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Competitiveness status of BIPV solutions in Europe

BIPVBOOST

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

Start date: October 2018 Duration: 4 Years

Coordinator: TECNALIA Grant Agreement No: 817991 www.bipvboost.eu

Executive Summary

This document aims at providing a complete overview of the competitiveness of various BIPV solutions in Europe. This overview is established by taking different point of views, starting from BIPV as a construction material and as a building envelope solution, with a static cost competitiveness assessment. These estimates show that BIPV elements and systems can hardly compete against conventional building components and envelope solutions. Only the most competitive BIPV products and systems can, in some cases, compete with most expensive competing conventional building solutions, on a pure cost basis.

Then, the perimeter of the analysis is progressively expanded, and more dynamic estimations are conducted. Firstly, in the form of an assessment of the competitiveness of BIPV as an electric generating unit. Secondly, a holistic evaluation of the competitiveness of BIPV as a building envelope solution is conducted, constituting the core of this report. For these two latter types of assessment, reference cases have been defined, covering both the residential and non-residential sectors. Each of these cases focuses on a combination of building typology and BIPV system, in order to be representative of the possibilities that exist for BIPV in Europe. Also, these assessments are conducted under three approaches. The first, “generic”, approach simply takes into account the total end-user cost of the BIPV solution. The second one, called “value-based”, takes into consideration the particularity of BIPV of being able to serve as a construction material and an electricity generation system at the same time. The third approach focuses on the estimated “extra cost” due to BIPV compared to a competing, conventional, building envelope solution. After having defined these three approaches, the competitiveness of BIPV as electricity generating unit has been assessed by calculating its LCOE and by putting it into perspective with current local compensable retail electricity prices. This demonstrated that the capability of BIPV to generate electricity at a competitive cost highly depends of the consumption profile of the investor. That being said, under the assumptions taken here, results tend to show that competitiveness of BIPV generated electricity is, in many cases, poor, even under the extra cost approach. Although, some countries where retail electricity prices are above average consistently stand out.

Then, the holistic competitiveness assessment yields, unsurprisingly, quite similar conclusions. In addition to the three previously described approaches, various business models are tested per country. These are based on the applicable domestic regulation, completed by a business model which can be seen as an “unsubsidized” one, where competitiveness must rely mostly on self-consumption of the generated PV electricity. Overall, the results, which are summarized in a single €/m² metric for each case, show that the total revenues of ownership of the BIPV system do not cover the costs, for most reference cases, countries and business models, even when the extra cost approach is considered. This is also confirmed by outcomes of the other common evaluation parameters that were computed, such as internal return rates or payback times. Nonetheless, BIPV appears already as an attractive investment, in many locations and cases, when roof systems applied on residential housing are investigated. The situation of façade systems is more complicated, from an economic point of view. Competitiveness is not reached in most cases, except where support schemes for PV and/or irradiation are particularly generous, such as in Belgium, Italy or Spain. This can be explained by the still relatively high end-user cost and the sub-optimal performances of the system due to the vertical tilt, among others.

Note that it is important to keep in mind that the present evaluation has been exclusively based on electricity revenues. It thus demonstrates that in most cases, the electricity generated cannot be valued at a sufficient level to cover the extra cost due to BIPV. But competitiveness of BIPV could be reinforced by other means,

for example if, thanks to BIPV, a premium could be charged on top of the normal rent or applied on top of the normal sale price. Furthermore, additional value could be created thanks to BIPV, leveraging its “green” image or potential energy efficiency improvements (e.g. passive properties, which need a case by case assessment in order to be quantified). Although, as these aspects are not easily quantified or adequately included to business models, they do not yet benefit BIPV competitiveness estimations.

Subsequently, an analysis of end-user cost levels to target in order to be competitive has been conducted. This allows to evaluate the remaining gap, for various solutions and in different countries, between average end-user cost of BIPV solutions and the level necessary to make BIPV an economically attractive investment, or at least a self-financing extra cost. These figures are also put into perspective with the estimated share of “fixed cost” and “extra cost” due to BIPV, giving indication on the extent to which BIPV stakeholders can actually reduce these remaining gaps. The results of this analysis show that, except for the office building reference case, the cost targets seem reasonably achievable, which mitigates the results of the competitiveness assessments.

Finally, as the different parameters that were used in the competitiveness evaluation are bond to evolve in the next years, such as system lifetime or module efficiency, a sensitivity analysis was carried out. It aims at determining which parameter can impact the most competitiveness values, and to evaluate if these parameters can mitigate the limited possibilities to reduce end-user cost. It allowed to highlight that various parameters, apart from cost, can significantly contribute to improve competitiveness. Indeed, significant competitiveness improvements can be reached even with a 10% variation compared to the current parameters’ values. For example, improving self-consumption rate from 30% to 33% and system lifetime from 30 to 33 years only (other parameters remaining equal) competitiveness can progress by approximately 40%. While a relative increase of 10% of module efficiency (i.e. a 1,5% increase in absolute terms, approximately) combined with a relative 10% decrease of the total end-user cost of the BIPV solution can improve competitiveness by 50%. This demonstrates that, as technological improvements will hit the market, embodied in improved module efficiencies or lengthened system lifetime, combined with cost reductions, even if these are marginal, BIPV competitiveness will be possibly reached in multiple countries and for various applications.

Document Information

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1 ABOUT THIS REPORT

1.1 Description of the deliverable content and purpose

This deliverable deals with the assessment of cost competitiveness of BIPV solutions in Europe by offering competitiveness evaluation at different levels and considering the singularity of BIPV being able to fulfil both a construction material function and an energy generation function. For this analysis to be representative of what the current possibilities are when it comes to BIPV solutions, eleven reference cases have been defined. This document also aims at offering an overview of cost objectives to be achieved in order to make BIPV solutions competitive. Finally, in order to forecast the impact that the evolution of some parameters (conversion efficiency, self-consumption rate, …) will have on competitiveness values and therefore on BIPV attractiveness, a sensitivity analysis was conducted on a set of selected parameters. Eventually, the outcomes of these two sections will help to design a coherent cost-reduction roadmap for the BIPV sector.

1.2 Relation with other activities in the project

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

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

Project activity	Relation with current deliverable
9.2	Data inputs on valuation of the electricity production and possible costs based
1.3	Data inputs for reference cases' characteristics

1.3 Reference material

Not applicable.

1.4 Abbreviation list

aSi – Amorphous silicon

BIPV – Building Integrated Photovoltaics

CB – Commercial building

CdTe – Cadmium Telluride

CIGS – Copper Indium Gallium Selenide

cSi – Crystalline silicon

DC, IA, IB, IC, ID – Consumption bands within certain specific range of yearly electricity consumption

DSO – Distribution system operator

EB – Educational building

FCF – Free cash flow

FiT – Feed-in tariff

IB – Industrial building

IBC – Interdigitated back contacts, based on n-type monocrystalline silicon cells

IGU – Insulated glass unit

IRR – Internal rate of return

HJT – Heterojunction, based on n-type monocrystalline silicon cells

LCOE – Levelized cost of electricity

MFH – Multifamily house

MIRR – Modified internal rate of return

Mono cSi – Monocrystalline silicon

Multi cSi – Multicrystalline silicon

NPV – Net Present Value

OB – Office building

OCM – Offset of conventional construction material

PV - Photovoltaic

SFH – Single-family house

WACC – Weighted average cost of capital

2 INTRODUCTION & OBJECTIVES

This report provides an overview of the level of competitiveness of various BIPV solutions in key Western European markets. As it will be further explained in the next section, this notion of "competitiveness" is assessed from various points of view. Such multi-level comparison has been conducted in order to obtain an exhaustive vision of the situation of BIPV in Europe. In addition, the last type of competitiveness evaluation allows to clearly identify the intrinsic economic attractiveness of BIPV as a building envelope solution. In this evaluation, an innovative approach is applied to take into account the role of building component fulfilled by BIPV elements, based on a "value-based" assessment.

As an innovative solution combining both the characteristics of a construction material and an electric generation unit, the value proposition of BIPV solutions can appear blurry. Eventually, the aim of the report is to clarify that aspect by helping the reader understand the unique position of BIPV solutions on the European market and the added value it can generate.

3 METHODOLOGY

3.1 Defining "competitiveness"

In this report, we evaluate the competitiveness of various BIPV solutions in Europe, taking different points of view. More precisely, these points of view refer to the perimeter of the competitiveness evaluation and comparison conducted. Here, three perimeters are considered to estimate the competitiveness of BIPV:

- Cost competitiveness:
    - The competitiveness as a single building component, i.e. construction material;
    - The competitiveness as a system, i.e. building envelope solution;
- The competitiveness as an electric generating unit.

In each of these evaluations, the same logic applies, and competitiveness is estimated based on a three-step process:

1. Defining the level of cost of the BIPV solution;
2. Defining the level of cost of solutions in direct competition with BIPV;
3. Comparing BIPV to competing solutions, which allows to define the level of competitiveness of BIPV.

Note that the comparisons will be conducted exclusively between products of the same range, i.e. with comparable features, and with the same target in terms of building type and application area. This explains the use of the terms "direct competition" in the list above. For that purpose, "reference cases" have been defined and are listed in a following section. Their characteristics will determine the basis of comparison.

Finally, to provide a holistic evaluation of the competitiveness of BIPV solutions in Europe, a different approach from those previously explained will be conducted, not based on a comparison, but evaluating the intrinsic competitiveness of the BIPV solution itself. This will consist in an analysis of the cash flows generated by the project, allowing to obtain an estimation of all costs but also all revenues associated with the BIPV systems on their operational lifetime (called total cost and revenues of ownership), and to easily evaluate if such investment is financially attractive.

3.2 Data collection

In order to collect the required data on costs and technical characteristics of BIPV products and systems, various sources were used. First, publicly available information has been used, such as technical datasheets or reports. Then, data obtained through a survey, conducted in 2018 by the Becquerel Institute, from 15 installers and manufacturers of BIPV elements as well as mounting systems from the Netherlands, Germany, Austria, Italy and Switzerland, was used. Such survey allowed to collect data from the field and obtain the point of view of varied type of BIPV stakeholders, active on different segments and markets. This survey contained, among others, questions on the efficiency of the BIPV elements (if applicable), the cost of these elements, the total cost of installation in function of system size, the various source of costs and details on the business model applied.

This information was completed and cross-checked using the data and experience of other partners, which are themselves manufacturers or installers of BIPV components, or contributed and contributes to BIPV projects. Among them are EURAC, Onyx Solar, Optimal Computing, PIZ, Schweizer, SUPSI, TULiPPS, Viriden+Partners. In addition, data collected through the Task 1.3 of BIPVBOOST project was used to define the characteristics of the reference cases presented in the following sections.

3.3 Segmentation

In this report, both BIPV products for roof and façade are included in the analysis. For each of these application areas, various types of BIPV product exist. This classification and the definitions of the products per type are partially based on previous research and initiatives on the topic. [1] [2] [3]

Table 3.1: BIPV products evaluated in this report and their applicate area

	Application area	
Type of BIPV product	**Roof**	**Facade**
PV tile	x	
In-roof mounting system	x	
Full roof solution	x	
Standing seam metal sheet	x	x
Rainscreen façade element		x
Non-ventilated façade element		x

In-roof mounting system PV tiles Full-roof solution

Standing seam metal sheet Curtain wall Rainscreen façade

Figure 3.1 Presentation of existing BIPV products

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

Regarding the BIPV solutions designed for facades, “non ventilated façade elements” are BIPV elements constitutive of BIPV systems installed as curtain walls. “Rainscreen façade elements” are BIPV elements constitutive of BIPV systems installed as rainscreen façade cladding.

Finally, “standing seam steel” refers to regular lightweight roofing made of steel, with an additional layer of photovoltaic thin film, typically composed of CIGS (Copper Indium Gallium Selenide) photovoltaic cells. Nevertheless, such products based on classical crystalline silicon start to appear on the market.

3.4 Reference cases

As mentioned in a previous section, 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 on the field and their characteristics and schemes are presented in the next pages. These have been mainly defined based on the experience of BIPVBOOST’s partners and the information collected through deliverable D1.3, using the building typology, the cladding typology and the technological systems as differentiation parameters.

In the following table, the term surface coverage ratio should be understood as the ratio between the surface that is actually covered by the BIPV modules and the total available surface on the roof or the façade, typically 50m² for a residential roof or around 300m² for an office façade. Indeed, the available surfaces can never be entirely used, 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 0,6 to around 0,9 depending on the case.

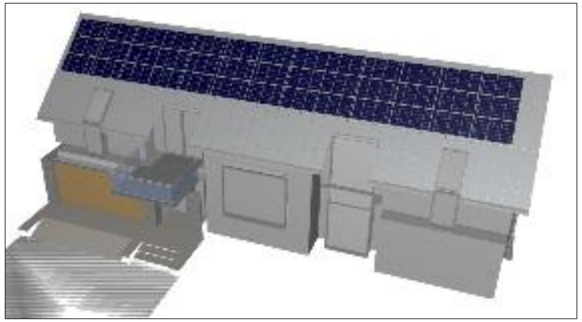
The transparency values that have been considered for the semi-transparent curtain wall are 30% for aSi (value taken from manufacturer data sheet) and 50% for cSi (value calculated based on the surface of the module occupied by the cells).

Note that other technical and cost characteristics, linked for example to the PV technology used, the country considered, or the system capacity are explicitly detailed, when relevant, in the following sections, together with results and analysis of the calculations. We consider state of the art performances for the PV technologies used in the different BIPV products described below.

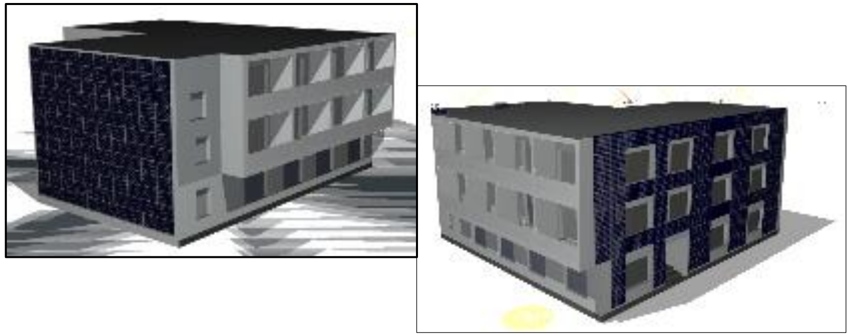
Illustrations of the reference cases and of typical alternative materials can be found after the tables. In addition, further information on technological systems and cladding typologies chosen for the reference cases are presented in Appendix 4 and 5.

