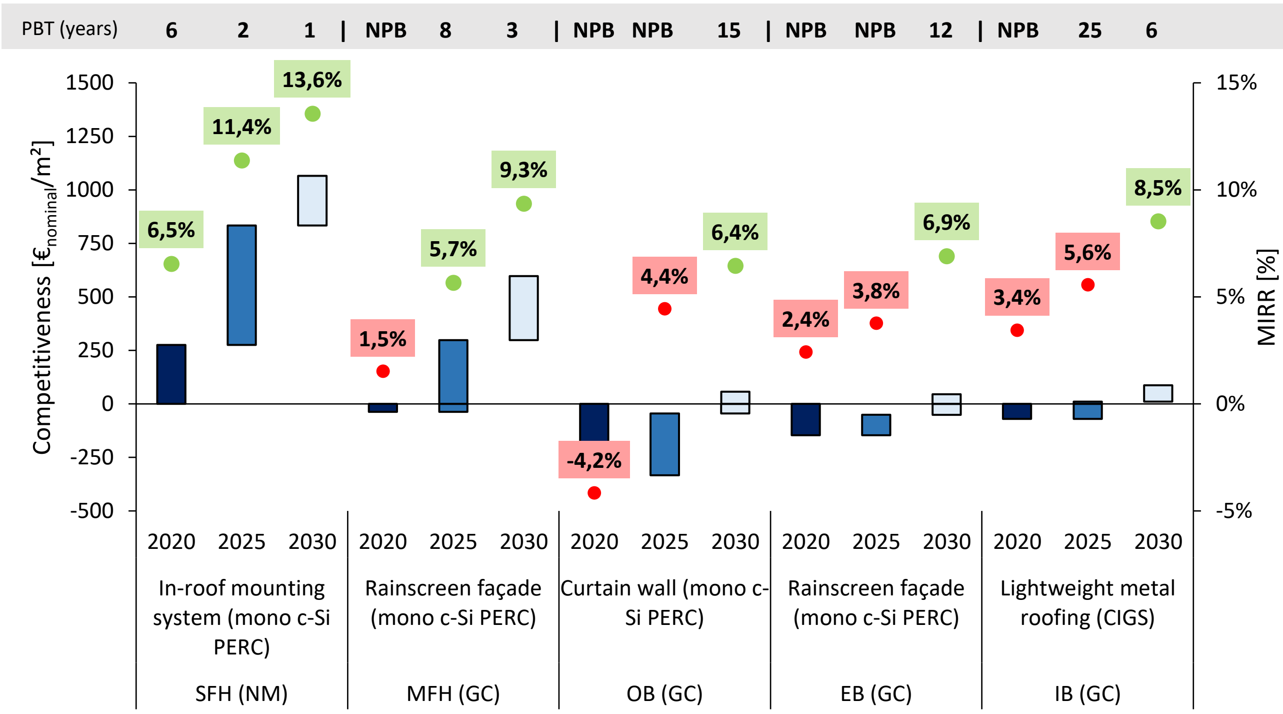
- **In-roof mounting systems** integrated to a **SFH** roof are already competitive in the northern region (Flanders) of Belgium with a current competitiveness of 247 €/m² corresponding to a pay-back time of 7 years and a MIRR of 6,3%. This is particularly possible thanks to the investment aid that is granted for small installations in Flanders and acceptable irradiance conditions on a south oriented roof in this region. The various improvements that will benefit to in-roof mounting BIPV systems will contribute to increase the profitability by 2030, allowing to reach a competitiveness of 659 €/m².
- The **ventilated MFH façade based on mono c-Si PERC** modules suffers from sub-optimal irradiance conditions being positioned vertically. Nevertheless, thanks to the low discount rate considered (2%) and the savings on the electricity bill based on the DC electricity prices, the competitiveness is almost reached in 2020 with -35 €/m², with the potential to reach close to 600 €/m² by 2030.
- The **ventilated EB façade based on mono c-Si PERC** modules also suffers from sub-optimal irradiance conditions being positioned vertically. Due to a higher discount rate (5,7%) and lower retail electricity prices for the IA consumption band compared to DC band, the competitiveness reached by 2020 is slightly worse than the MFH case. Eventually, the competitiveness threshold should be reached by 2030, allowing a competitiveness of 32 €/m².
- The **OB curtain wall** façade based on **semi-transparent mono c-Si PERC** modules suffers not only from sub-optimal irradiance conditions being positioned vertically, but it also hindered by a reduced energy production due to the semi-transparency of the modules used and their consequent lower efficiency as well as a higher end-user extra cost. All these elements lead to a negative competitiveness in 2020. Nonetheless, this BIPV products' important end-user extra costs also represent an opportunity for possible important cost reductions which should allow the case to become competitive by 2030.
- The **IB, CIGS-based lightweight metal roofing** combines multiple advantages such as being installed on a roof thus allowing better yields and coming at a relatively low end-user extra cost. Despite the important self-consumption rate considered for this case (90%), the low retail electricity prices of the IC consumption band limits the attractiveness of this case. Eventually, this case should only be competitive by 2030, reaching 72 €/m².

BELGIUM – Wallonia



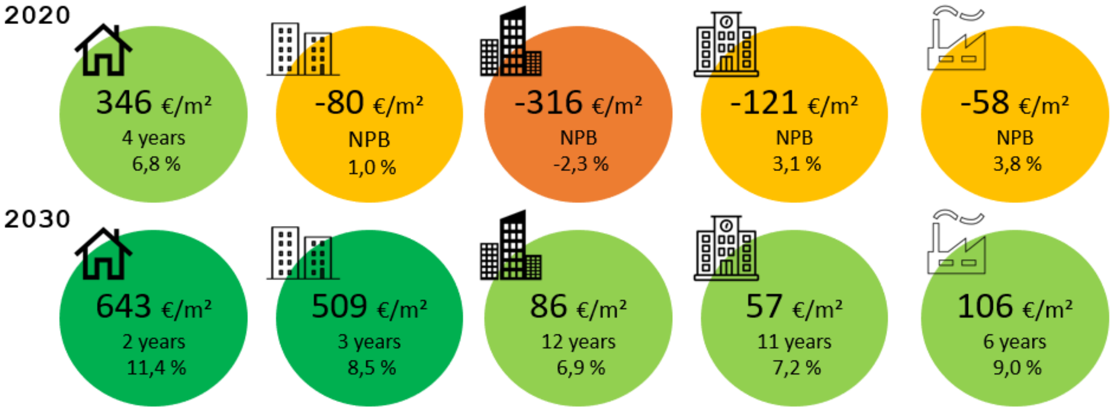
In Wallonia, self-consumption is allowed for all studied systems, thus allowing revenues through savings on the electricity bill. In addition, small installations (below 10 kWp), a **net-metering** scheme applies for a duration of 30 years. For these small installations, a prosumer tariff (of 80 €/kWp, on average) applies since October 2020. Larger installations, with an installed capacity between 10kWp and 1000kWp are entitled to receive **Green Certificates** for each kWh produced. In addition, excess electricity produced is assumed to be resold at the average **wholesale market price**.

Electricity prices for households in Wallonia can be considered **high compared to the European average** lying at **28 c€/kWh** (23 c€/kWh of which are compensable). In the same way, electricity prices for small non-household consumers (IA) can also be considered **relatively high compared** to other European countries lying at around **23 c€/kWh** (16 c€/kWh of which are compensable). Industrial consumers belonging to the IC consumption band have access to a retail electricity price of **12 c€/kWh** (9 c€/kWh of which are compensable). [18]



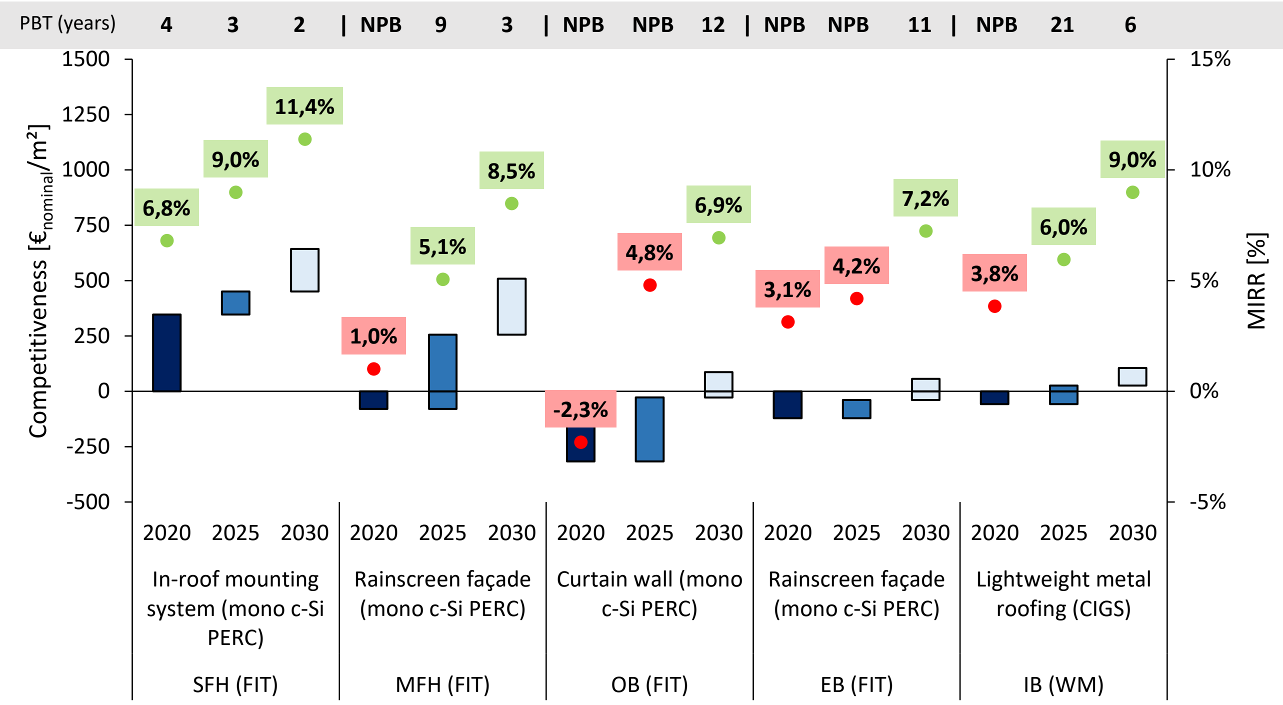
- **In-roof mounting systems** integrated to a **SFH** roof are already competitive in Wallonia with a current competitiveness of 276 €/m² corresponding to a pay-back time of 6 years and a MIRR of 6,5%. This is particularly possible thanks to a very advantageous net-metering support and acceptable irradiance conditions obtained on a south oriented roof in this region. The various improvements that will benefit to in-roof mounting BIPV systems should contribute to increase the profitability by 2030, with the potential to reach a competitiveness of more than 1000 €/m².
- The **ventilated MFH façade based on mono c-Si PERC** modules suffers from sub-optimal irradiance conditions being positioned vertically. Nevertheless, thanks to the low discount rate considered (2%) and the savings on the electricity bill based on the DC electricity prices, the competitiveness is almost reached in 2020 with -37 €/m², with the potential to reach close to 600 €/m² by 2030.
- The **ventilated EB façade based on mono c-Si PERC** modules also suffers from sub-optimal irradiance conditions being positioned vertically. Due to a higher discount rate (5,7%) and lower retail electricity prices for the IA consumption band compared to DC band, the competitiveness reached by 2020 is slightly worse than the MFH case. Eventually, the competitiveness threshold should be reached by 2030, allowing a competitiveness of 45 €/m².
- The **OB curtain wall** façade based on **semi-transparent mono c-Si PERC** modules suffers not only from sub-optimal irradiance conditions being positioned vertically, but it also hindered by a reduced energy production due to the semi-transparency of the modules used and their consequent lower efficiency as well as a significantly higher end-user extra cost. All these elements lead to a negative competitiveness in 2020. Nonetheless, this BIPV products' important end-user extra costs also represent an opportunity for possible important cost reductions which should allow the case to become competitive by 2030.
- The **IB, CIGS-based lightweight metal roofing** combines multiple advantages such as being installed on a roof thus allowing better yields and coming at a relatively low end-user extra cost. Despite the important self-consumption rate considered for this case (90%), the low retail electricity prices for the IC consumption band limits the attractiveness of this case. Eventually, this case should only be competitive by 2030, reaching 86 €/m².

FRANCE



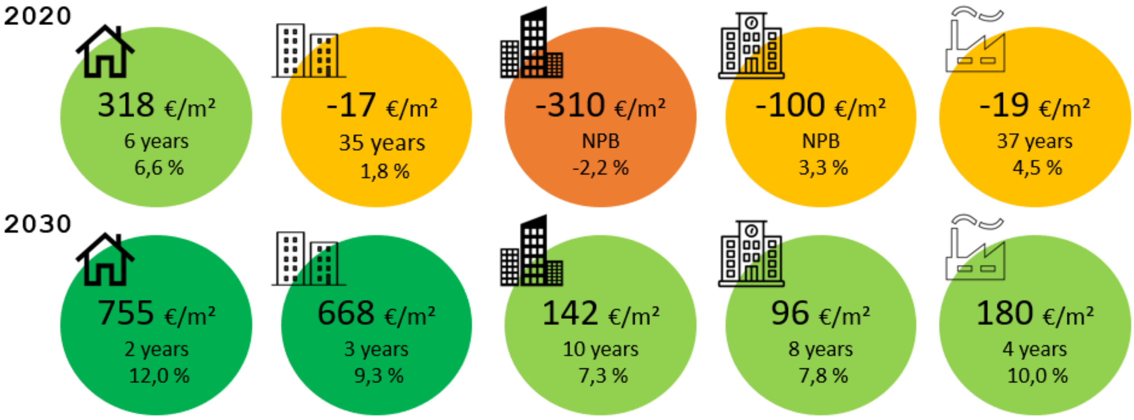
In France, self-consumption is allowed for all studied systems, thus allowing revenues through savings on the electricity bill. For small installations with an installed capacity below 100 kWp (which is the case of all studied systems except for the industrial building reference case) a **feed-in tariff** can be received for injected electricity. Once the duration of this support scheme has elapsed, and while the 30-year system lifetime has not yet been reached, excess electricity produced is assumed to be resold at the average **wholesale market price**.

Electricity prices for households in France can be considered **relatively low compared to the European average** lying at **19 c€/kWh** (17 c€/kWh of which are compensable). In the same way, electricity prices for small non-household consumers (IA) can also be considered **relatively low compared** to other European countries lying at around **17 c€/kWh** (14 c€/kWh of which are compensable). Industrial consumers belonging to the IC consumption band have access to a retail electricity price of **11 c€/kWh** (9 c€/kWh of which are compensable). [18]



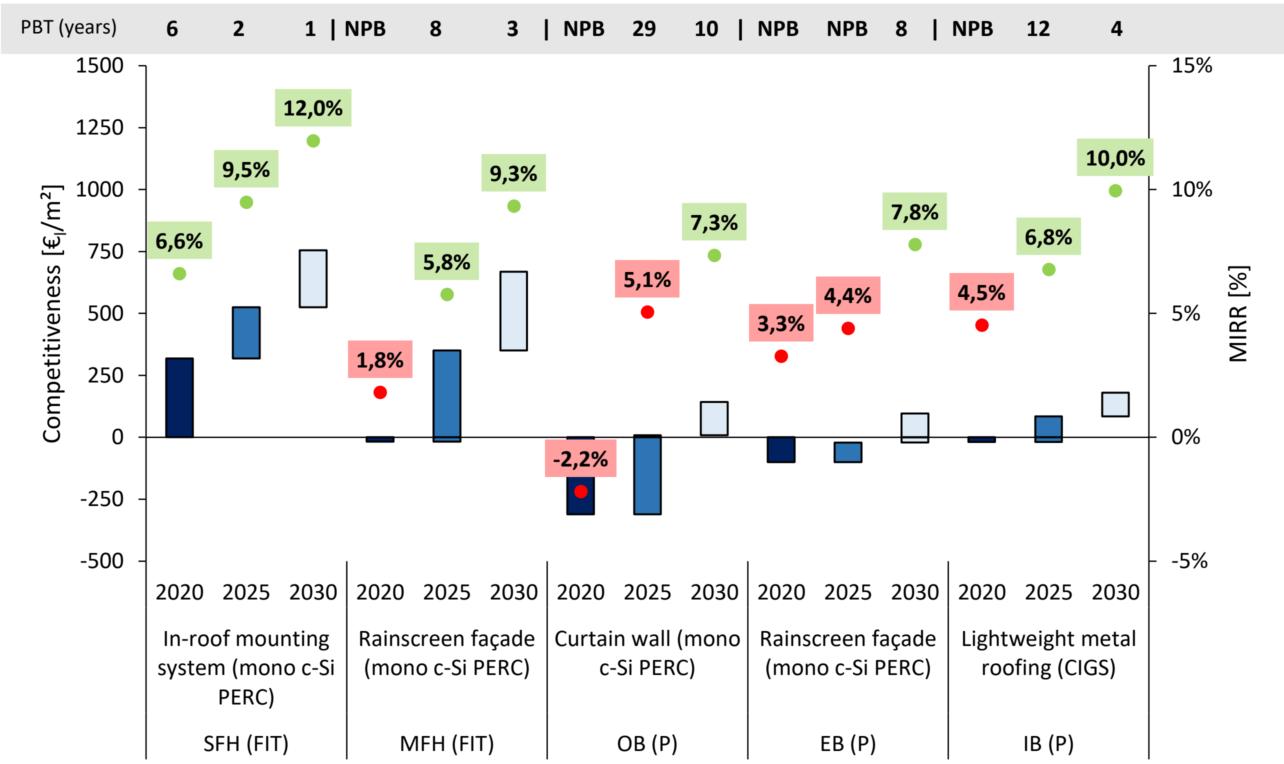
- **In-roof mounting systems** integrated to a **SFH** roof are already competitive in France with a current competitiveness of 346 €/m² corresponding to a pay-back time of 4 years and a MIRR of 6,8%. This is particularly possible thanks to feed-in tariff support and relatively good irradiance conditions obtained on a south oriented roof in this country. The various improvements that will benefit to in-roof mounting BIPV systems should contribute to increase the profitability by 2030, allowing to reach a competitiveness of 643 €/m².
- The **ventilated MFH façade based on mono c-Si PERC** modules suffers from sub-optimal irradiance conditions being positioned vertically. Nevertheless, thanks to the low discount rate considered (2%) and the savings on the electricity bill based on the DC electricity prices, the competitiveness is almost reached in 2020 with -80 €/m², with the potential to reach more than 500 €/m² by 2030.
- The **ventilated EB façade based on mono c-Si PERC** modules also suffers from sub-optimal irradiance conditions being positioned vertically. Due to a higher discount rate (5,7%) and lower retail electricity prices for the IA consumption band compared to DC band, the competitiveness reached by 2020 is slightly worse than the MFH case. Eventually, the competitiveness threshold should be reached by 2030, allowing a competitiveness of 57 €/m².
- The **OB curtain wall** façade based on **semi-transparent mono c-Si PERC** modules suffers not only from sub-optimal irradiance conditions being positioned vertically, but it also hindered by a reduced energy production due to the semi-transparency of the modules used and their consequent lower efficiency, as well as a significantly higher end-user extra cost. All these elements lead to a negative competitiveness in 2020. Nonetheless, this BIPV products' important end-user extra costs also represent an opportunity for possible cost reductions which should allow the case to become competitive by 2030.
- The **IB, CIGS-based lightweight metal roofing** combines multiple advantages such as being installed on a roof thus allowing better yields and coming at a relatively low end-user extra cost. Despite the important self-consumption rate considered for this case (90%), the low retail electricity prices for the IC consumption band limits the attractiveness of this case. In addition, the remaining 10% can only be values on the wholesale market as for the considered installed capacity no feed-in tariff applies. Eventually, this case should only be competitive after 2025, reaching 106 €/m² by 2030.