Category of parameter	Parameter	Single family house			Multi-family building	Office building	
		Roof application	**Roof application**	**Roof application**	**Façade application**	**Façade application**	**Façade application**
Technical parameters	*Reference case ID*	SFH_a	SFH_b	SFH_c	MFH	OB_a	OB_b
	Technological system	PV tiles	In-roof mounting system	Full-roof solution	Rainscreen façade	Curtain wall	Curtain wall
	Cladding typology	Glazed opaque solution without thermal properties	Glazed opaque solution without thermal properties	Glazed opaque solution without thermal properties	Glazed opaque solution with added insulation layer	Insulated glazing semi-transparent solution	Insulated glazing semi-transparent solution
	Alternative construction material	Ceramic tiles	Ceramic tiles	Ceramic tiles	Metal	Glazing	Glazing
	PV technology	Mono cSi	Multi cSi	CIGS	Mono cSi (IBC)	aSi	Mono cSi
	Surface available for the system [m²]	50	50	50	300	270	270
	Module efficiency [%]	18,9%	18,0%	15,1%	17,5%	2,7%	10,4%
	Surface coverage ratio	0,65	0,88	0,88	0,88	0,9	0,9
	System surface power density [Wp/m²]	123,2	158,7	132,6	154,3	24,6	94
	Capacity installed [kWp]	6,2	7,9	6,6	46,3	6,7	25,4
	Tilt	35°	35°	35°	90°	90°	
	Azimuth (south orientation = 180°)	180°	180°	180°	90°-270°	180°	
	Degradation rate year 1	1,8%	1,8%	0,7%	1,0%	1%	1,8%
	Degradation rate from year 2	0,45%	0,5%		0,25%		0,45%
Economic parameters	*Total end-user cost (exc. VAT) [€/m²] (all costs included)*	332	208	249	684	652	797
	*O&M cost [€/m²*year]*	2			5	5	
	Cost of alternative material [€/m²] (material only)	45			80	150	
	Electricity consumption band	DC			DC	IA	
	Self-consumption rate	30%			60%	70%	
	Nominal discount rate	2%			2%	Country specific	
	Valuation of production (business model)	Country specific			Country specific		

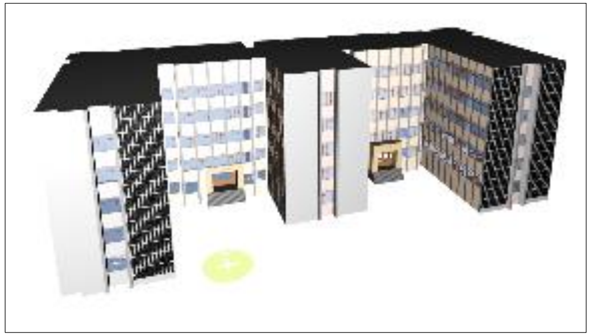
Category of parameter	Parameter	Educational building		Commercial building		Industrial building
		Façade application	**Façade application**	**Façade application**	**Façade application**	**Roof application**
Technical parameters	*Reference case ID*	EB_a	EB_b	CB_a	CB_b	IB
	Technological system	Rainscreen façade	Rainscreen façade	Rainscreen façade	Rainscreen façade	Lightweight metal roofing
	Cladding typology	Glazed opaque solution without thermal properties	Glazed opaque solution without thermal properties	Glazed opaque solution without thermal properties	Glazed opaque solution without thermal properties	Opaque standing seam metal sheet without thermal properties
	Alternative construction material	Metal		Metal		Metal
	PV technology	CIGS	Mono cSi	CIGS	Mono cSi	CIGS
	Surface available for the system [m²]	470		250		1400
	Module efficiency [%]	15,1%	16,6%	15,1%	16,6%	15,1%
	Surface coverage ratio	0,88	0,88	0,88	0,88	0,85
	System surface power density [Wp/m²]	132,6	146,1	132,6	146,1	128,6
	Capacity installed [kWp]	62,9	68,7	33,4	33,4	180,1
	Tilt	90°		90°		0°
	Azimuth	180°		270° & 180° & 90°		0°
	Degradation rate year 1	0,7%	1,8%	0,7%	1,8%	0,7%
	Degradation rate from year 2		0,45%		0,45%	
Economic parameters	*Total end-user cost (exc. VAT) [€/m²] (material only)*	412	462	412	462	350
	*O&M cost [€/m²*year]*	5		5		2
	Cost of alternative material [€/m²] (material only)	80		80		25
	Electricity consumption band	IA		IB		IC or ID
	Self-consumption rate	70%		90%		90%
	Nominal discount rate	Country specific				
	Valuation of production (business model)					



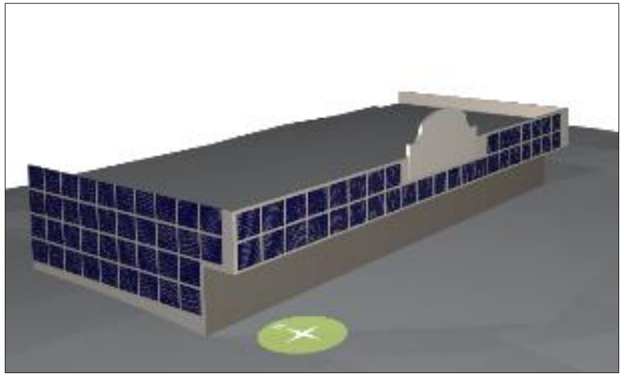
Reference case : Single Family House (SFH_a, SFH_b, SFH_c)



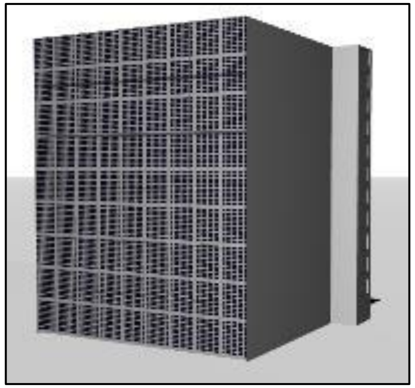
Reference case : Multi Family House (MFH)



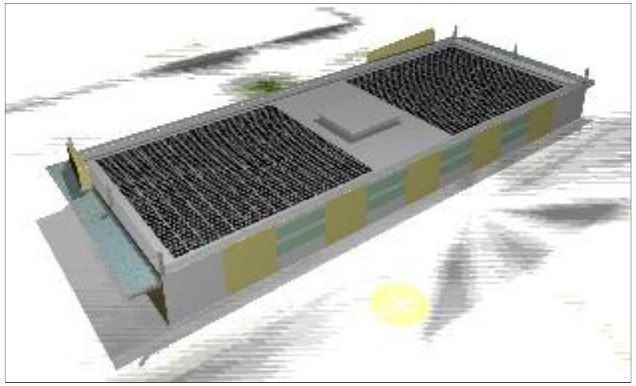
Reference case : Educational Building (EB_a, EB_b)



Reference case : Commercial Building (CB_a, CB_b)



Reference case : Office Building (OB_a, OB_b)



Reference case : Industrial Building (IB)

Figure 3.2 Illustrations of the reference cases

Glass façade

Stone façade

Metal façade

Wood façade

Roof with ceramic tiles

Metal roof

Figure 3.3 Example of some conventional construction materials considered as alternatives to BIPV solutions

4 COST COMPETITIVENESS STATUS

4.1 Material-level competitiveness

Here, a comparison of the cost of single building components, i.e. without other sources of cost such as balance of system (e.g. mounting or cabling, fastening, inverter, etc.), is conducted. Mainstream building components usually applied on roofs or façade are put in regards of BIPV elements.

Results are shown in €/m², as this is the most commonly used metric in the construction and building sector and are based on value gathered during the data collection process. These costs, which represent what can be expected by the end-user, are without VAT and any transportation costs.

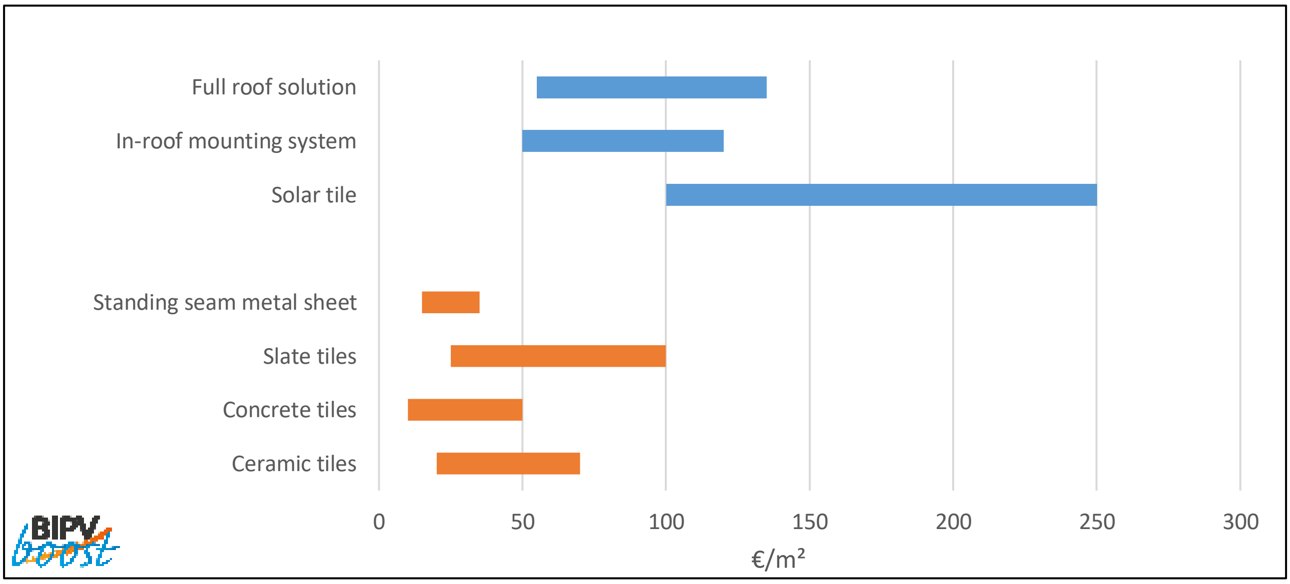


Figure 4.1 Comparison of the cost of various roofing materials

On Figure 4.1 Comparison of the cost of various roofing materials below various types of roofing material are compared. Concerning active ones, it is important to precise that solar tiles considered in this cost assessment are equipped with crystalline silicon PV cells. Also, the tile itself can be made of different material, such as ceramic, concrete or plastic, which explains the wide cost range for this product. Then, in the case of in-roof mounting system and full roof solutions, what is referred to as the “roofing material” is the PV module, as they are the primary components of such system. Typically, cheapest solutions are mainstream multi-crystalline silicon products, while higher range is made of premium products, such as modules based on IBC or HJT cells. Thin-film technologies are also making up the medium to higher cost range of these products, mainly CIGS-based ones, but CdTe-based products can be found on the market. The slight price discrepancy between in-roof mounting systems and full roof solutions can be explained by the fact that, for the latter, additional components and accessories are required for each module, to improve integration (to guarantee water tightness, for example).

It can be seen that active roofing material such as BIPV are on average more costly than regular, non-active roofing materials. The cost gap is particularly noticeable in the case of solar tiles, which cannot compete, on a material-level, with any of the four regular roofing materials included in the comparison. In the case of in-roof mounting systems and full roof solutions, the cost gap is less extreme. In these categories, products making up for the lower part of the cost range can be cheaper than high-end tiles such as ceramic or slate ones.

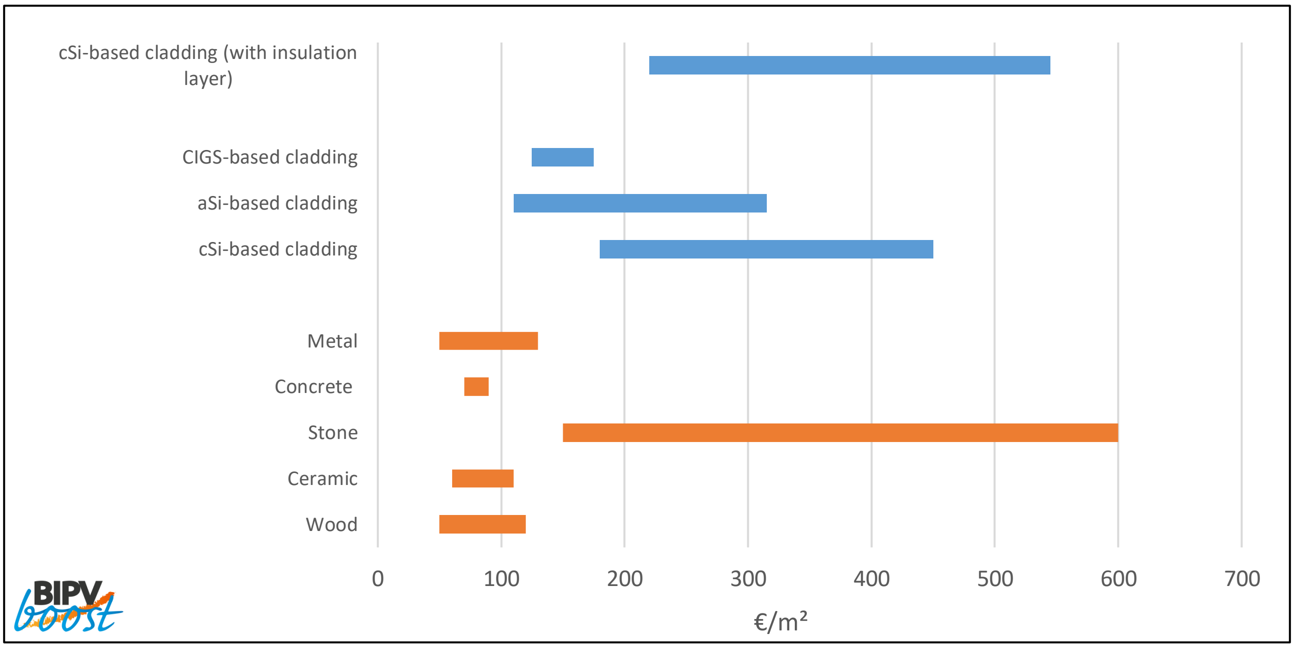


Figure 4.2 Comparison of the cost of various ventilated (rainscreen) façade cladding elements

On Figure 4.2 above the costs of different façade cladding materials are compared. BIPV elements considered here are based on three different PV technologies, namely amorphous silicon, crystalline silicon and CIGS (including (semi-transparent) or opaque glazing). In the case of cSi, the cost of the cladding with and without insulation layer is presented. Although, to remain consistent, the comparison with regular cladding elements should be conducted with the non-insulated BIPV elements, as the cost of the former is considered without any insulation layer. Note that the visual characteristics of the products such as the level of transparency or special colouring lead to different prices that are included in the ranges. But these are not the only source of price divergence. The large range of price can be also explained by the fact that the end-user cost per m² vary highly in function of the scale of the project, the dimensions of the BIPV elements (standard or customized) or the type and thickness of the glass, among others. The composition per layer of the various claddings can be seen in Appendix 5 for more details.

In this segment, the situation is relatively similar to what was observed with roofing materials. Except for the high-end material, i.e. stone as façade cladding, all the regular cladding materials have the advantage in terms of cost when put in regards of active materials. Nonetheless, cheapest BIPV solutions based on thin-film, i.e. amorphous silicon as well as CIGS, can potentially compete with higher range bricks or wood cladding. The cost advantage of cladding elements based on amorphous silicon can be partially explained by the lower cost of raw materials, while CIGS-based cladding typically refers to standardized modules equipped with specific sub-structure, which allows to limit the cost of production.

Finally, the situation of curtainwall façade elements is depicted below. In this comparison, all elements, active or not, are made of glass, as they are constitutive of curtain walls.

As for the previous categories analysed, the competitiveness status is rather clear. There is an unquestionable cost gap between regular glazing and glazing equipped with PV cells, which is not surprising, as the active glazing requires additional raw materials and processes to be manufactured.

What can be concluded from this subsection, assessing the level of competitiveness on a material-level basis, is that BIPV elements are more costly than competing regular building components, in a vast majority of cases. Note that, in case glazing equipped with “solar control coating” is considered as alternative material, the gap with BIPV is diminishing, as the cost can substantially increase, in function of the technology used for the coating.