GERMANY



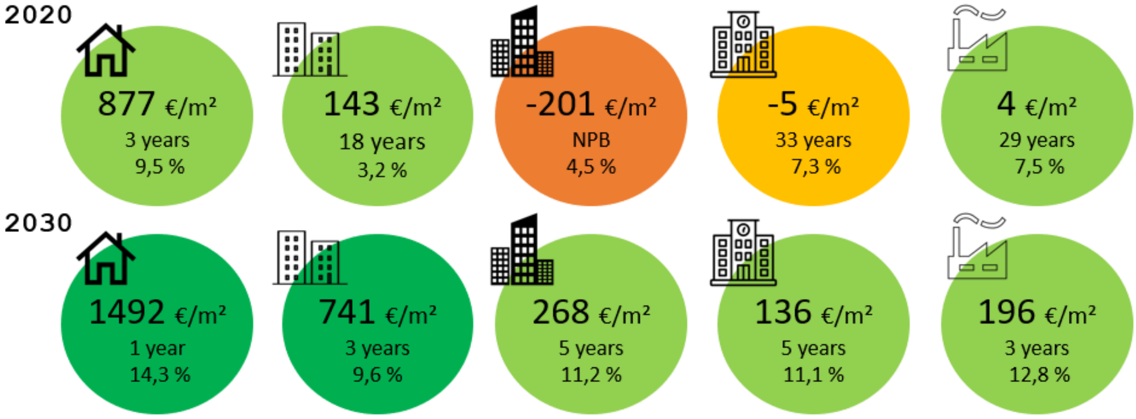
In Germany, self-consumption is allowed for all studied systems, thus allowing revenues through savings on the electricity bill. For small installations with capacity below 100 kWp, a **feed-in tariff** applies for the injected electricity. Concerning installations with an installed capacity between 100 and 750kWp, a **feed-in premium** can be obtained for the injected electricity. Once the duration of the specific support scheme has elapsed and while the 30-year system lifetime has not yet been reached, excess electricity produced is assumed to be resold at the average **wholesale market price**.

Electricity prices for households in Germany can be considered **high in comparison to the European average** lying at **30 c€/kWh** (28 c€/kWh of which are compensable). In the same way, electricity prices for small non-household consumers (IA) can also be considered **relatively high compared** to other European countries lying at around **25 c€/kWh** (22 c€/kWh of which are compensable). Industrial consumers belonging to the IC consumption band have access to a retail electricity price of **18 c€/kWh** (16 c€/kWh of which are compensable). [18]



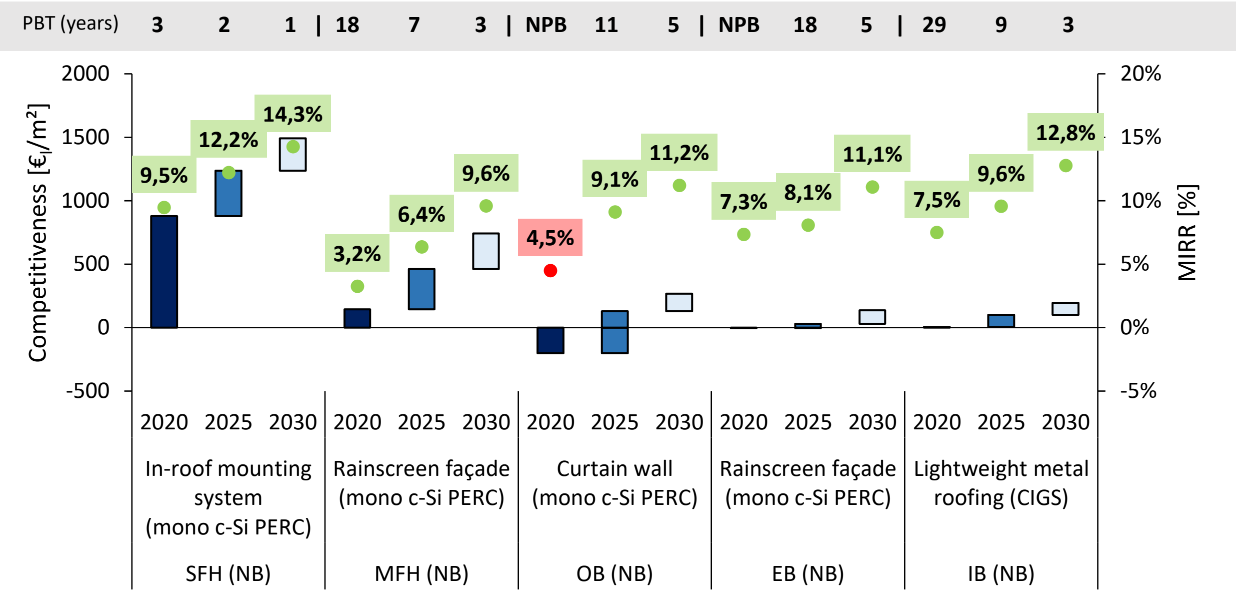
- **In-roof mounting systems** integrated to a **SFH** roof are already competitive in Germany with a current competitiveness of 318 €/m² corresponding to a pay-back time of 6 years and a MIRR of 6,6%. This is particularly possible thanks to feed-in tariff support and acceptable irradiance conditions obtained on a south oriented roof in this country. The various improvements that will benefit to in-roof mounting BIPV systems will contribute to increase the profitability by 2030, allowing to reach a competitiveness of 755 €/m².
- The **ventilated MFH façade based on mono c-Si PERC** modules suffers from sub-optimal irradiance conditions being positioned vertically. Nevertheless, thanks to the low discount rate considered (2%) and the savings on the electricity bill based on the DC electricity prices, the competitiveness is almost reached in 2020 with -17 €/m², with the potential to reach 668 €/m² by 2030.
- The **ventilated EB façade based on mono c-Si PERC** modules also suffers from sub-optimal irradiance conditions being positioned vertically. Due to a higher discount rate (5,2%) and lower retail electricity prices for the IA consumption band compared to DC band, the competitiveness reached by 2020 is slightly worse than the MFH case. Eventually, the competitiveness threshold should be reached by 2030, allowing a competitiveness of 96 €/m².
- The **OB curtain wall** façade based on **semi-transparent mono c-Si PERC** modules suffers not only from sub-optimal irradiance conditions being positioned vertically, but it also hindered by a reduced energy production due to the semi-transparency of the modules used and their consequent lower efficiency as well as a significantly higher end-user extra cost. All these elements lead to a negative competitiveness in 2020. Nonetheless, this BIPV products' important end-user extra costs also represent an opportunity for possible cost reductions which should allow the case to become competitive by 2030.
- The **IB, CIGS-based lightweight metal roofing** combines multiple advantages such as being installed on a roof thus allowing better yields and coming at a relatively low end-user extra cost. Despite the self-consumption rate considered for this case (90%), the low retail electricity prices for the IC consumption band limits the attractiveness of this case. Eventually, this case should only be competitive by 2025, reaching 180 €/m² by 2030.

ITALY



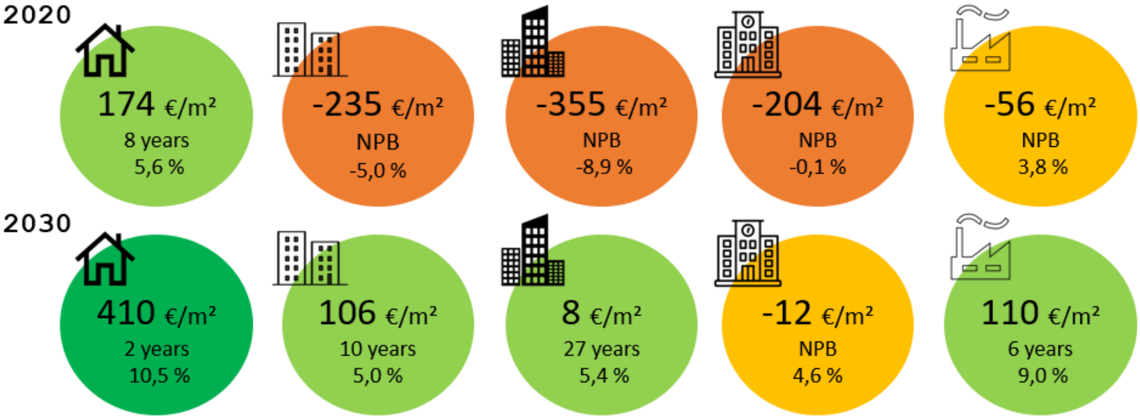
In Italy, self-consumption is allowed for all studied systems, thus allowing revenues through savings on the electricity bill. For small installations with capacity below 100 kWp two support coincide (but cannot be combined). A feed-in **premium** or a net-billing scheme can be applied. Concerning installations with capacity between 100 and 500kWp, the **net-billing** scheme only applies. Once the duration of the specific support scheme has elapsed, and while the 30-year system lifetime has not yet been reached, excess electricity produced is assumed to be resold at the average **wholesale market price**.

Electricity prices for households in Italy can be considered **close to the European average** lying at **22 c€/kWh** (20 c€/kWh of which are compensable). On the contrary, electricity prices for small non-household consumers (IA) can be considered **high compared** to more northern European countries lying at around **30 c€/kWh** (23 c€/kWh of which are compensable). Industrial consumers belonging to the IC consumption band have access to a retail electricity price of **15 c€/kWh** (13 c€/kWh of which are compensable). [18]



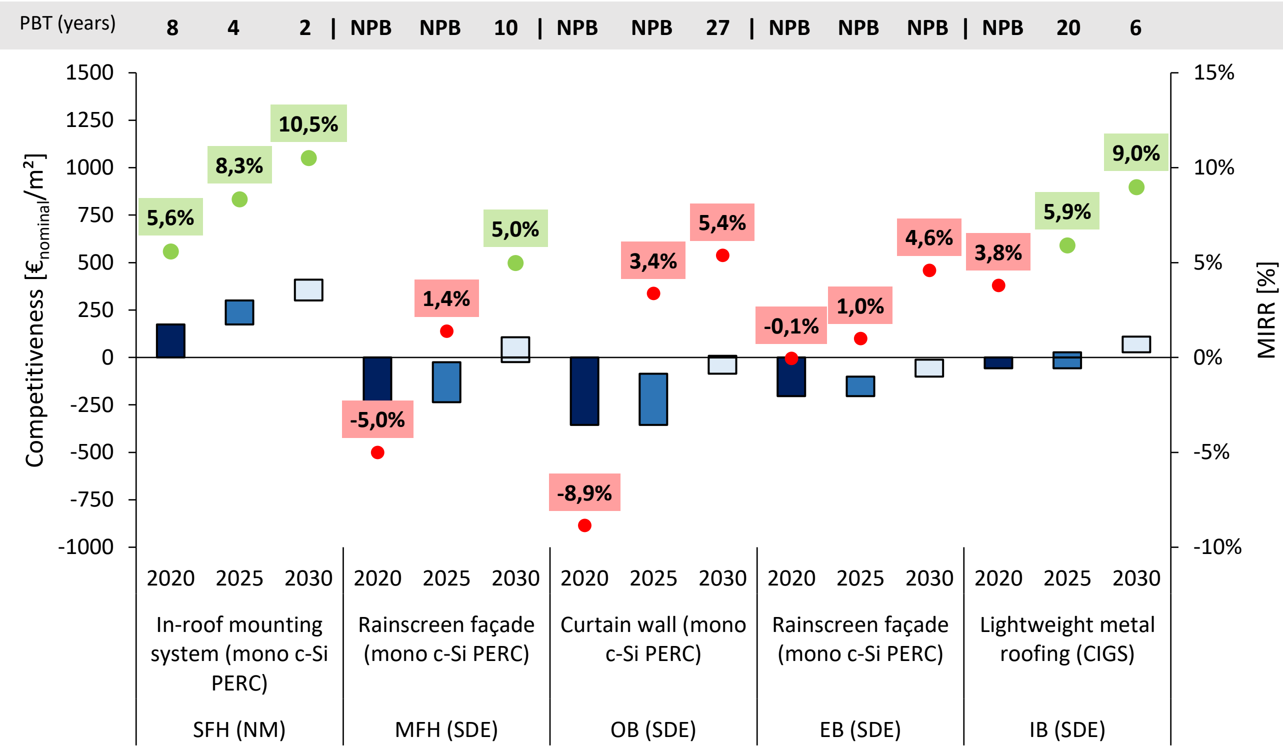
- **In-roof mounting systems** integrated to a **SFH** roof are already clearly competitive in Italy with a current competitiveness of 877 €/m² corresponding to a pay-back time of 3 years and a MIRR of 9,5%. This is particularly possible thanks to an attractive support scheme and excellent irradiance conditions obtained on a south oriented roof in this country. The various improvements that will benefit to in-roof mounting BIPV systems should contribute to increase the profitability by 2030, allowing to reach a competitiveness of close to **1500 €/m²**.
- The **ventilated MFH façade based on mono c-Si PERC** modules suffers from sub-optimal irradiance conditions being positioned vertically. Nevertheless, thanks to the low discount rate considered (2%), the net-billing scheme and the savings on the electricity bill based on the DC electricity prices, the competitiveness is already reached in 2020 with 143 €/m², with the potential to reach 741 €/m² by 2030.
- The **ventilated EB façade based on mono c-Si PERC** modules also suffers from sub-optimal irradiance conditions being positioned vertically. Due to a higher discount rate (6,2%) and higher retail electricity prices for the IA consumption band compared to DC band, the competitiveness reached by 2020 is similar to the MFH case. Eventually, the competitiveness should reach 136 €/m² by 2030.
- The **OB curtain wall** façade based on **semi-transparent mono c-Si PERC** modules suffers not only from sub-optimal irradiance conditions being positioned vertically, but it also hindered by a reduced energy production due to the semi-transparency of the modules used and their consequent lower efficiency, as well as a significantly higher end-user extra cost. All these elements lead to a negative competitiveness in 2020. Nonetheless, this BIPV products' important end-user extra costs also represent an opportunity for possible important end-user extra cost reductions which should allow the case to become competitive by 2025.
- The **IB, CIGS-based lightweight metal roofing** combines multiple advantages such as being installed on a roof thus allowing better yields and coming at a relatively low end-user extra cost. Despite the important self-consumption rate considered for this case (90%), the relatively low retail electricity prices for the IC consumption band limits the attractiveness potential of this case. However, this case is already competitive in 2020 and should reach 196 €/m² by 2030.

THE NETHERLANDS



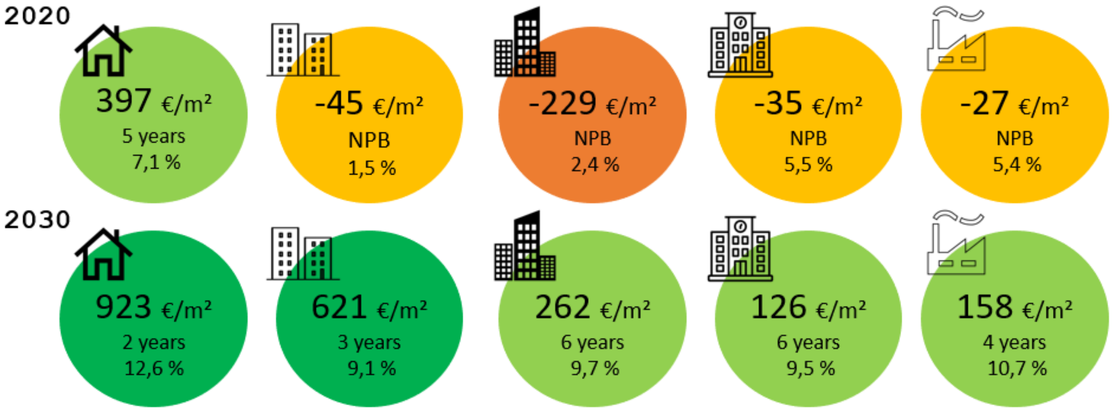
In Netherlands, self-consumption is allowed for all studied systems, thus allowing revenues through savings on the electricity bill. For small installations with an installed capacity lower than 15 kWp, a **net-metering scheme** is applicable. Concerning installations with an installed capacity higher than 15 kWp, **a SDE contribution** can be obtained. Once the duration of the specific support scheme has elapsed, and while the 30-year system lifetime has not yet been reached, excess electricity produced is assumed to be resold at the average **wholesale market price**.