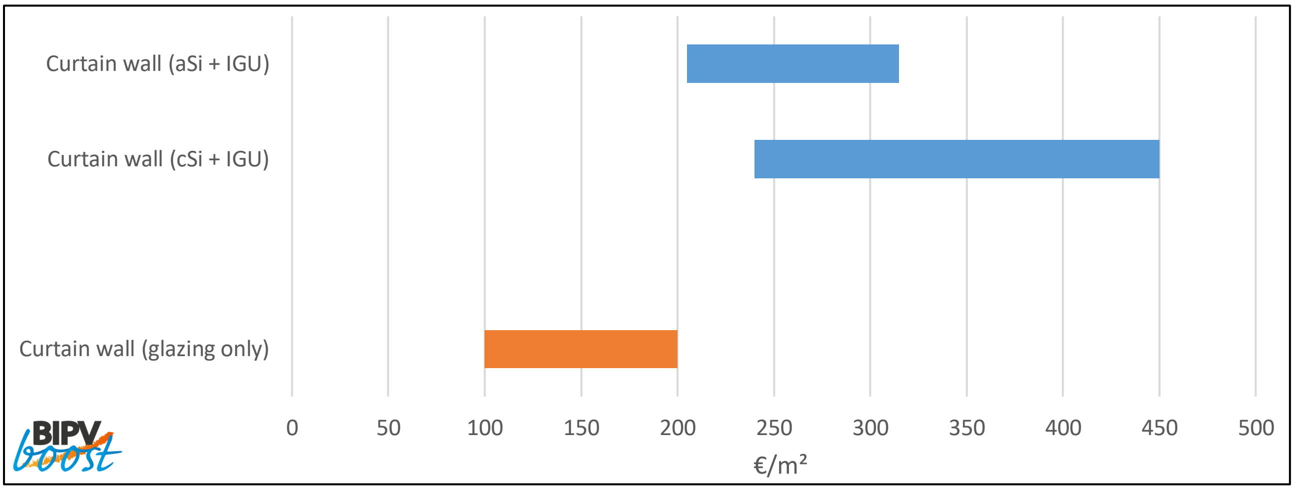


Figure 4.3 Comparison of the cost of various non-ventilated façade (curtain wall) elements

4.2 System-level competitiveness

Going one step further, an assessment of the competitiveness at the level of the system, i.e. building envelope solutions, can be conducted. As previously, the range of end-user costs of various BIPV systems is presented and put in regards of the end-user cost of competing, non-active solutions. In this case all costs are taken into account. It means that in addition to the cost of the primary material, costs of the fastening system, the possible accessories, the planning and installation works or the administrative work, are also considered, among others.

Note that as it is considered that BIPV products should be first seen as building components before PV elements, the competing solutions consist of mainstream building envelope solutions, taken individually. Nonetheless, when relevant, namely for roof applications, the cost of residential BAPV systems will be shown as well, to complete the analysis. The end-user cost of the BAPV system will be added to the end-user cost of the mainstream building envelope solutions to evaluate if BIPV, as a system combining the roles of both these solutions, is more competitive.

Similar PV technologies and application areas will be considered as for the material-level competitiveness evaluations. Again, this comparison is conducted in €/m² and these costs, which represent what can be expected by the end-user, are without VAT and any transportation costs.

On Figure 4.4 the end-user costs of typical roofing solutions are shown. While cheap metal roofing seems like an untouchable competitor, especially for industrial building constructions, other regular roofing solutions can be challenged by BIPV, at system-level. It even appears that the gap has decreased compared to the material-level competitiveness assessment conducted in the previous section.

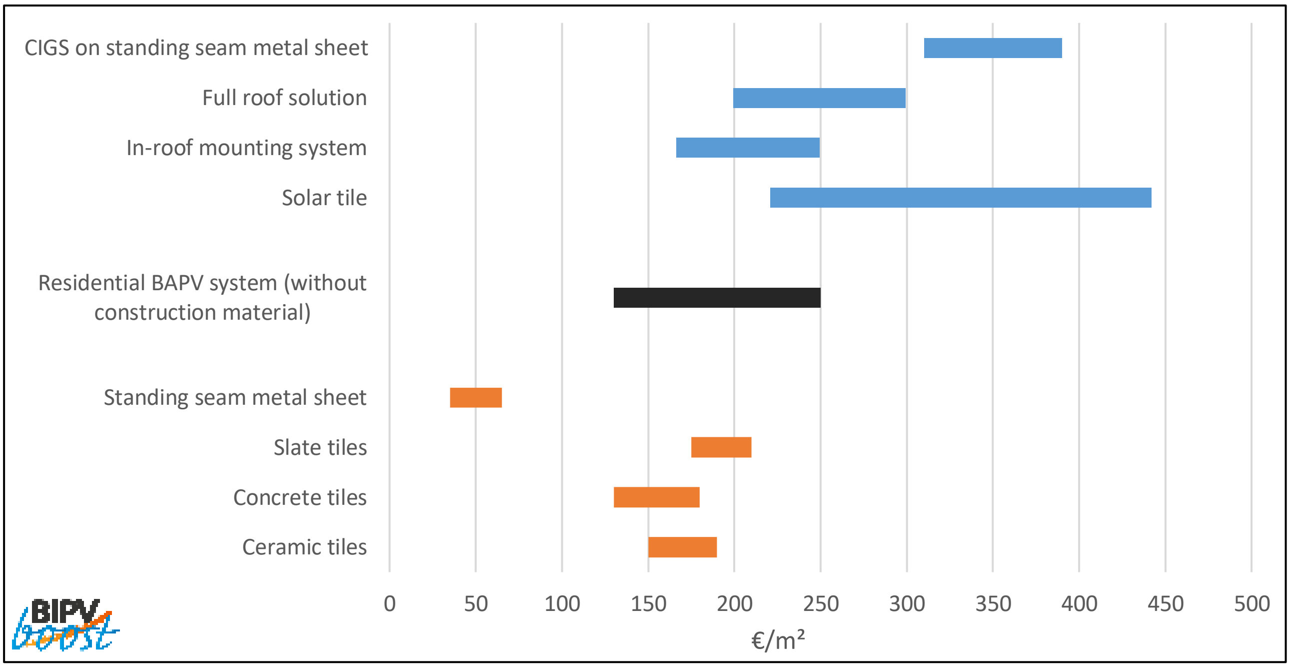


Figure 4.4 Comparison of the end-user cost of various roofing solutions

Results show that simple solutions such as in-roof mounting system can be more competitive than slate tiles, while being able to be on par with other types of tiles, in some cases. Full roof solutions, which are slightly costlier, are not as competitive but can still compete with solutions based on slate tiles. On the other extreme of the chart, most expensive active solutions such as solar tiles or seam metal roofing with an active layer can hardly be seen as competitive, compared to regular roofing solutions. However, it is worth noting that the latter product is not mature yet and substantial cost reductions are still possible and expected.

Then, when considering the sum of both the regular roofing solution and the BAPV system, the competitiveness of BIPV solutions is clearly strengthened. Taking the example of a cheap tile-based solution at 130 €/m², on the top of which a PV system is added at 130 €/m², most in-roof mounting systems reveal to be more competitive, as well as the cheapest half of full roof solutions. While competitive solar tiles-based solutions remain mostly less competitive than this BAPV on top of regular roofing option, the cheapest systems can be considered as serious challengers. Furthermore, it is important to note that a larger range of active solutions could possibly be competitive, if the most economical roofing and BAPV solutions had not been selected for the comparison.

Shifting to rainscreen façade systems, the end-user cost of cladding solutions is summarized on Figure 4.5. The wide cost ranges can be explained by the fact that, from one project to another, circumstances can highly vary, for example concerning the workload. In the case of active cladding coupled with insulation, the type of insulation chosen, and the reinforced fastening system possibly required can be mentioned as additional explanatory factors.

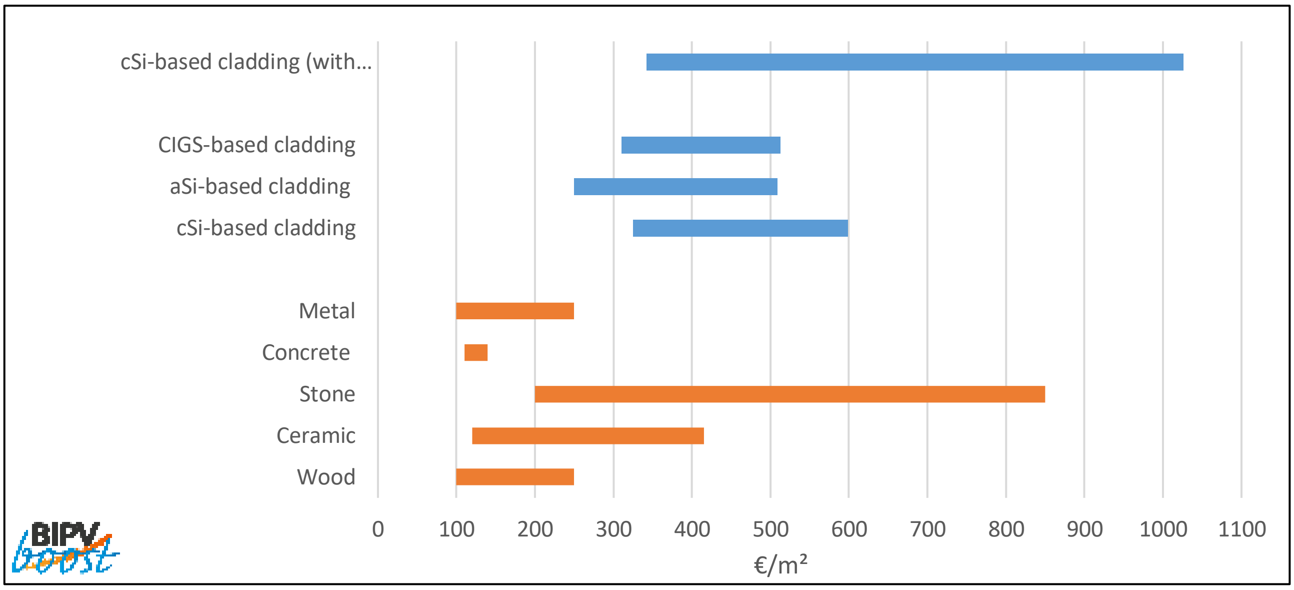


Figure 4.5 Comparison of the end-user cost of various ventilated (rainscreen) façade solutions

Compared to the material-level competitiveness chart, the cost gaps have decreased, and the situation is more homogeneous. Still, 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.

The case of curtain walls, finally, is depicted on Figure 4.6. The analysis is rather similar, though less extreme, than for cold façades. Regular curtain walls belonging to the low to medium price range remain out of reach for BIPV. Nevertheless,a majority of active curtain walls can compete, on a cost basis, with most expensive regular warm façade solutions.

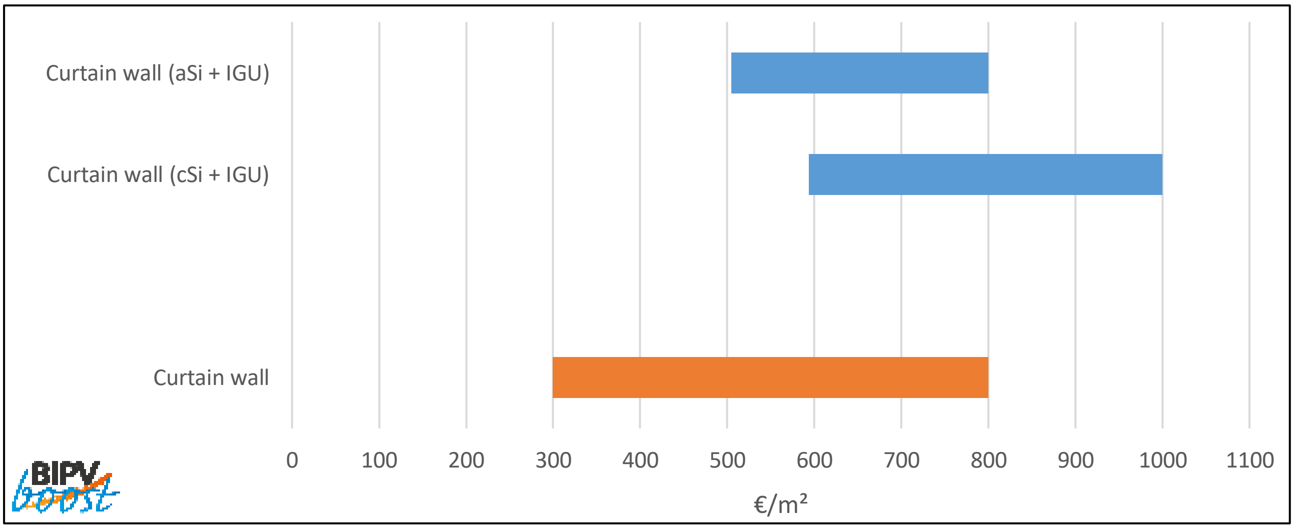


Figure 4.6 Comparison of the end-user cost of non-ventilated façade (curtain wall) solutions

The main outcome of this system-level competitiveness assessment is that, while the end-user cost gaps have been reduced between active and non-active solutions, in most cases, compared to what was seen in the previous section, active solutions remain to a large extent less competitive than regular building envelope solutions. As mentioned already, this fact is not surprising as the supplementary function of electricity generation comes with an extra cost. Further analysis will be conducted in this report to see if these extra costs can be compensated by the extra value generated.

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. The main advantage comes from the fact the various cost items are not doubled, such as the material but also installation or mounting system.

5 COMPETITIVENESS AS AN ELECTRIC GENERATING UNIT

As energy generating systems, BIPV solutions can also be evaluated based on the cost of the electricity they produce. For such competitiveness assessment, all costs linked to the installation and operation of the system during its lifetime must be taken into account. These will allow to compute the levelized cost of electricity (LCOE) generated by the BIPV system. Once calculated, the LCOE will be put in regard of the compensable retail electricity price, to evaluate the level of competitiveness of the BIPV systems as electric generating unit. The LCOE of the analysed BIPV solutions could have been compared to the LCOE of BAPV systems, but these are only suited for roofing solutions, thus the comparison could have been conducted for only a few of the cases. In addition, BAPV systems, as they are not fulfilling the same functions as BIPV and not subject to the same constraints, are not considered as direct competitors. Hence, such comparison was considered as irrelevant.

Prior to the results of this competitiveness assessment, assumptions made as well as various parameters are presented in the following sub-sections.

5.1 Assumptions and parameters used

The "**levelized cost of electricity**" can be defined as the cost that, assigned to every unit of electricity produced by the system over its (theoretical) useful lifetime, will equal the total life cycle costs of the system when discounted back to the initial year of the investment. This allows to provide a single figure, in €/kWh in this case, representative of the total costs linked to the ownership and exploitation of the electric generating unit, taking into account its predicted electricity production.

Then, the following assumptions were made about some of the parameters that take part in the LCOE formulae. 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. Note that for residential housing cases, the discount rate used equals 2% and is the same across all considered countries. Indeed, PV production is foreseeable and well understood, whereas real estate investments are widely recognized as safe. As a simplifying assumption, asset **depreciation** is assumed to be linear and applied according to theoretical BIPV system useful lifetime.

Regarding the different parameters, the total **system lifetime** is assumed to be equal to 30 years. The **operations and maintenance costs**, including cleaning, are assumed to be constant on the useful life of the system, in real value. In 2019, operations and maintenance costs are assumed to equal 2 €/m² 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 is considered. [4]. The **corporate tax rate** varies from one country to another, ranging from 8.5% in Switzerland up to 33.33% in France. [5] As a simplifying assumption, it is assumed that this tax rate remains constant on system lifetime. Concerning, **inflation** it is assumed to be similar across Eurozone countries and equal to 1.5% every year. [6] The same value is used for Switzerland. Then, in the case of residential housing (single-family and multi-family), the VAT must be added to the total end-user costs, in order to reflect the real expense incurred by the investor.

About technical considerations, system **degradation rate** is based on typical module degradation rates. It corresponds to the average values obtained from recent studies, from 0,4 to 0,5%/year for cSi modules 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) cause an initial degradation of performance of about 1,8%. Then, aSi-based systems have performances' decreases of larger magnitude, on average, equal to approximately 1%/year. [7] [8] [9] 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.

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". [10]

Table 5.1 Summary of used parameters

	Belgium	France	Italy	Germany	Netherlands	Spain	Switzerland
Nominal WACC	5,24%	5,18%	7,24%	4,96%	5,17%	5,94%	5,15%
Yearly inflation	1,5%						
Real WACC	3,69%	3,62%	5,66%	3,41%	3,61%	4,37%	3,59%
Corporate tax rate	29%	33,33%	24%	15%	25%	25%	8,5%

5.2 Additional fees

Additional fees must be taken into account when calculating the competitiveness of BIPV systems. They can either be linked to a particular business model or apply to all cases. Some examples for each case are given in the table below.

Table 5.2 Additional fees impacting BIPV solutions' total life cycle cost

Type of additional fee	Description
Specific to a business model	A prosumer tariff applies in Flanders in Belgium, in the case of residential housing, when the business model based on net-metering is chosen.
Applicable to all business models	In Germany an EEG surcharge applies to finance the expansion of renewables. In Italy, fees applied by GSE for the management of electricity sales must also to be added.

5.3 Valuing BIPV as building component

Building integrated photovoltaics, in addition to producing electricity, have the unique ability to fulfil the functionalities of a building component. BIPV also makes the investment in alternative construction materials unnecessary, thus offsetting the cost of these conventional, alternative materials. This ability should be valued and integrated to calculations. To do so, a value-based approach is applied. The added value of these building component’s characteristics is estimated by using a proxy. This proxy is defined as the value, i.e. the material 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”. For that reason, as BIPV systems considered in the calculations lies in the median part of the end-user costs’ range presented in Section 4.2, the offset cost of conventional construction material is also based on the median part of material costs’ range presented in Section 4.1. Precise values are available in the reference cases’ table on page 12.

In the case of LCOE calculations, a first generic approach will be conducted by only considering the notions and values presented in Section 5.1. Then, following the logic developed here above, a second approach will be applied, taking into account the offset of conventional construction material (OCM). This will result in a second LCOE value more adapted to BIPV. Mathematically, this translates to a LCOE formula where the CAPEX is diminished by the OCM value, later referred to as LCOE_2 (value-based approach).[1]

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[1] Further explanation on the LCOE can be found in Appendix 6

5.4 Extra cost of BIPV

Going one step further than the value-based approach explained here above, the assessment of competitiveness as an electric generating unit can be conducted solely on the estimated “extra costs” due to BIPV, compared to a conventional building envelope solution. This relies on the same logic as the one underlying the inclusion of the offset cost of conventional construction material. As BIPV elements are core parts of building’s envelope, they cannot be removed without altering the integrity of the building. Hence, they have to be replaced by an alternative building envelope system in any case, of which the end-user cost can be considered as a fixed cost. Concretely, this means that in the calculations, the total end-user cost is reduced by an amount equal to these estimated fixed costs, in order to consider only the extra costs of BIPV. In the LCOE formula, this would translate in an end-user cost reduced exclusively to its share identified as the extra costs of BIPV. This will later be referred in this section to as the LCOE_3 (extra cost approach).[2]

This approach is enabled by an analysis of the end-user cost’s structure presented on Figures 4.7 and 4.8. 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. In order to evaluate these extra costs, the total end-user cost of the BIPV system is broken-down into categories (labour, materials, logistic, …) and sub-categories (cabling, monitoring system, inverters, …). These are then evaluated one by one. Note that to simplify the analysis, this methodology is applied on “typical” cost structures, defined as standard cases for different type of application. Here, two main applications are considered, a roof case and a façade case.

To determine the typical cost structure for a roof application, three cases, respectively based on PV tiles, an in-roof mounting system and a full-roof solution have been studied. As far as façade application are concerned, three cases of façade cladding (CIGS without insulation, cSi without insulation, cSi with insulation) have been used. It is important to insist on the fact that end-user costs’ structure could differ substantially for some BIPV projects due to specific local conditions or project’s characteristics.

Note that, as the composition of 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. The simplifications made are necessary to conduct a generic analysis, as intended by this report. But this extra cost estimation should be considered with caution, as it might not be representative of all BIPV projects. It is worth highlighting that 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. In addition, in the sensitivity analysis conducted in section 7, the influence of increasing or decreasing end-user costs is analysed, and the results are also valid when the approach focusing on extra costs of BIPV is applied.

As seen on the charts, some cost items such as “Labour – Electrical Installation”, “Materials – Cabling” can easily be identified as one hundred percent linked to the energy generating function of BIPV. For other cost items such as “Labour – Structural Planning”, “Logistic – 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 of

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[2] Further explanation on the LCOE can be found in Appendix 6

the “Materials – BIPV Module”, “Indirect – Certification/Permitting” and “Indirect – Administrative & Legal Planning” cost items 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, based on what was explained in previous sections. The OCM, considered as a proxy for the fixed share of BIPV module cost, is subtracted to eventually determine the amount and share of extra costs. In the SFH_a reference case for example, as illustrated below, the initial end-user cost amounts to 332€/m². The BIPV module represents 40% of this total and the offset cost of conventional construction materials, i.e. ceramic tiles, equals 45 €/m². Therefore, we can deduce that the share of OCM in the BIPV module cost is: ${}^{45}/_{(0{,}4\,*\,332)} = 34\%$.

In the end, it can be drawn from the assessment that BIPV represents an extra cost of almost 50% for BIPV roofs (ranging from 43,7% to 58,3% depending on the considered reference case) and of almost 60% (ranging from 49% to 56% depending on the chosen reference case) for BIPV façades, compared to a conventional building envelope solution.

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 where BIPV will be installed, but also the remaining façades 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.

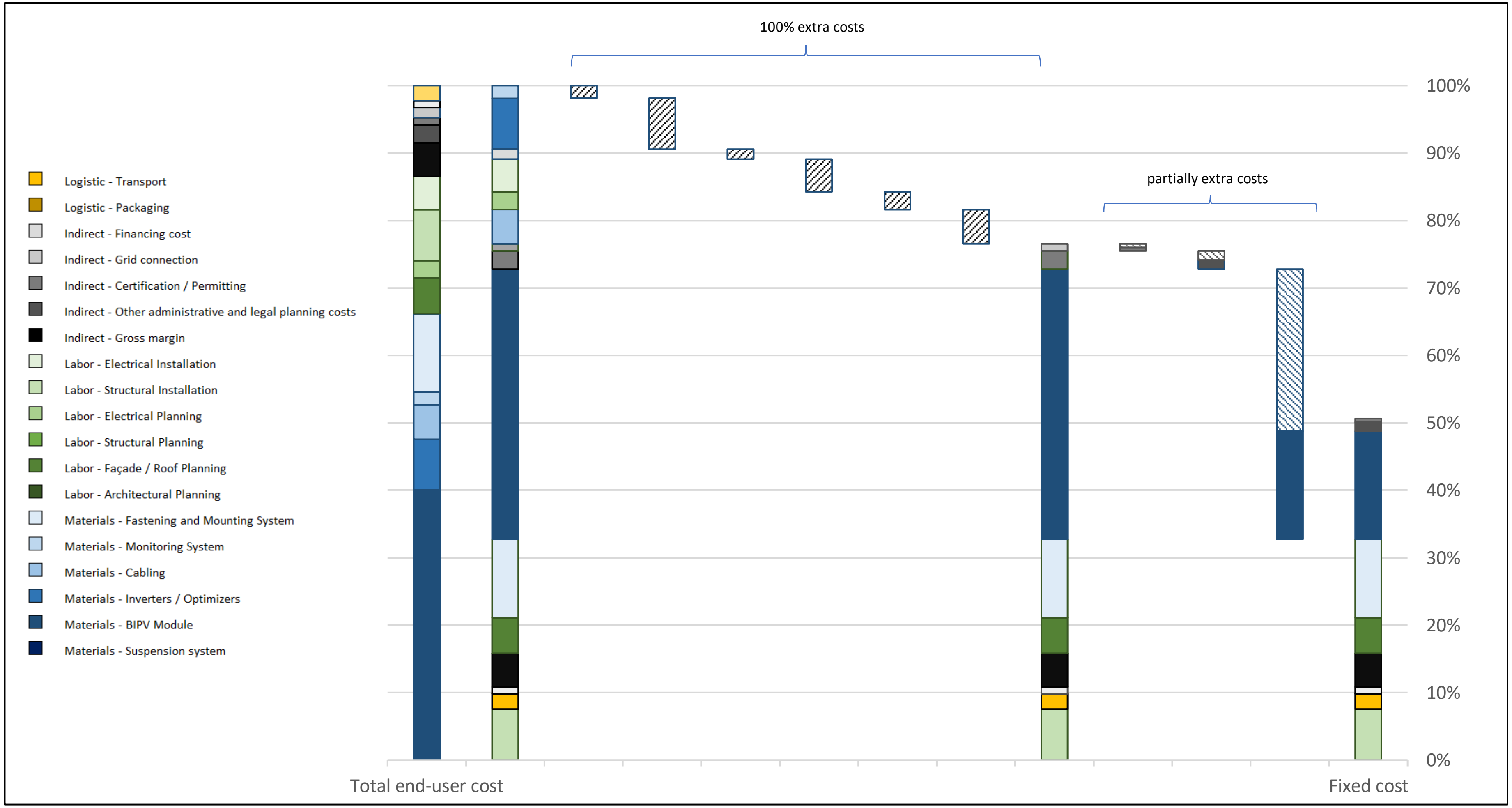

Figure 5.1 Structure of the BIPV end-user cost and extra costs analysis - Case of a BIPV roof

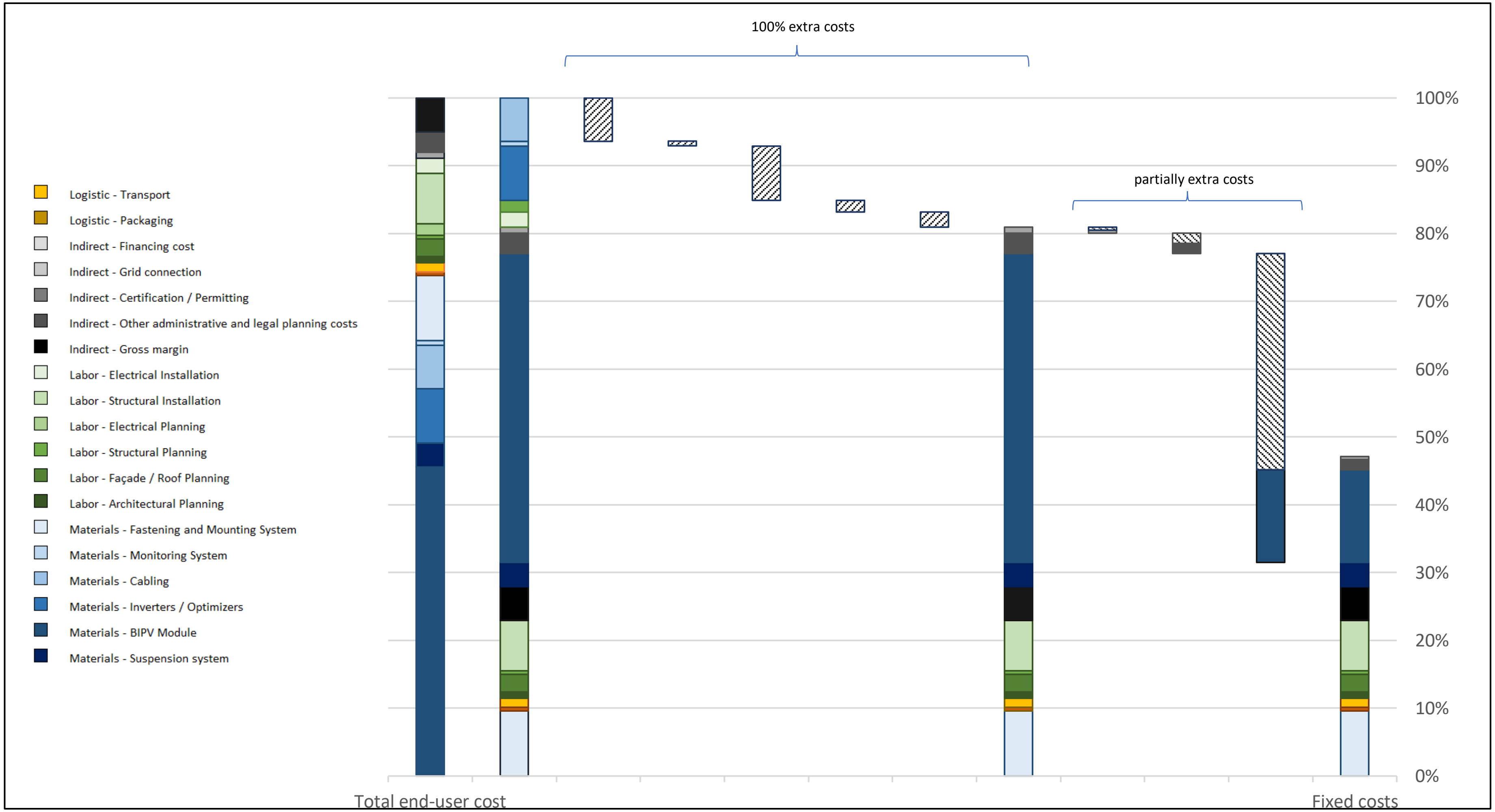

Figure 5.2 Structure of the BIPV end-user cost and extra costs analysis - Case of a BIPV facade

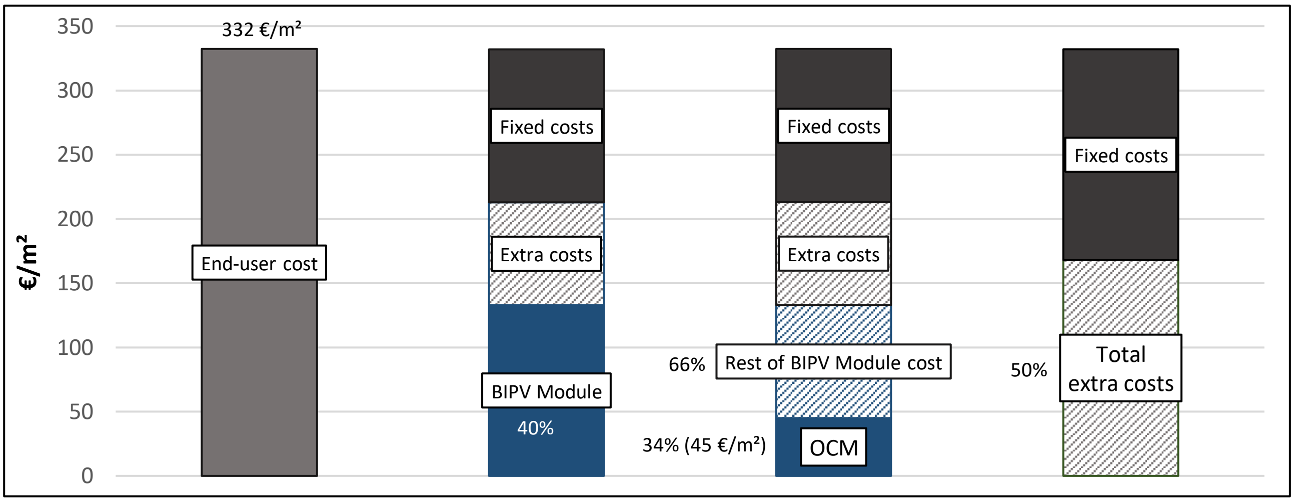

Figure 5.3 Detailed explanation of the extra cost approach – Illustration with a residential BIPV roof case

5.5 Results for reference cases

Based on the previously described methodologies (generic approach, value-based and extra cost ones), three LCOEs for each of the eleven reference cases have been calculated and are displayed in the different charts below. Along with the LCOE figures are shown the wholesale and compensable[3] retail prices of electricity of each given country to allow relevant comparison. In order to lighten the text, the terms LCOE_1, LCOE_2 and LCOE_3 will be respectively used to designate the LCOE based on a (_1) generic approach, on a (_2) value-based approach and on an (_3) extra cost approach.