Electricity prices for households in Netherlands can be considered very **low compared to the European average** lying at **14 c€/kWh** (10 c€/kWh of which are compensable). In the same way, electricity prices for small non-household consumers (IA) can also be considered **low compared** to other European countries lying at around **16 c€/kWh** (12 c€/kWh of which are compensable). Industrial consumers belonging to the IC consumption band have access to a retail electricity price of **14 c€/kWh** (11 c€/kWh of which are compensable). [18]



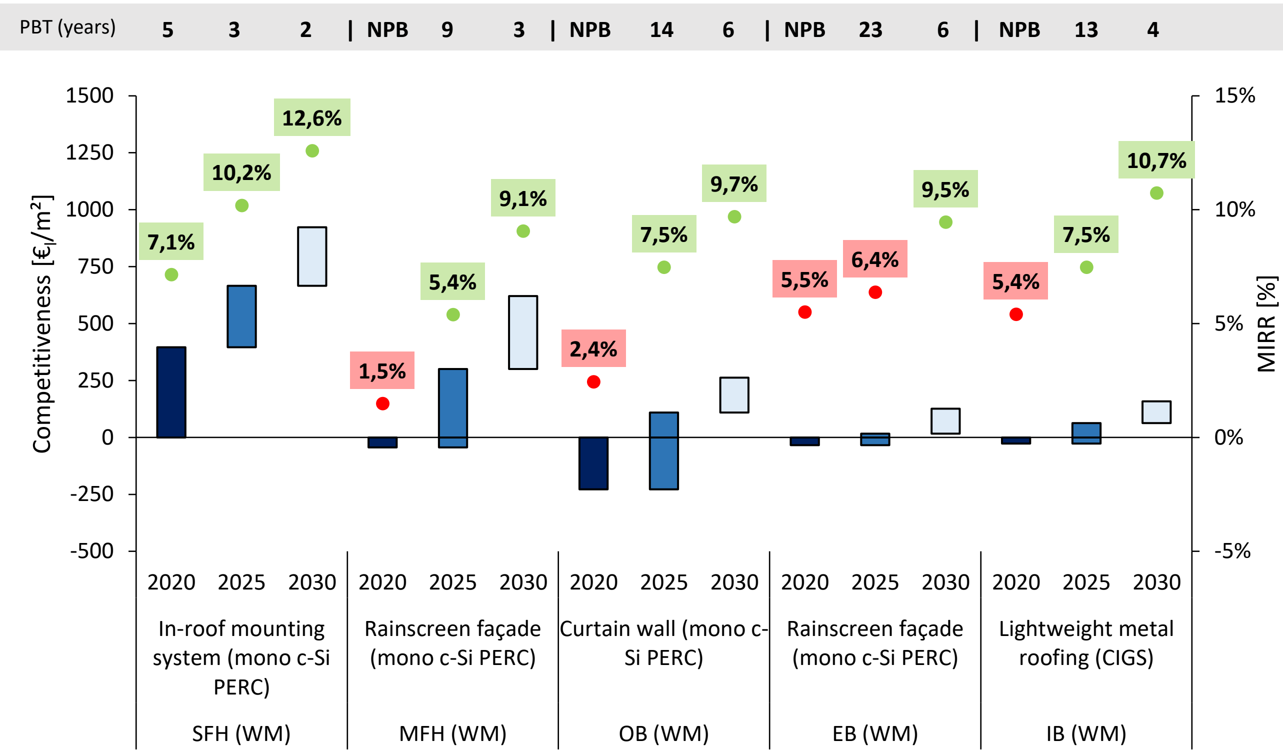
- **In-roof mounting systems** integrated to a **SFH** roof are already competitive in Netherlands with a current competitiveness of 174 €/m² corresponding to a pay-back time of 8 years and a MIRR of 5,6%. Even if net-metering is at first glance an excellent support scheme, due to the low compensable electricity price in Netherlands the potential profit thanks to net-metering is limited. The various improvements that will benefit to in-roof mounting BIPV systems should contribute to increase the profitability by 2030, allowing to reach a competitiveness of 410 €/m².
- The **ventilated MFH façade based on mono c-Si PERC** modules suffers from sub-optimal irradiance conditions being positioned vertically. Even though a low discount rate is considered (2%) and the savings on the electricity bill based on the DC electricity prices allowed by a relatively high self-consumption rate are substantial, the competitiveness is not reached in 2020 with -235 €/m². Although, it has the potential to reach 106 €/m² by 2030.
- The **ventilated EB façade based on mono c-Si PERC** modules also suffers from sub-optimal irradiance conditions being positioned vertically. Due to a higher discount rate (5,6%) and higher retail electricity prices for the IA consumption band compared to DC band, the competitiveness reached by 2020 is similar to the MFH case. Unfortunately, the competitiveness threshold should not be reached even by 2030.
- The **OB curtain wall** façade based on **semi-transparent mono c-Si PERC** modules suffers not only from sub-optimal irradiance conditions being positioned vertically, but it is also hindered by a reduced energy production due to the semi-transparency of the modules used and their consequent lower efficiency as well as a significantly higher end-user extra cost. All these elements lead to a negative competitiveness in 2020. Nonetheless, this BIPV products' important end-user extra costs also represent an opportunity for possible cost reductions which could allow the case to become competitive by 2030.
- The **IB, CIGS-based lightweight metal roofing** combines multiple advantages such as being installed on a roof thus allowing better yields and coming at a relatively low end-user extra cost. Despite the important self-consumption rate considered for this case (90%), the low retail electricity prices for the IC consumption band limits the attractiveness of this case. Eventually, this case should only be competitive by 2025, reaching 110 €/m² by 2030.

SPAIN



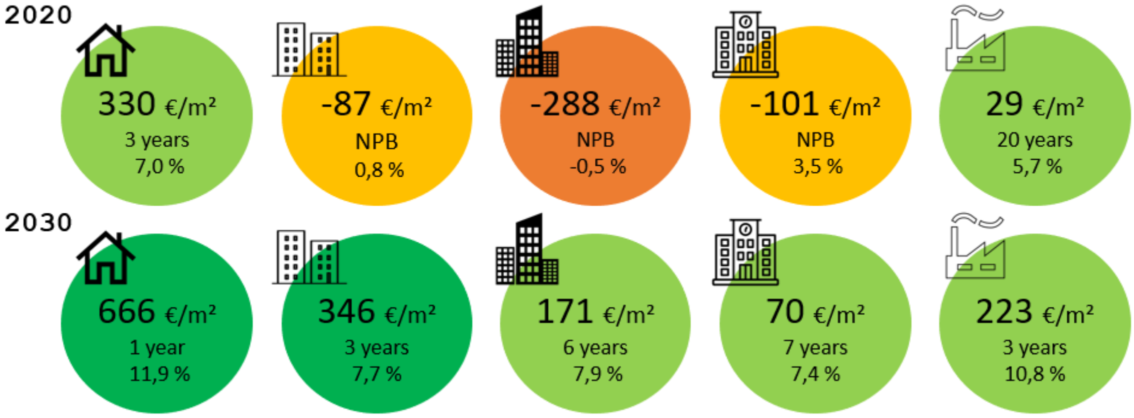
In Spain, the only possible revenues are the savings on the electricity bill and excess electricity produced is assumed to be resold at the average **wholesale market price**, and this for all considered installed PV capacities.

Electricity prices for households in Spain can be considered **close to the European average** lying at **22 c€/kWh** (18 c€/kWh of which are compensable). On the contrary, electricity prices for small non-household consumers (IA) can be considered **relatively high compared** to more northern European countries lying at around **25 c€/kWh** (21 c€/kWh of which are compensable). Industrial consumers belonging to the IC consumption band have access to a retail electricity price of **11 c€/kWh** (9 c€/kWh of which are compensable). [18]



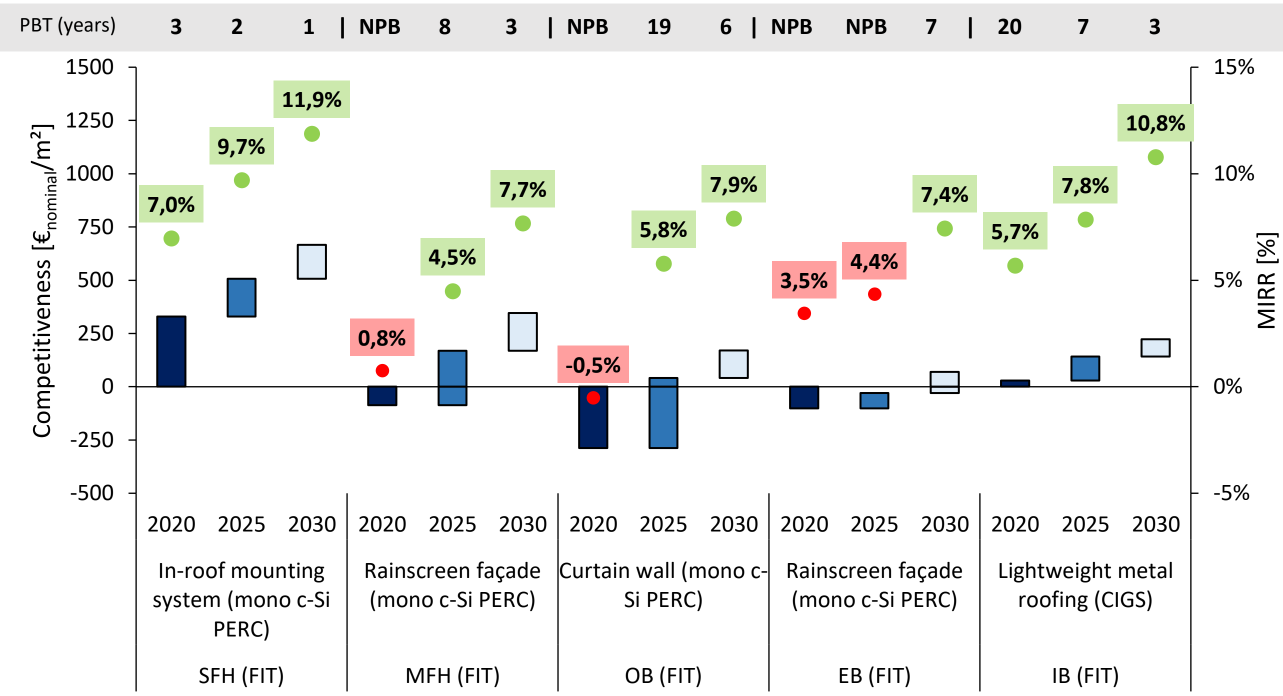
- **In-roof mounting systems** integrated to a **SFH** roof are already competitive in Spain with a current competitiveness of around 400 €/m² corresponding to a pay-back time of 5 years and a MIRR of 7,1%, even if no specific remuneration of fed-back electricity is attributed in Spain. This is possible thanks to excellent irradiance conditions obtained on a south oriented roof in this country. The various improvements that will benefit to in-roof mounting BIPV systems will contribute to significantly increase the profitability by 2030, allowing to reach a competitiveness of 923 €/m².
- The **ventilated MFH façade based on mono c-Si PERC** modules suffers from sub-optimal irradiance conditions being positioned vertically. Nevertheless, thanks to the low discount rate considered (2%) and the savings on the electricity bill based on the DC electricity prices, the competitiveness is almost reached in 2020 with -45 €/m², with the potential to reach more than 600 €/m² by 2030.
- The **ventilated EB façade based on mono c-Si PERC** modules also suffers from sub-optimal irradiance conditions being positioned vertically. Due to a higher discount rate (6,4%) and higher retail electricity prices for the IA consumption band compared to DC band, the competitiveness reached by 2020 is similar to the MFH case. Eventually, the competitiveness threshold should be reached by 2030, allowing a competitiveness of 126 €/m².
- The **OB curtain wall** façade based on **semi-transparent mono c-Si PERC** modules suffers not only from sub-optimal irradiance conditions being positioned vertically, but it also hindered by a reduced energy production due to the semi-transparency of the modules used and their consequent lower efficiency as well as a higher end-user extra cost. All these elements lead to a negative competitiveness in 2020. Nonetheless, this BIPV products' important end-user extra cost also represents an opportunity for possible important end-user extra cost reductions which should allow the case to become competitive by 2030.
- The **IB, CIGS-based lightweight metal roofing** combines multiple advantages such as being installed on a roof thus allowing better yields and coming at a relatively low end-user extra cost. Despite the important self-consumption rate considered for this case (90%), the low retail electricity prices for the IC consumption band limits the attractiveness of this case. Eventually, this case should only be competitive by 2025, reaching 158 €/m² by 2030.