Note that for residential cases, as expressed in section 5.1, the relevant VAT rates have been applied to the end-user cost of the BIPV solutions.

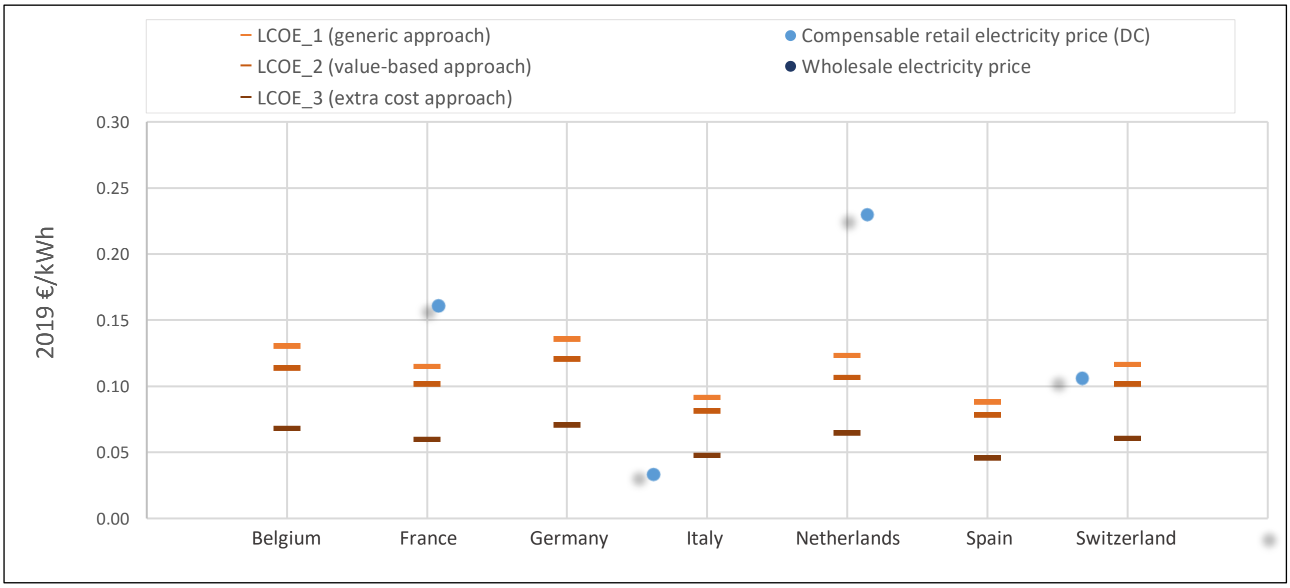

Figure 5.4 LCOE of reference case SFH_a

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[3] See section 6.1.1 for more details about electricity prices

This **first case** concerns a single-family house with roof tiles equipped with mono cSi PV cells. The LCOE_1 and LCOE_2 values are all ranging between the wholesale price and, except for the case of the Netherlands, the compensable retail price. This Dutch exception can be explained by two factors. The first one is that retail electricity prices are particularly low in this country, the second one is that only a small share of this price is variable, i.e. compensable. Although, when LCOE_3 is considered, the values are under the compensable retail price even in the Netherlands. It can also be noted that the high compensable retail prices in Belgium and in Germany can be explained by the exact opposite factors: high retail prices with a notable variable share. Because the LCOE stays below the compensable retail price in six out of seven countries (seven out of seven when LCOE_2 or LCOE_3 is considered) and is comparable to it in the Netherlands, it can be considered that the given BIPV technology is a competitive energy generating unit. In that sense, grid parity is already reached in most cases. On the other hand, wholesale parity is only reached in Italy and Spain, and exclusively when the extra cost approach is considered. In other analysed countries, while LCOE_3 is close to wholesale market price, it remains above it.

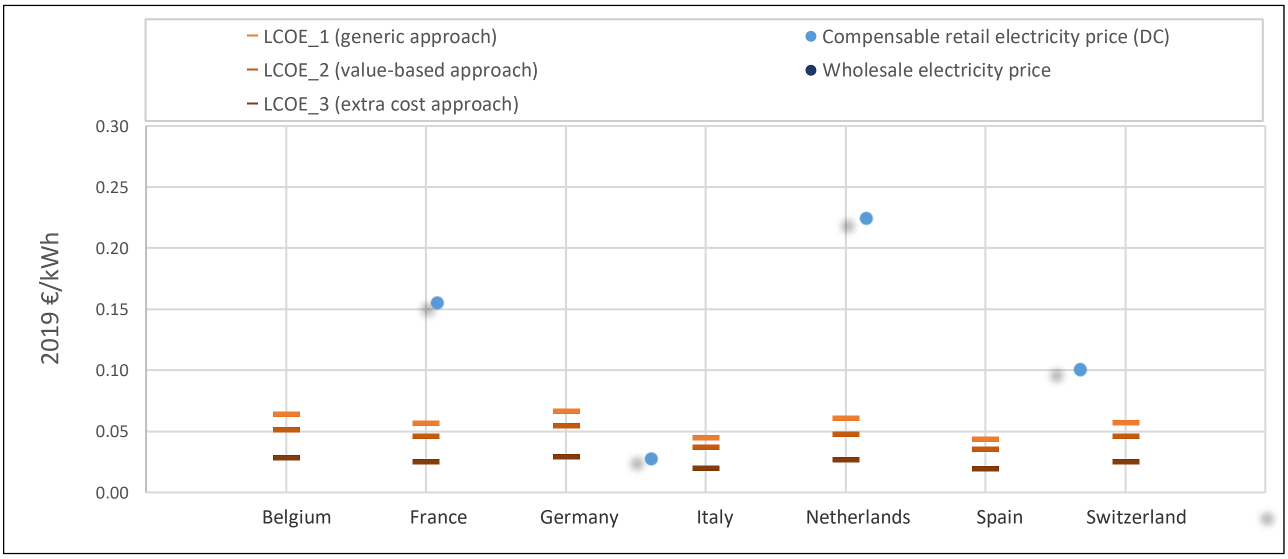

Figure 5.5 LCOE of reference case SFH_b

In this **second case** concerning a single-family house, here equipped with an in-roof mounting system, based on multi crystalline silicon modules, the compensable retail prices are the same as in the previous case because they refer to the same electricity consumption band, i.e. for households, as the consumption profile of the occupant is identical. But, because this technology has a lower end-user cost, the LCOEs have shifted down, thus approaching the wholesale electricity prices. For some countries where solar irradiation is particularly advantageous and wholesale electricity prices above average (Italy and Spain), all LCOEs are even reaching values below the wholesale prices and therefore far below compensable retail prices. In this case, wholesale parity is reached, as all LCOE_3 values are inferior to wholesale market prices. Consequently, this BIPV technology can be considered as a competitive energy generating method for all analysed countries.

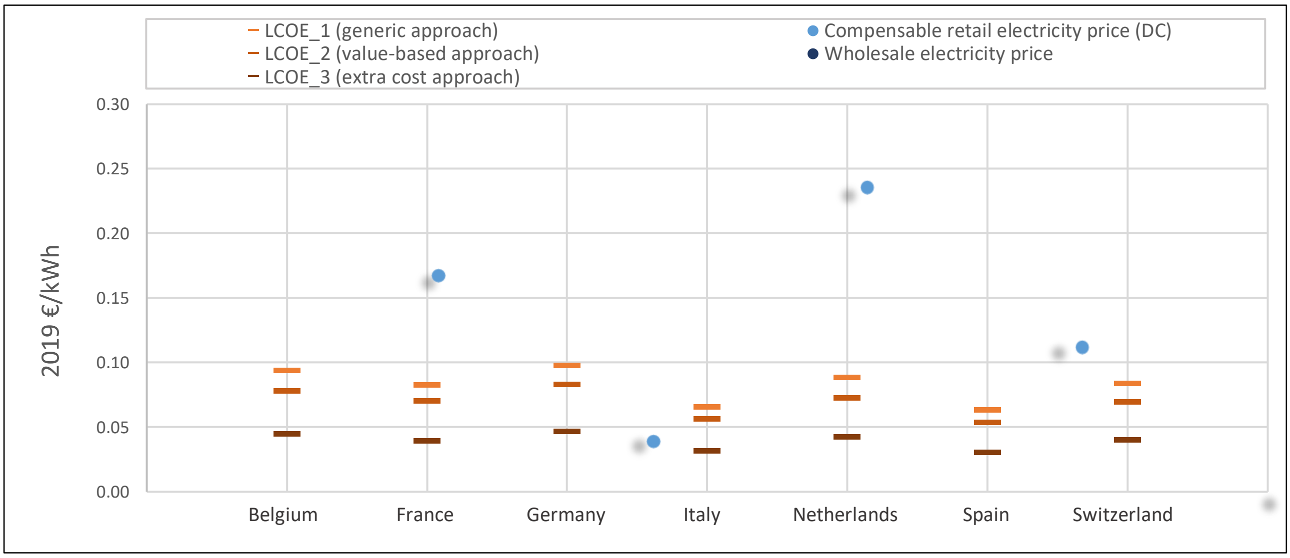

Figure 5.6 LCOE of reference case SFH_c

Then, for the results of the **third reference case**, presented on Figure 5.6, which relates to a single-family house with a full roof CIGS solution, the same trend as in the second case can be observed but slightly less pronounced. Indeed, the LCOE values are again nearing the wholesale prices and consequently, although to a lesser extent in the case of the Netherlands, well below the compensable retail price. It can thus be said that this type of BIPV system a competitive energy producing method as well, considering that grid parity is reached in all seven countries and that wholesale parity is given, or close to be. It is worth noting that wholesale market prices can vary, sometimes highly, even within a single day. Numbers which have been selected and are used here are averages, which by definition are only representative of a portion of the reality. Hence, conclusions should not be drawn too quickly when LCOE values lies close to the wholesale electricity prices shown here, as natural variations of market prices could occur and alter, or even invert, their respective positions.

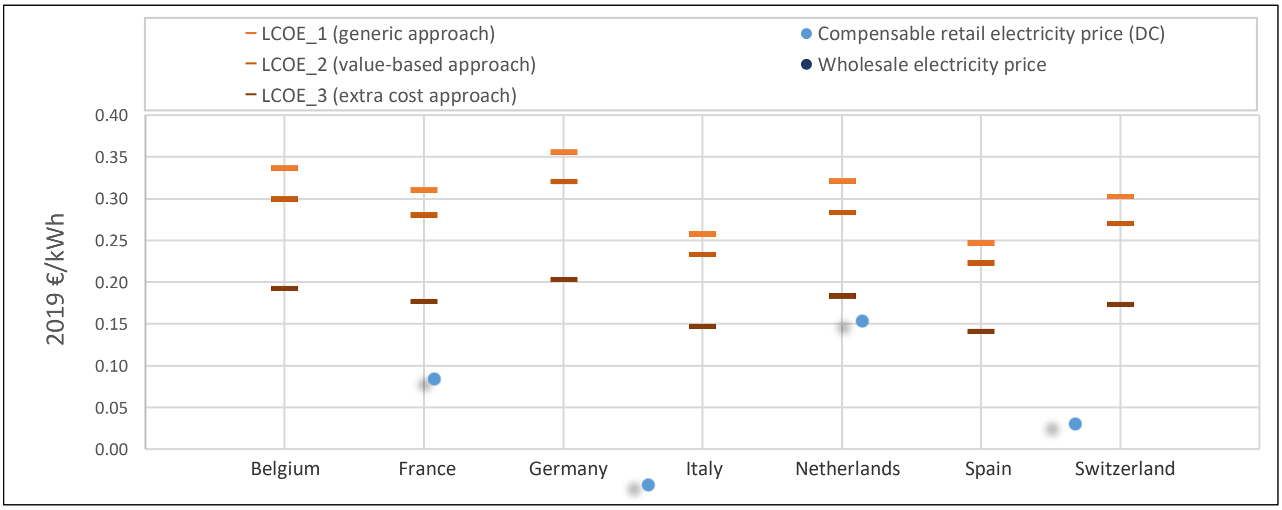

Figure 5.7 LCOE of reference case MFH

Concerning the **last reference case belonging to the residential sector**, where a monocrystalline silicon-based opaque cladding with insulation is installed on the façade of a multifamily housing building, a significant difference can be observed compared to the previously studied cases. This can be explained by the fact that the end-user cost of the previously analysed residential BIPV roofing systems where much lower, on a €/Wp or €/m² basis, than the sophisticated façade cladding system considered here. As depicted on Figure 5.7 above, with no exception the LCOE_1 and LCOE_2 values exceed the compensable retail price. Only the extra cost approach allows the LCOE_3 to be below the compensable retail price, but in four countries only. Nevertheless, the compared values remain in the same order of magnitude with LCOE values that are less than twice as high as the compensable retail price, except for the Netherlands. A difference can also be observed when it comes to the gap between LCOE_1 and LCOE_2, which is due to the influence of taking OCM into account in the calculations. This can be explained by the fact that the first three cases were concerning roof installations and not façade installations where conventional construction materials, which costs are offset by BIPV, are almost twice as more expensive.

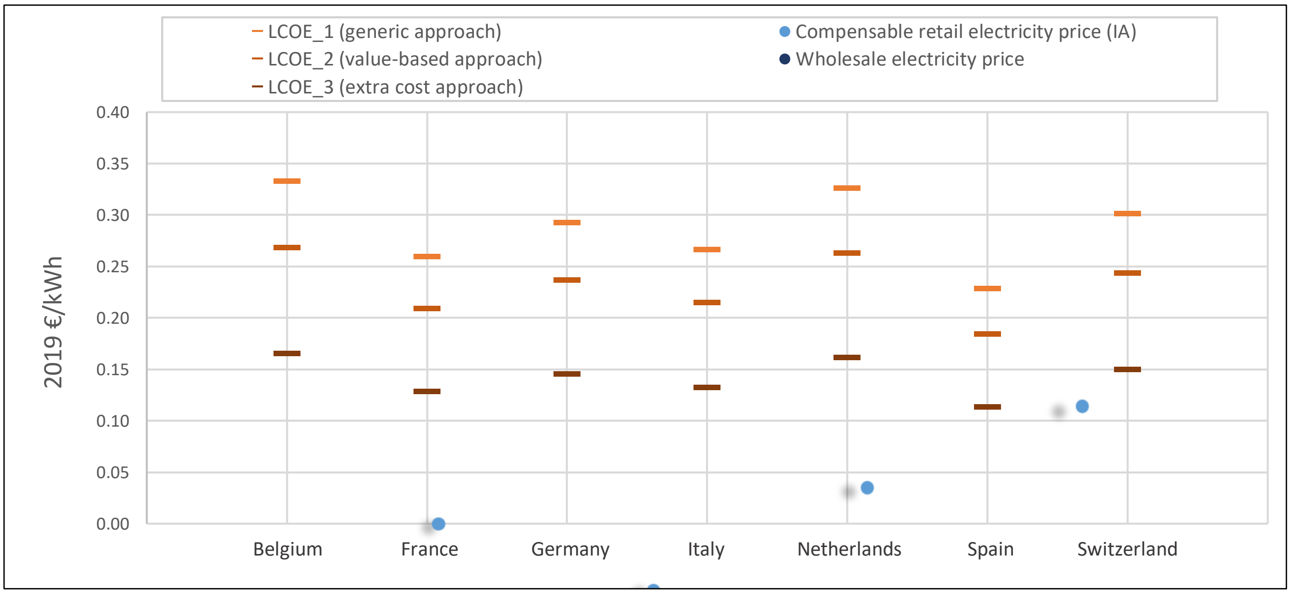

Figure 5.8 LCOE of reference case EB_a

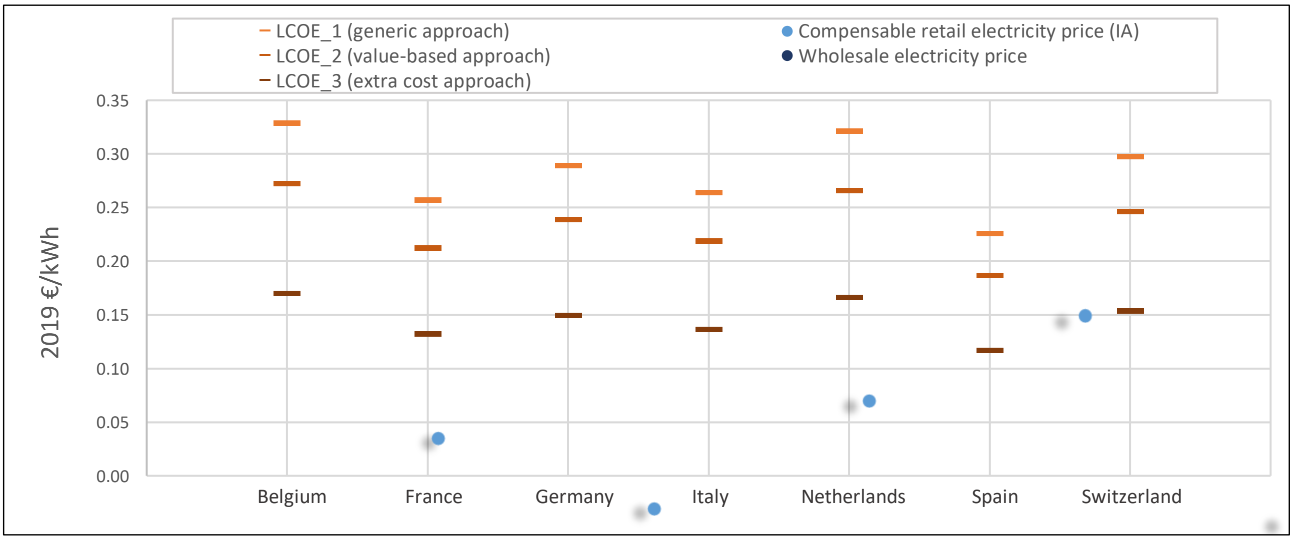

Figure 5.9 LCOE of reference case EB_b

In this **fifth case**, focusing on an **educational building** equipped with CIGS opaque facade cladding and illustrated on Figure 5.8, most LCOE values exceed the compensable retail prices. Except for Spain, where compensable retail prices are high enough so that the studied technology remains competitive as an energy generator. Nonetheless, in six countries LCOE_3 values stand below the compensable retail electricity prices. The gap between LCOE_1 and LCOE_2 values and the compensable retail price is smaller in countries such as Germany, Spain or Italy because they have higher retail electricity prices for the IA consumption band, which was chosen as the benchmark when studying educational buildings. Results for the **sixth reference case**, shown on Figure 5.9, dealing with an **educational building** with mono cSi-based opaque façade cladding, show that a difference of only a few cents per kWh can be observed compared to the previous case. This is due to the fact that their characteristics marginally differ, both in terms of efficiency and of total end-user cost. For these two reference cases, while in most countries results of LCOE calculations based on the extra cost approach tend to demonstrate that grid parity is reached, or close to be, the wholesale parity remains, unsurprisingly, far out of reach. The specific case of the Netherlands stands out as particularly non-attractive, for the same reasons as previously mentioned, and the two types of BIPV façades investigated here can hardly be considered as competitive electricity generating units in this country.

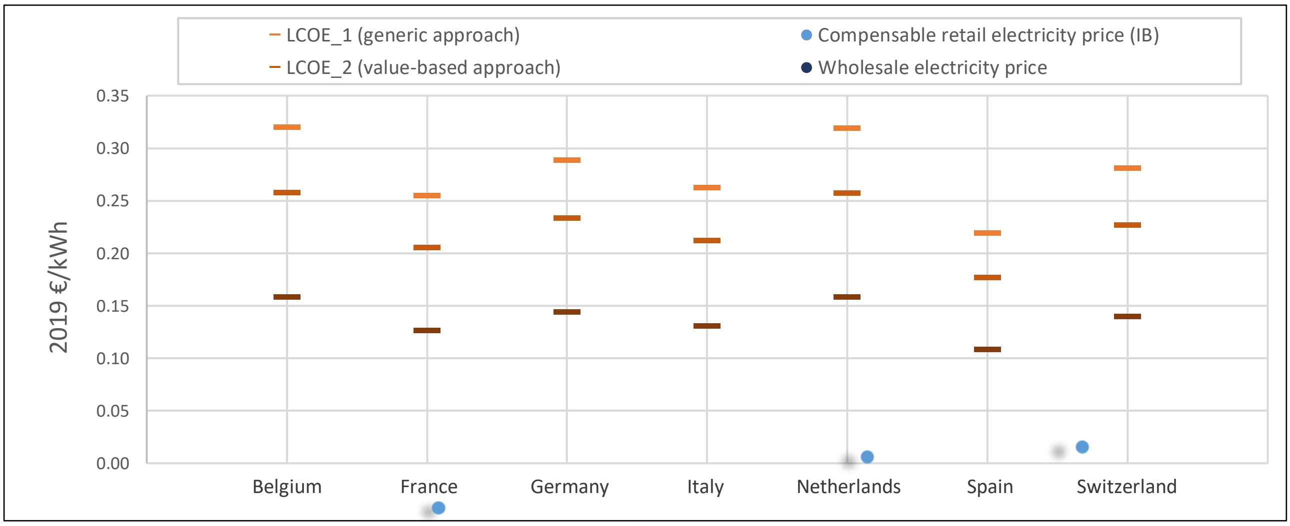

Figure 5.10 LCOE of reference case CB_a

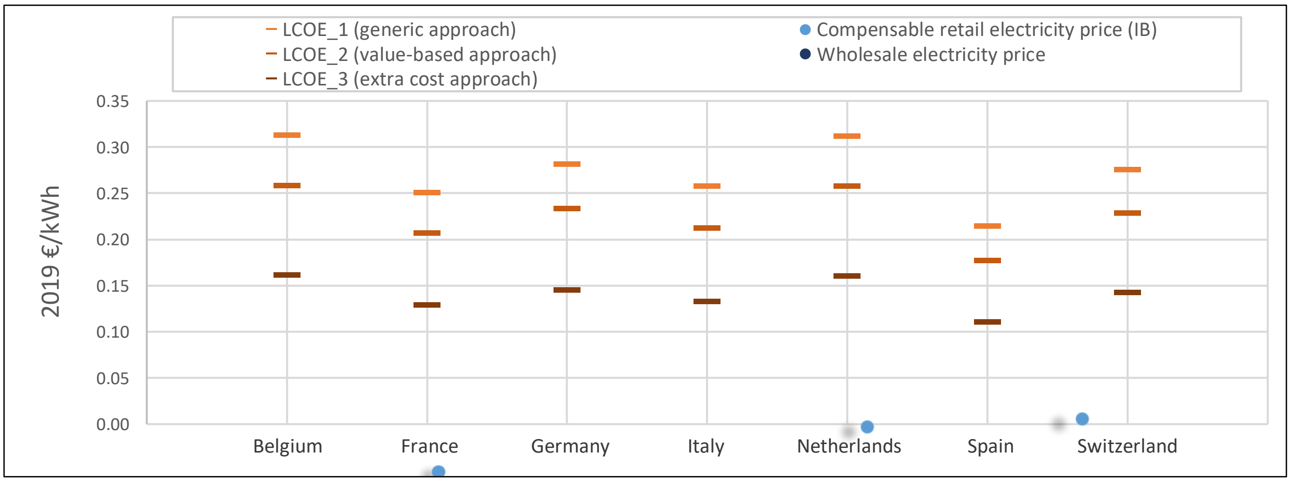

Figure 5.11 LCOE of reference case CB_b

Regarding the reference case of a **commercial building** equipped with a CIGS opaque facade cladding installation, looking at the LCOE values only, very few differences are noticeable compared to its equivalent on an educational building. Nevertheless, it must be noted that the compensable retail electricity prices have shifted down because they refer to those of the IB consumption band. Thus, harming the competitiveness of BIPV technology as an electricity generator. This change of benchmark is justified by the fact that commercial buildings are assumed to be heavier electricity consumer, hence benefitting from more attractive retail electricity prices. **The second commercial building** reference case, based on a mono cSi opaque façade cladding system, the same remarks as for case CB_a can be made. In all countries, LCOE_1 and LCOE_2 values are well above the compensable retail electricity prices. Looking at LCOE_3 values, they stand below compensable retail electricity prices in Germany, Italy and Spain, while standing slightly above it in Switzerland and France, and standing significantly above it in Belgium and the Netherlands. In other words, BIPV façade cladding solutions, no matter the PV cell technology considered, appear in majority as non-competitive electricity generating units.

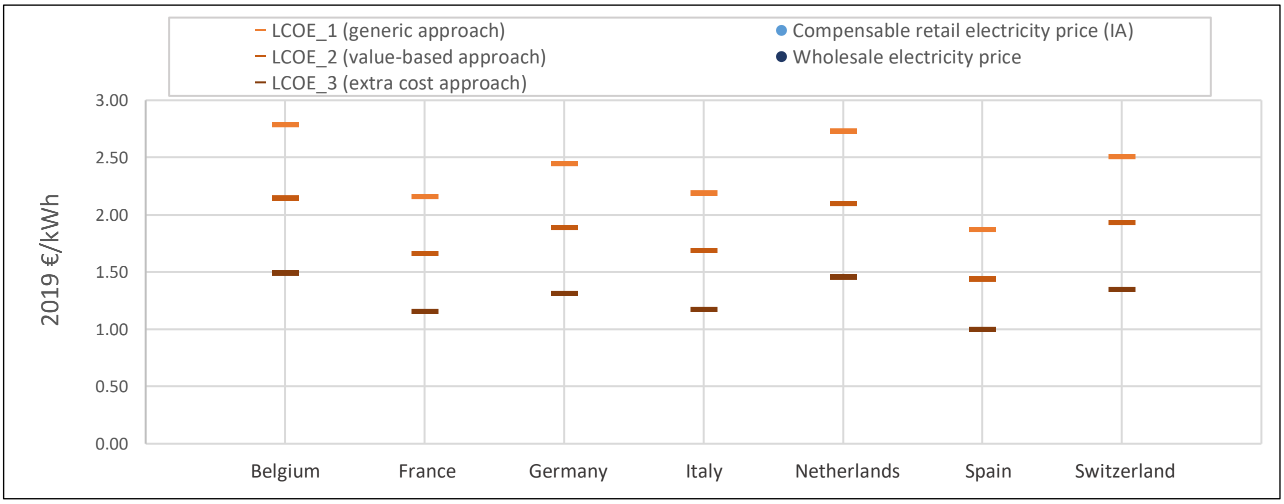

Figure 5.12 LCOE of reference case OB_a

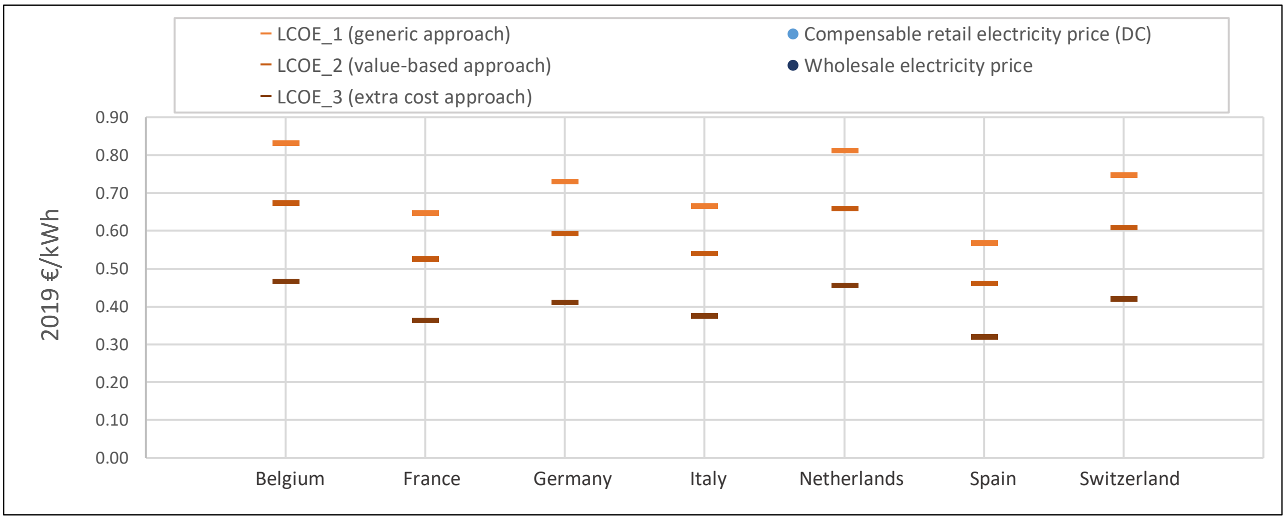

Figure 5.14 LCOE of reference case OB_b

On Figure 5.12 and Figure 5.13 are presented the result of the analysis of the **ninth and tenth reference cases**, respectively referring to an aSi-based semi-transparent curtain wall (OB_a) and its equivalent based on mono cSi cells (OB_b), installed on **an office building.** There, it can be noticed that the LCOE values have increased around tenfold compared to previous cases. Because of their transparency characteristics,30% for aSi and 50% for cSi, as presented in Section 3.4, the surface power densities of both systems are considerably lower than in the previous cases, making the yearly production drop dramatically and consequently the LCOE raise as, on the other hand, end-user costs remain relatively similar. Consequently, as shown on the two following figures, these two types of BIPV systems can clearly be characterized as non-competitive electricity generating units.

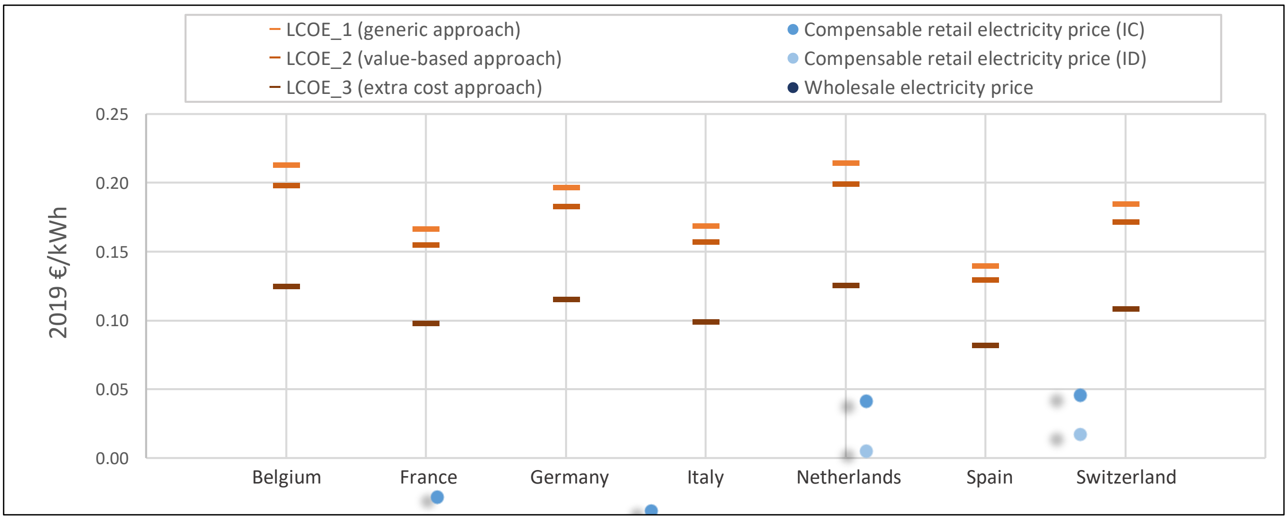

Figure 5.13 LCOE of reference case IB

Finally, in this **last reference case**, treating a BIPV roofing system made of steel plates with a CIGS layer, installed on an **industrial building**, LCOE_1 and LCOE_2 values are all above compensable retail electricity prices of both IC and ID consumption bands. For countries where these prices are quite low and/or where the variable share in the final retail electricity price is small, like Belgium, the Netherlands or France, the competitiveness of this technology as an energy generator is not reached, even when considering the LCOE based on the extra cost approach. Although, this is achievable in Italy, Spain, and in Switzerland and Germany, under certain conditions. This can be explained by the very competitive electricity prices enjoyed by heavy consumers, translated by the IC and ID consumption bands selected as benchmarks. In the case the building occupant is consuming less electricity and must pay retail electricity prices applicable in the IB band, competitiveness, at least considering LCOE_3, would be reached in all countries.