SWITZERLAND



In Switzerland, self-consumption is allowed for all studied systems, thus allowing revenues through savings on the electricity bill. In addition, many energy suppliers offer to buy the excess electricity produced by (BI)PV systems at attractive prices (this is treated and referred to as FIT in the charts and text). It is noteworthy that a specific investment aid is applicable for BIPV. This aid can cover up to 40% of the investment costs (compared to up to 30% in the case of BAPV).

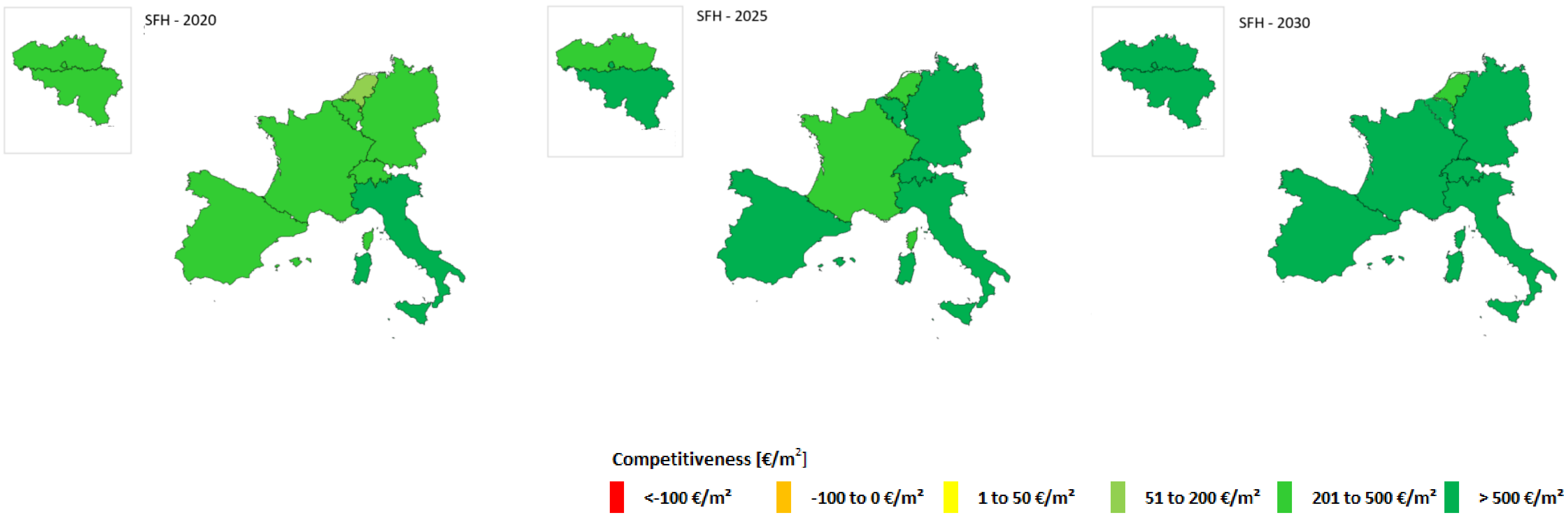
Electricity prices for households in Switzerland can be considered **low compared to the European average** lying at **18 c€/kWh** (16 c€/kWh of which are compensable). In the same way, electricity prices for small non-household consumers (IA) can also be considered **low compared** to other European countries lying at around **19 c€/kWh** (16 c€/kWh of which are compensable). Industrial consumers belonging to the IC consumption band have access to a retail electricity price of **14 c€/kWh** (13 c€/kWh of which are compensable). [19]



- **In-roof mounting systems** integrated to a **SFH** roof are already competitive in Switzerland with a current competitiveness of 330 €/m² corresponding to a pay-back time of 3 years and a MIRR of 7,0%. This is particularly possible thanks to a specific investment aid and acceptable irradiance conditions obtained on a south oriented roof in this country. The various improvements that will benefit to in-roof mounting BIPV systems should contribute to increase the profitability by 2030, allowing to reach a competitiveness of 666 €/m².
- The **ventilated MFH façade based on mono c-Si PERC** modules suffers from sub-optimal irradiance conditions being positioned vertically. Nevertheless, thanks to the low discount rate considered (2%) and the savings on the electricity bill based on the DC electricity prices, the competitiveness is almost reached in 2020 with -87 €/m², with the potential to reach 346 €/m² by 2030.
- The **ventilated EB façade based on mono c-Si PERC** modules also suffers from sub-optimal irradiance conditions being positioned vertically. Due to a higher discount rate (5,3%) and similar retail electricity prices for the IA consumption band compared to DC band, the competitiveness reached by 2020 is similar to the MFH case. Eventually, the competitiveness threshold should be reached by 2030, allowing a competitiveness of 70 €/m².
- The **OB curtain wall** façade based on **semi-transparent mono c-Si PERC** modules suffers not only from sub-optimal irradiance conditions being positioned vertically, but it is also hindered by a reduced energy production due to the semi-transparency of the modules used and their consequent lower efficiency, as well as a significantly higher end-user extra cost. All these elements lead to a negative competitiveness in 2020. Nonetheless, this BIPV products' important end-user extra costs also represent an opportunity for possible important end-user extra cost reductions which could allow the case to become competitive by 2025.
- The **IB, CIGS-based lightweight metal roofing** combines multiple advantages such as being installed on a roof thus allowing better yields and coming at a relatively low end-user extra cost. Despite the important self-consumption rate considered for this case (90%), the low retail electricity prices for the IC consumption band limits the attractiveness potential of this case. However, this case is already competitive in 2020 and should reach 223 €/m² by 2030.