These results show that, as electric generating units, BIPV systems can be competitive. Indeed, the LCOE calculated under at least one approach (the extra cost approach) is inferior to the compensable retail electricity prices, in all countries for the three single family houses cases. For the multifamily housing, the educational, the commercial building and the industrial building (when the IC consumption band is considered), the LCOE does not always compete with the compensable retail price but the values are quite comparable. Then, for the office building, the LCOE outreaches by far the compensable retail price. Then, structural differences between countries can be noted, which can lead to situations where negatively impacting elements (such as low electricity prices, high fixed share of retail electricity prices or low irradiation) add up, as it is the case for the Netherlands. On the opposite, some countries combine multiple favourable factors, as it is the case in Italy. It must also be underlined that a LCOE value lying below the compensable retail price is not a sufficient condition to actually benefit from savings on the electricity bill. Indeed, sufficiently high self-consumption rates are also an underlying condition to benefit from those savings.

Finally, the competitiveness assessment, cannot be based on the LCOE analysis only, and further elements must be investigated. This will be developed in the following section.

6 TOTAL COST & REVENUES OF OWNERSHIP COMPETITIVENESS

In this final 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, permitting to obtain a metric in € of 2019. The final metric obtained is also converted in €/m², which is a metric more commonly used in the construction sector. 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 allow to earn on 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?

Note that, similarly to the methodology developed in section 5, a triple assessment is conducted for each reference case. A competitiveness assessment based on the total end-user cost. Then, to take into account the specific ability of BIPV to also fulfil the functionalities of a building component, a value-based assessment is conducted, through the inclusion of the "offset cost of conventional construction material" parameter. Finally, an approach based on the estimated extra cost of BIPV only is performed.

6.1 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. Eventually, the electricity price considered in the savings' calculation is called the compensable retail electricity price. To accurately define the latter, 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 5.16, 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 too profoundly impact the competitiveness evaluation.

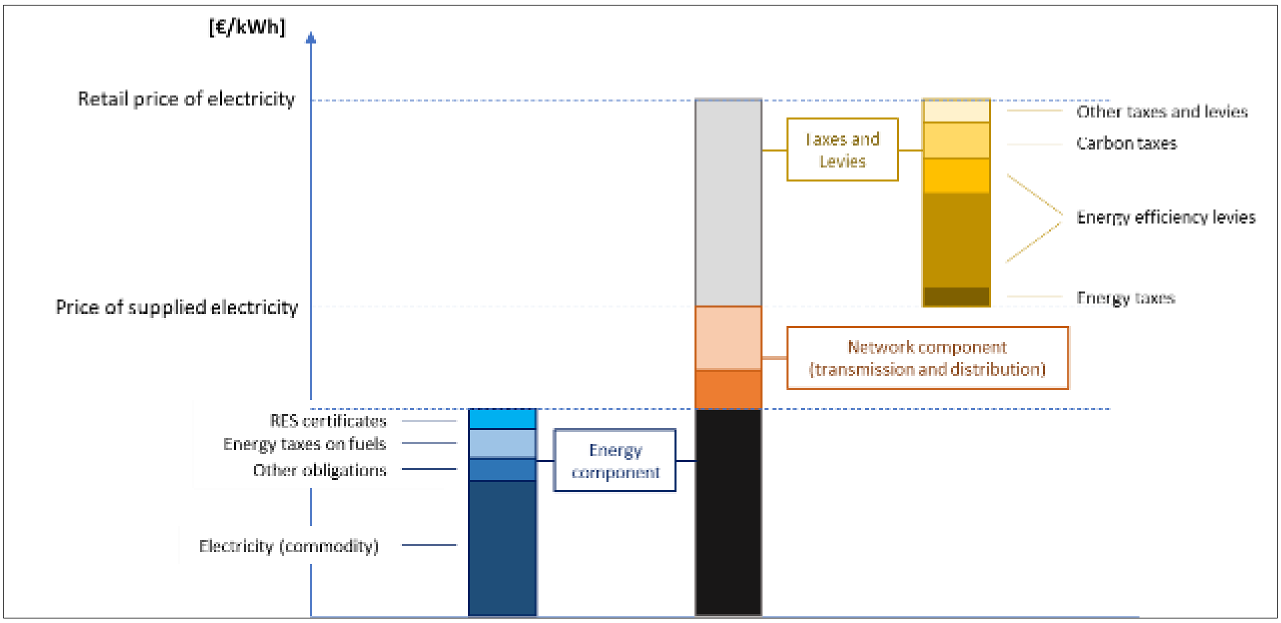

Figure 6.1 Schematic example of the typical structure of retail electricity price in Europe

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, five of them are considered. These are described in the table below.

Table 6.1 Selected consumption bands and their respective ranges of yearly electricity consumption

Consumption band	Lower yearly limit [MWh]	Upper yearly limit [MWh]
DC	2,5	5
IA	0	20
IB	20	500
IC	500	2000
ID	2000	20000

The DC band is applied in the case of residential buildings, single- or multi-family. The IA and IB bands are typically considered for small to medium non-household consumers, in function of their profile. Then, IC and ID bands are applied in the case heavy of consumers of electricity. In the case of occupancy by non-household consumers, the retail electricity price, and consequently the compensable retail price as well, is considered without VAT. Indeed, this share of the electricity bill can be recovered and should then not be as a revenue.

It is also worth mentioning that with the development of smart BEMS (Building Energy Management Systems), the revenues from the savings on the electricity bills will be optimised by means of load-shifting-based on time-of-use tariffs and power capacity peak-shaving.

Valuation of building component’s functionality

The previously presented notion of “offset cost of conventual construction material” is considered as a revenue realized in period 0, at the time of installation. The logic is that the expense usually linked to the conventional building components (e.g. tiles or façade cladding) is made unnecessary thanks to the installation of the BIPV system, which fulfils the same functions, and that it should be viewed as a revenue, in the same way that electricity bills savings are. Again, note that only the cost of the alternative construction material itself is taken into account in the "value-based" approach, other sources of cost such as labour or mounting systems are not considered. Although, a share of these additional source of costs are deduced of the initial end-user costs in the "extra cost" approach.

Incentives

Even if it is a decreasing trend, additional direct and indirect incentives are still granted to individuals or organizations 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" [21].

Total revenues

The sum of all sources of revenues can be summarized as follows:

$$PV(Total\ revenues\ on\ lifetime) = \sum_{n=0}^{N} \frac{Incentives_n}{(1+d)^n} + \sum_{n=1}^{N} \frac{Electricity\ Revenues_n}{(1+d)^n}$$

Where

- N is the total number of periods, i.e. years, during which the system will be operated;
- $Incentives_n$ is the amount, in €, received in year n as incentive;
- $Electricity\ Revenues_n$ is the amount, in €, earned thanks to the generated electricity (through electricity bill savings and the fed back electricity);
- *d* is the chosen discount rate, in our case the nominal WACC.

Note that if incentives are exclusively related to the valuation of non-self-consumed electricity, such as in the case of feed-in tariff or net-metering schemes, this equation can be simplified.

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 utilization of a BIPV system exist and have been already investigated by some researchers. [26] 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. [27] 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, to charge a premium in case of sale 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. [28]

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, as well as on the configuration of the system. [29] [30] [31]

6.2 Evaluation of project 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. Examples of these two accounting procedures are provided in Tables 6.2 and 6.3. 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, which can vary in function of the approach taken:
    - Simple approach:

      I = total end-user cost
    - Value-based approach:

      I = (total end-user cost – OCM). This offset cost of conventional construction material is calculated by multiplying the cost of the alternative building component to the total area occupied by the BIPV system.
    - Extra cost approach:

      I = (total end-user cost $*$ estimated share of BIPV extra cost)

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.

6.3 Results for reference cases

In order to assess the competitiveness of the chosen reference cases, this indicator has been calculated according to the previously explained methodology and displayed in the following charts.

As for the LCOE, the competitiveness has also been both computed using three different approaches. The first chart at the top, in each case, shows the results of the generic, i.e. based on the total end-user cost, and of the value-based methodologies. This results in a “competitiveness range”. The second chart at the bottom of each page is representing the results of the extra cost methodology. In addition, on this chart is also depicted the competitiveness range defined through the two first approaches, allowing to compare all results more efficiently, on a single chart.

Furthermore, as evoked previously, for each country and each approach, two business models are tested. The first one is the one applicable at the time of publication, according to the local regulation, for this specific segment of installed nominal power. It is referred to as the “classic” business model. The second one is the “wholesale” business model, relying on “unsubsidized” revenues, where no incentives or additional costs are considered. Revenues are exclusively related to electricity bill savings and sales of the non-self-consumed electricity production at the wholesale market price. A summary of used abbreviations is provided in Table 6.2 below.

Table 6.2 Summary of used abbreviations for business models

Business Model Abbreviation	Business model complete name
FIT	Feed-in tariff
FIP	Feed-in premium
GC	Green Certificates
MP	Market Premium
NB	Net-billing
NM	Net-metering
P	Premium
SDE	SDE Contribution
W	Wholesale market price

As a further element of analysis, the modified internal rate of return (MIRR) of the Project is represented along with the competitiveness, on all charts. Its value can then be compared to the discount rate used in each case to support or nuance the competitiveness results. 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. [32] In our calculation, we assume that the reinvestment rate is the WACC that has been computed for the BIPV project, in the relevant country. Ideally, this reinvestment rate should equal the WACC of the company, but this is not applicable as we are investigating generic reference cases.

For various reference cases, the payback times are also provided, in a summarizing table. When no table is provided, it means that the investment is not paid back on the estimated lifetime of the system, for the considered reference case.

Finally, a colour code has been used to provide an overview of the competitiveness values and ranges at a glance. It is summarised in Figure 6.2 below. As mentioned previously, 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 allow to earn on the lifetime of the system. Eventually, this holistic competitiveness metric can help answering this question: is it worth investing in such electricity generating construction material, compared to a conventional building component?