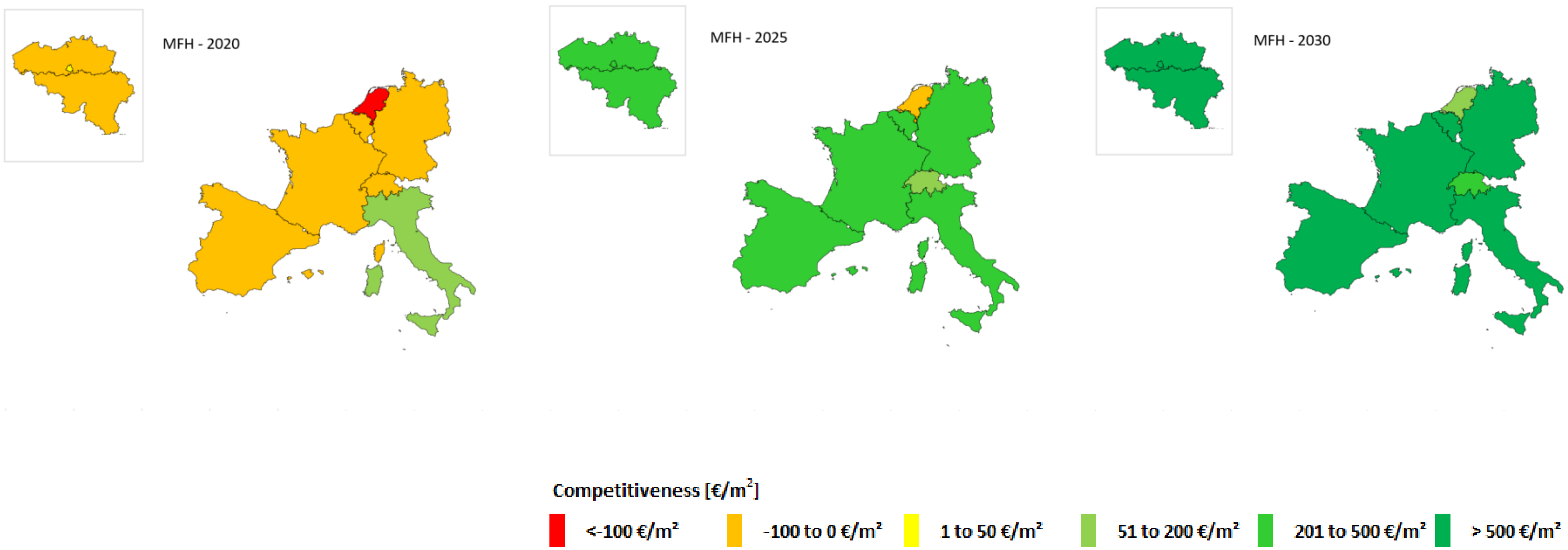
RESULTS’ RECAP FOR EUROPE

Single-family houses with BIPV roof



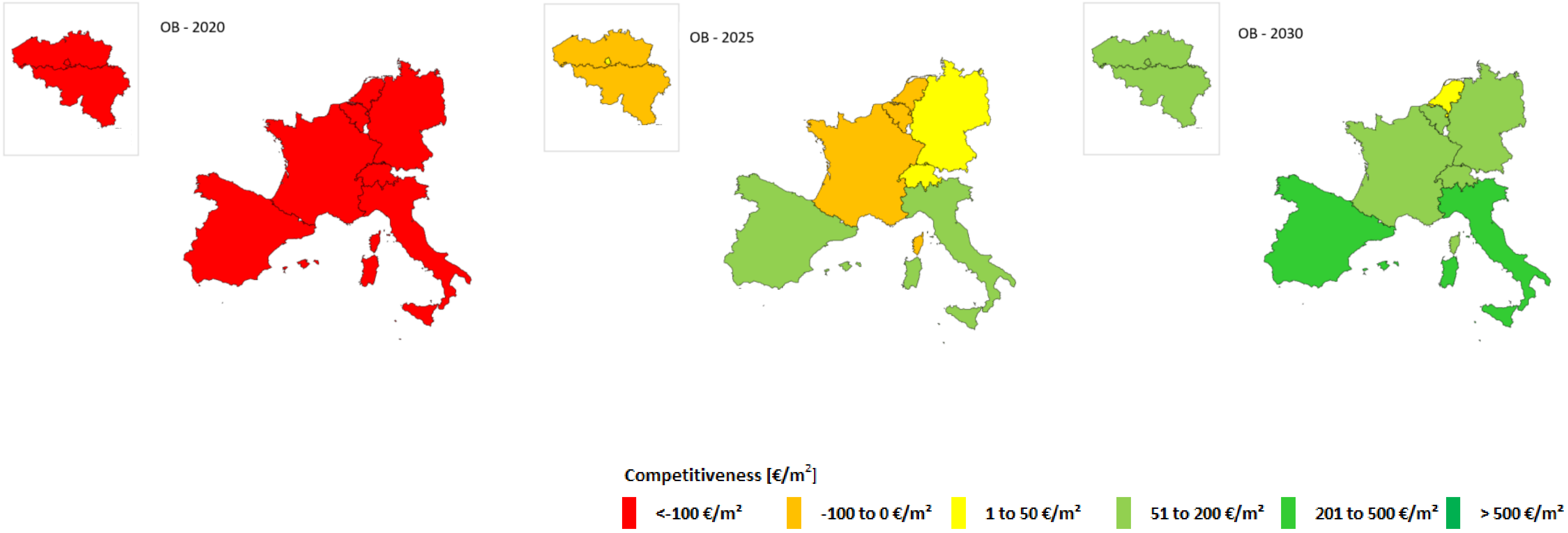
The BIPV solution studied for the **SFH case is already competitive in all studied locations** and its competitiveness should be further increased in the coming years, as various improvements increase the cost efficiency (efficiency increase and cost decrease) of this type of BIPV system (under the condition of no major support scheme’s changes impacting the competitiveness).

Multi-family houses with ventilated BIPV façade



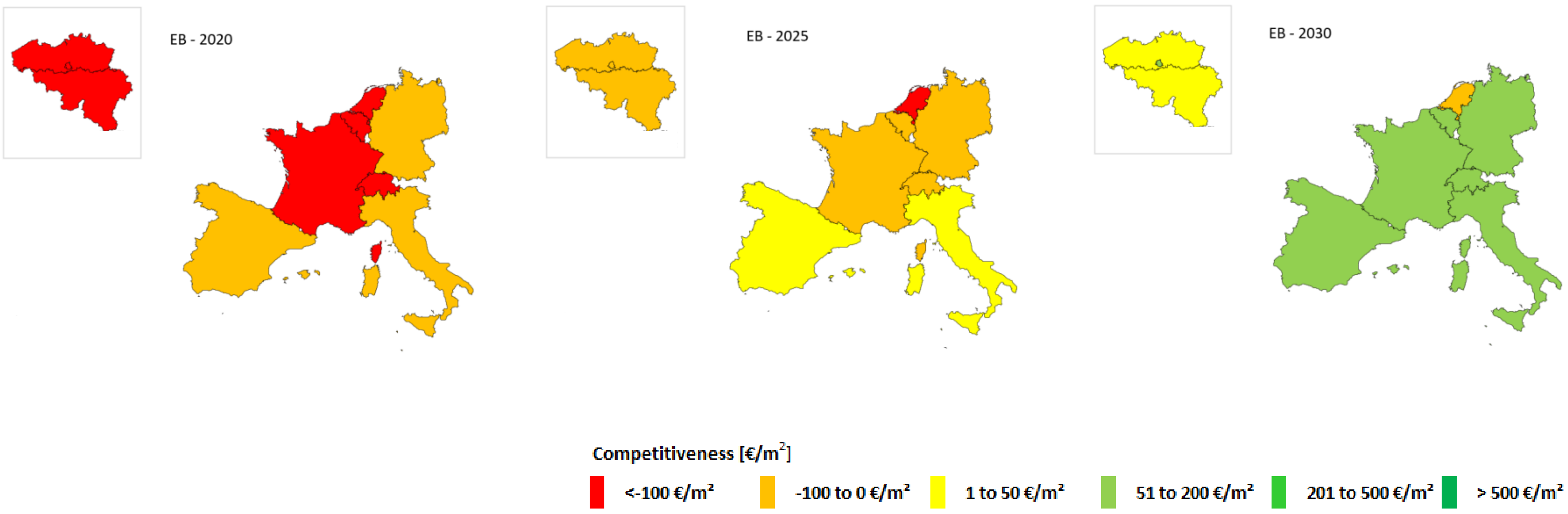
The BIPV solution studied for the **MFH case is already competitive in Italy and the center region of Belgium (Brussels).** By 2025, this solution will be competitive in all studied locations except for the Netherlands, in which the competitiveness threshold should only be reached by 2030, again under the condition of no major support scheme's changes impacting the competitiveness.

Office building with non-ventilated BIPV façade



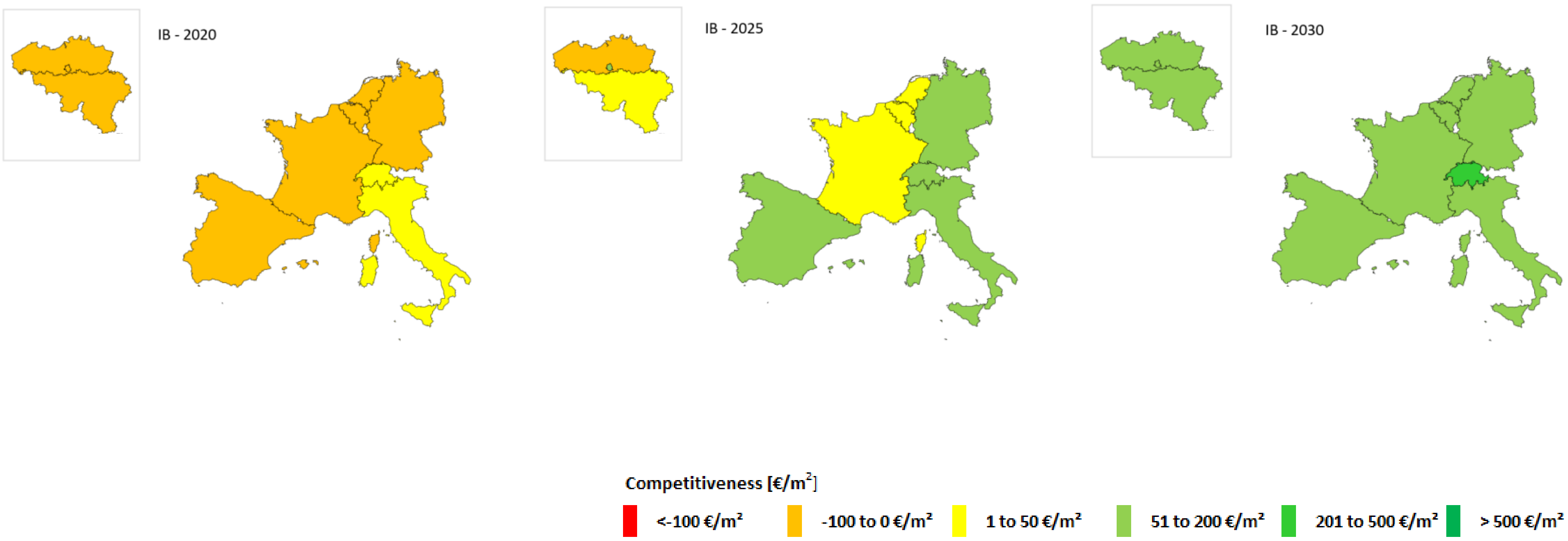
The BIPV solution studied for the **OB case is currently not competitive in all the studied locations**. By 2025, this solution could be only competitive in Italy, Spain and Switzerland. Concerning the rest of the studied locations, the competitiveness threshold should not be reached before 2030, under the condition of no major support scheme's changes impacting the competitiveness.

Educational building with ventilated BIPV façade



The BIPV solution studied for the **EB case is currently not competitive, with the exception of Italy where the competitiveness threshold is just reached.** By 2030, this solution will be competitive in all studied locations, except for the Netherlands for which the competitiveness threshold should not be reached within the considered timeframe under the condition of no major support scheme changes impacting the competitiveness.

Industrial building with BIPV roof



The BIPV solution studied for the **IB case is already competitive in Italy and Switzerland**. By 2025, this solution will be competitive in all studied locations except for the south and north regions of Belgium (respectively Wallonia and Flanders), where the competitiveness threshold should only be reached by 2030, under the condition of no major support scheme changes impacting the competitiveness.

KEY TAKEAWAYS

"As electricity generating units, BIPV systems can be competitive."

As **BIPV solutions are multifunctional**, their **competitiveness can and should be studied through a multidimensional analysis.** At first sight, BIPV as a building component is hindered by quite **uncompetitive end-user costs in comparison with traditional construction components and solutions**, due to its additional electricity generating function. Although, when examining competitiveness with a dynamic point of view, i.e. on the entire operating lifetime, economic attractiveness can be observed in multiple cases**. Hence, it is clear that as electricity generating units, BIPV systems can be competitive**.

Then, the **competitiveness assessment of BIPV**, taking into account BIPV's building functionality and the valuation of the generated PV electricity, allowed to highlight various elements. As expected, competitiveness is highly dependent on the compensable retail electricity prices and the support schemes existing in each country. For example, **Italian cases** have shown multiple **positive competitiveness values,** due to attractive support schemes and good irradiation conditions. On the other hand, in other countries, like **the Netherlands**, **competitiveness is currently rarely achieved**, due to the combination of unfavourable factors, mainly low compensable retail prices and poor irradiation conditions.

That being said, BIPV already appears as an **attractive investment**, in many locations and cases, when **roof systems applied on residential housing** are investigated. The situation is less straightforward for other cases, and **most façade systems can be considered as uncompetitive**, except where support schemes for PV and/or irradiation are particularly generous. This can be explained by the still relatively high extra cost compared to conventional solutions and the sub-optimal performances of the system due to the vertical tilt, among others.

*"BIPV roof systems integrated to SFH already are **attractive investments**."*

These gloomy figures must be nuanced. Indeed, as a building component, **BIPV should not be considered as a main source of income but as a supplementary investment** that should offer reasonable pay-back periods. This reduces the scope of some of the current negative results presented. In addition, it is worth reminding that only values that can be directly quantified have been considered in this competitiveness assessment. Other elements can also contribute to nuance the quite weak competitiveness of some reference cases. For instance, thanks to the **green image** or the **unique aesthetical aspect** that BIPV can give to a building, added value can be created and captured through increased rents, building sale's price and occupancy rates, thus **contributing positively but indirectly to improving BIPV competitiveness**. Moreover, **BIPV systems can be cost-efficient solutions to reach nZEB regulations' requirements** in terms of building primary energy balance or renewable energy systems' installation, as demonstrated by other research activities conducted in the frame of the BIPVBOOST project and summarized in D1.4 "Potential contribution to BIPV systems to nearly Zero

*"In most cases, BIPV **competitiveness will be reached** on the medium term."*

Energy Buildings and methodology for project outputs assessment" [19]. But these elements are difficult to model as part of reference cases, because they highly depend on local project's conditions.

Furthermore, there are reasons to be optimistic for the future. Indeed, when taking a short to medium term vision, additional elements will contribute to increase the competitiveness of BIPV solutions in Europe. Indeed, **end-user costs will continue to decrease** as this technology will mature and some of the defined extra cost targets will likely be reached in the future. Except for the office building reference case, equipped with a semi-transparent BIPV curtain wall, the **cost targets seem reasonably achievable** in most countries and cases. Moreover, other parameters, apart from cost, can significantly contribute to improve competitiveness. As **technological improvements** hit the market, embodied in improved module efficiencies for example, **BIPV competitiveness should be significantly improved in all countries and applications on the short to medium term.**

Nevertheless, it should be highlighted here that these improvements will only be able to contribute to increasing the competitiveness if they go hand in hand with **an appropriate support from policy makers and an appropriate legislation**. Indeed, competitiveness results presented here are estimated based on existing support schemes. Since these are bound to evolve in the next years, this source of uncertainty should be beard in mind when looking at the 2025 & 2030 results. Finally, the development of **innovative business models**, for example helping to increase self-consumption rates by extending energy exchanges to neighbouring buildings or reducing the mismatch between electricity consumption and production, will also broaden the range of possibilities to value one's produced electricity, **thus enhancing competitiveness.** Globally, although it should be reminded that it is essential to assess each case individually to conduct a relevant and precise BIPV attractiveness analysis**,** it is clear that **BIPV systems, in particular on roofs but also on facades in some cases, already make sense from an economic point of view in many European countries and under multiple business models and have a bright future ahead of them**.

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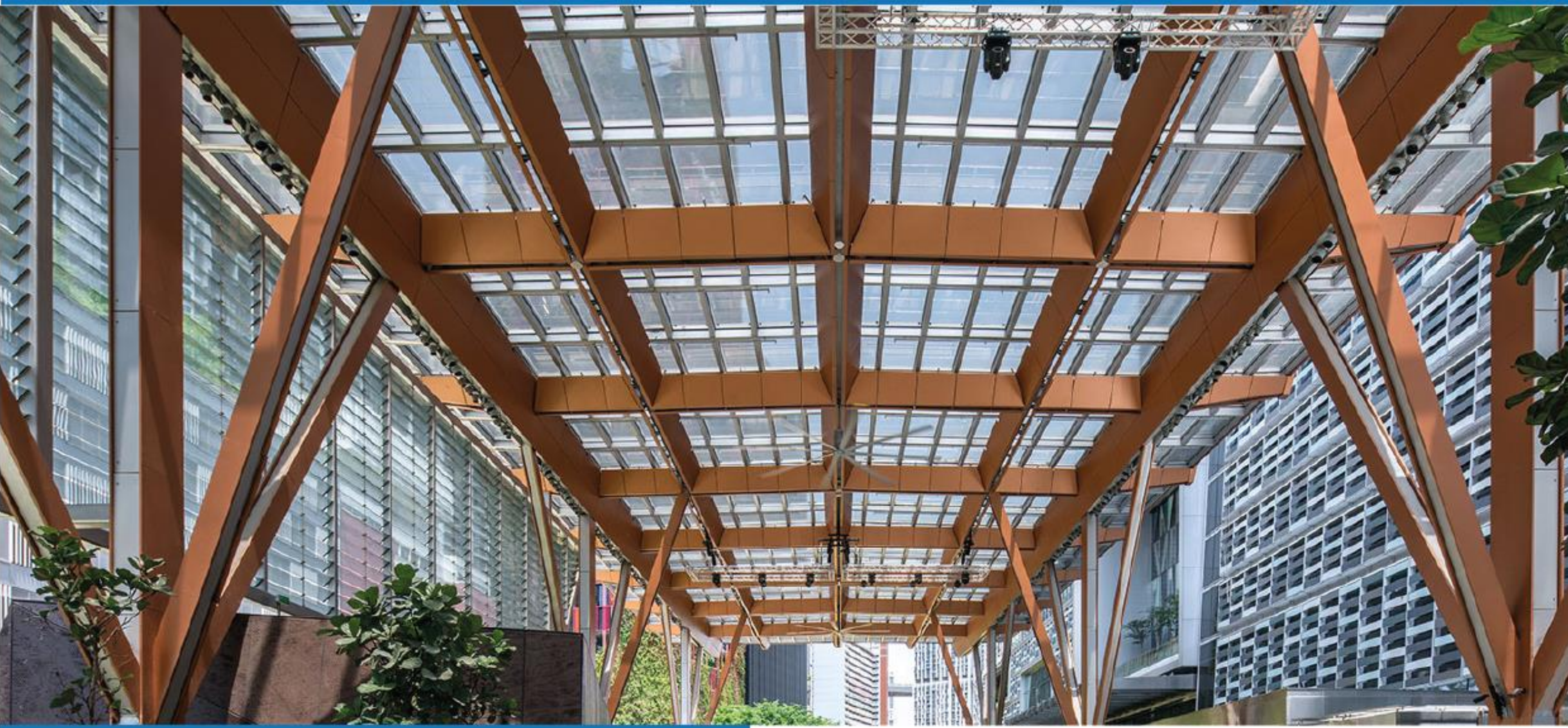

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