🟥 the competitiveness value or range is negative

🟨 the competitiveness ranges from a negative to a positive value

🟩 the competitiveness value or range is positive

Figure 6.2 Colour code used for the presentation of the competitiveness results

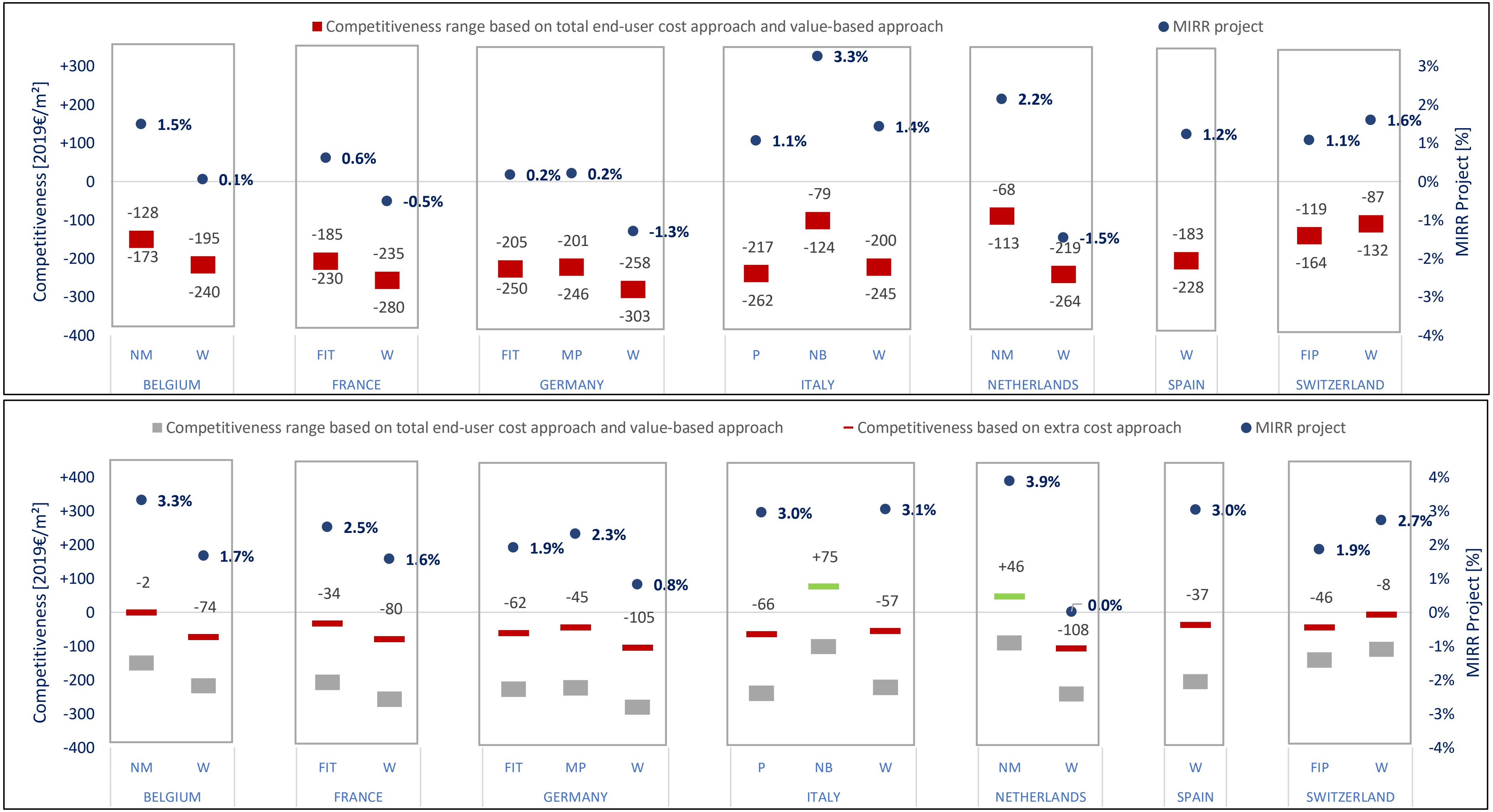

Figure 6.3 Competitiveness of reference case SFH_a

Figure 6.4 Competitiveness of reference case SFH_b

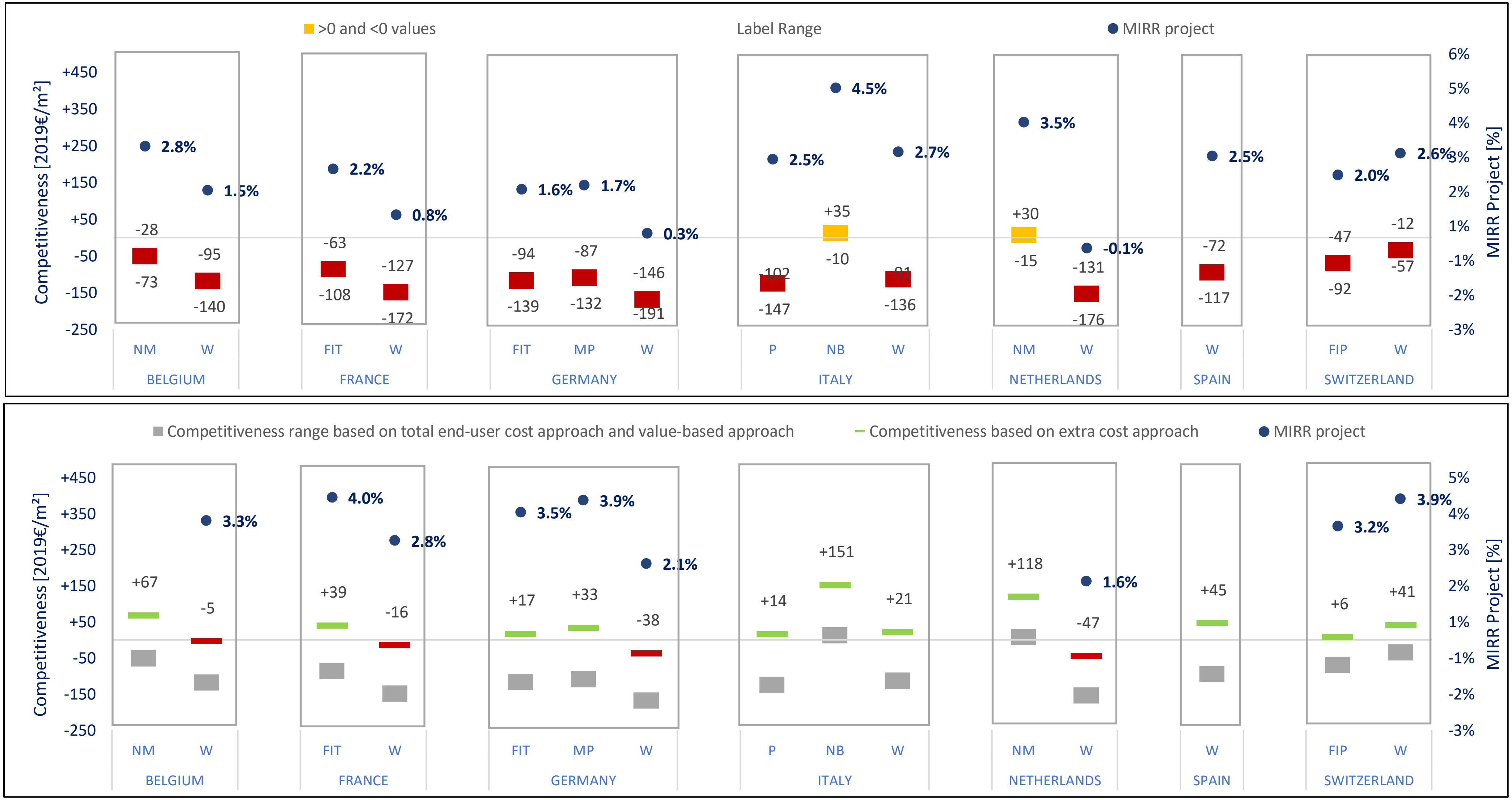

Figure 6.5 Competitiveness of reference case SFH_c

Tablec.3 Payback times, in years, of single-family housing reference cases (SFH_a, SFH_b and SFH_c)

		Belgium		France		Germany			Italy			Netherlands		Spain	Switzerland	
		Net-metering	Wholesale	Feed-in tariff	Wholesale	Feed-in tariff	Market Premium	Wholesale	Premium	Net-billing	Wholesale	Net-metering	Wholesale	Wholesale	Feed-in premium	Wholesale
SFH_a	Value-based	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!
	Extra cost	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	14	Not paid back!	12	Not paid back!	Not paid back!	Not paid back!	Not paid back!
SFH_b	Value-based	13	Not paid back!	19	Not paid back!	Not paid back!	26	Not paid back!	Not paid back!	9	27	8	Not paid back!	23	21	12
	Extra cost	7	12	5	10	10	9	19	9	4	8	4	Not paid back!	8	10	6
SFH_c	Value-based	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	19	Not paid back!	14	Not paid back!	Not paid back!	Not paid back!	Not paid back!
	Extra cost	11	Not paid back!	13	Not paid back!	21	19	Not paid back!	23	7	18	7	Not paid back!	15	21	11

Generic and value-based approaches

On the three first reference cases belonging to the residential sector, three different BIPV roofing systems technologies are analysed: solar tiles based on mono cSi (SFH_a), in-roof mounting system based on multi cSi (SFH_b) and full roof solution based on CIGS (SHF_c). The charts displaying their respective competitiveness results demonstrate a similar pattern, with relatively close to competitiveness values. Nevertheless, depending on the reference case chosen, the magnitude varies. The highest values are reached in the case SFH_b with eight out of fifteen cases which are competitive, while the lowest ones are found in case SFH_a.

Turning to a more detailed analysis of the observed pattern, it is relevant to distinguish the classic business models, specific to each country, and the wholesale business model.

First, among the country-specific business models, the net-billing scheme in Italy and to a lesser extent the net-metering business model in Belgium and in the Netherlands, turn out to be the most advantageous ones. Indeed, an impressive 9 years payback time can be noticed for the net-billing business model. This can go up to 19 years when the SFH_c case is considered under the value-based approach. In the case of the premium business model, the payback periods ranging from 9 to 23 years for reference cases SFH_b and SFH_c are also satisfactory for a building component. For SFH_a, the pay back times exceed the system lifetime in all considered country and business model combinations. The explanation is plural, originating from a mix of diverse favourable factors: high irradiation, generous fed-back valuation and higher than average compensable retail as well as wholesale market prices. The Belgian case relying on a net-metering scheme is also among the most competitive ones. This result can be especially highlighted since among the three[4] possible regional situations, the case of Flanders was selected, which is the less favourable, as no direct incentive exists, and an annual prosumer tariff is plumbing the revenues. On the contrary, countries such as France, Germany or the Netherlands show lower competitiveness values. This can be explained by lower valorisation of fed-back electricity, higher fees and charges, and/or fewer solar irradiance. In France and the Netherlands, the low compensable retail electricity price also plays a significant role, even if it is limited by the self-consumption rate of only 30%. This trend is even more true for the wholesale market business model.

When it comes to the wholesale market business model, supposedly a less advantageous model, one exception can be noticed. In Italy, since the guaranteed premium is lower than the average wholesale market price, the same result can be seen. In Spain, the wholesale business model also appears as an interesting framework as the wholesale market price is the highest of the seven countries and as for small systems (<10 kW installed capacity), grid fees do not apply. A significant difference can be noticed between the competitiveness under the wholesale business models in Germany and in Belgium even though the main set parameters are similar or equal (solar irradiation, self-consumption rate, compensable retail electricity price, …). This difference can be attributed to the EEG fee that applies in Germany and not in Belgium, which demonstrates how this fee burdens the competitiveness values.

As far as the MIRR Project is concerned, each positive competitiveness is associated to a MIRR Project bigger than the nominal discount rate of 2% considered, thus underlying the competitiveness.

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[4] Flanders, Brussels and Wallonia, each of these regions independently defining its own energy legislation

Extra cost approach

The second charts show that if an extra cost approach is taken, the number of competitive reference cases and their associated technologies is important. The payback times are also, in all cases, much shorter when the extra cost approach is considered. In very few cases, they can be as low as 4 to 5 years.

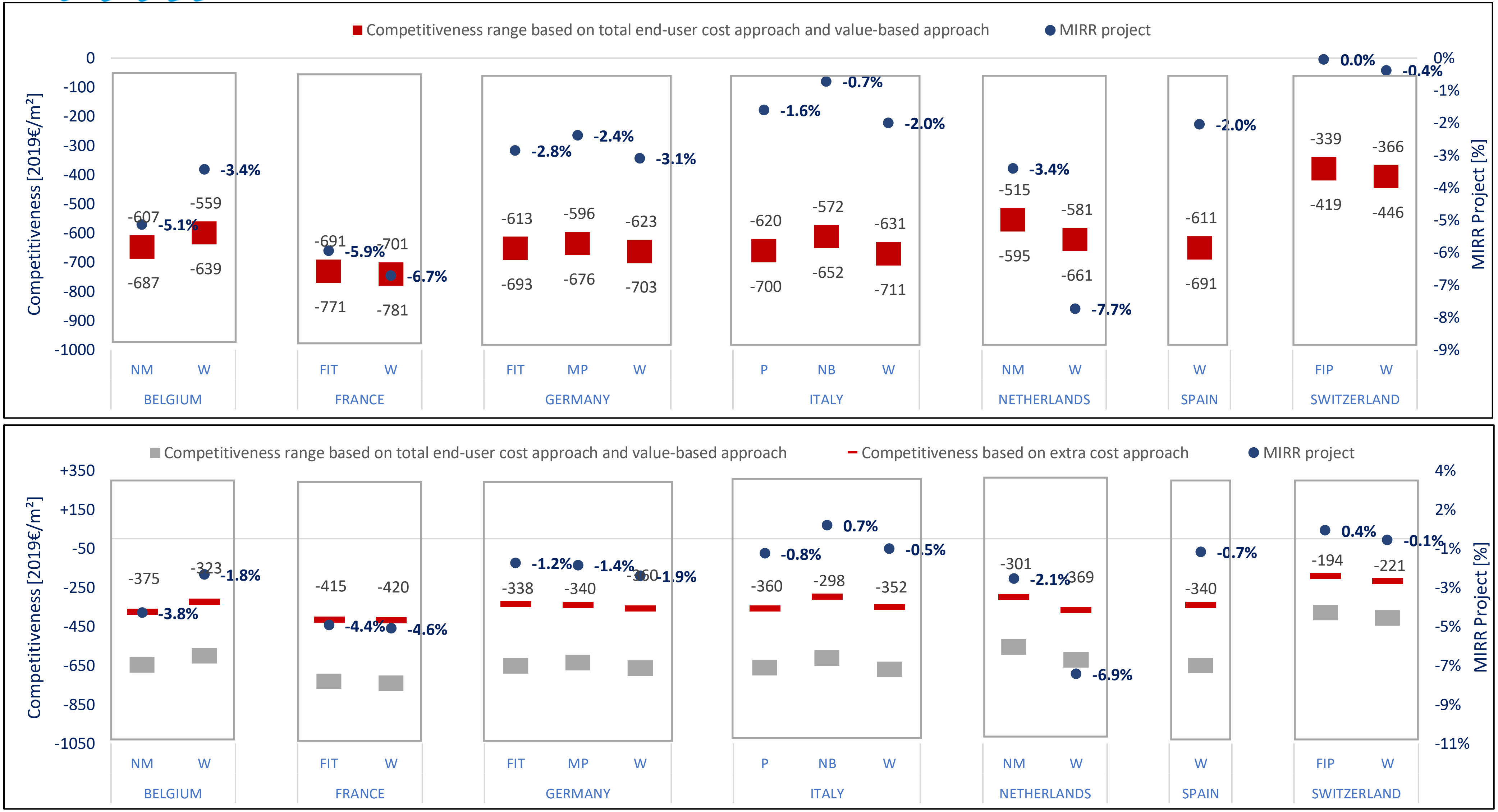

Figure 6.6 Competitiveness of reference case MFH

Generic and value-based approaches

For the fourth and last residential case, the analysis of competitiveness results in very low values overall and the investigated BIPV system, i.e. façade cladding with insulation, based on mono cSi (IBC), is never competitive, no matter the considered approach. The reason for that is a two to three times more expensive technology and lower yields because of their 90° inclination. Looking more in details to each case and business model, the general shape of the pattern is quite similar to the single-family housing cases. Nevertheless, some differences can be noticed. Indeed, in the case of France for example, the gap between the two business models has diminished. As the installed capacity has grown from 6-7kW to almost 50kW, a new and less attractive feed-in tariff level applies. In Belgium, because the yield is quite low (531 kWh/kW$_p$), the electricity production is harmed. Therefore, the prosumer tariff becomes a more influencing parameter. As in the wholesale market business model this tariff is not taken into account, it reveals to be more attractive.

Extra cost approach

Even when we only consider the extra cost of BIPV, results of the competitiveness assessment do not turn out positive, maintaining the fact that this reference case associated to its technology is still far from being competitive.

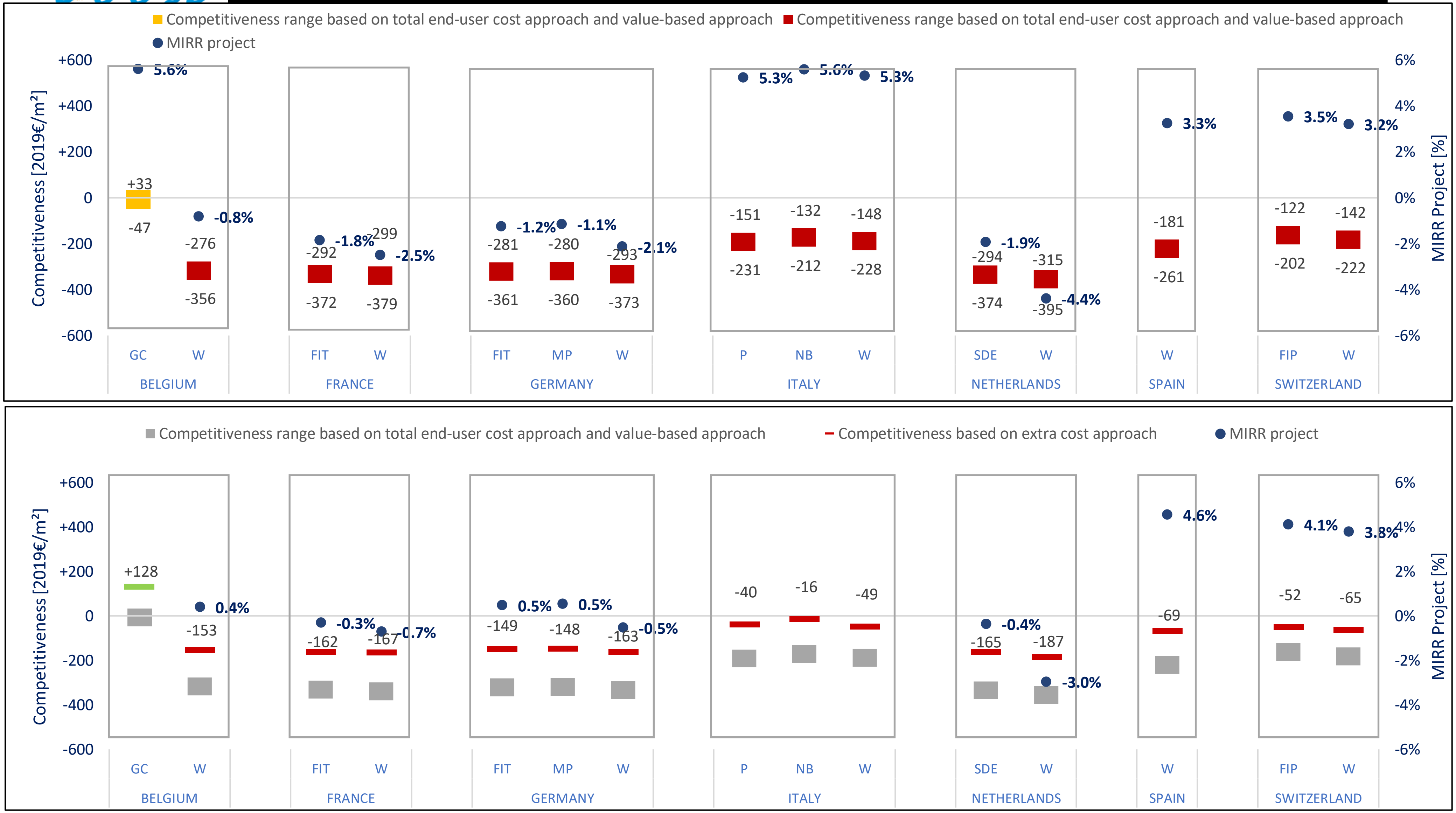

Figure 6.7 Competitiveness of reference case EB_a

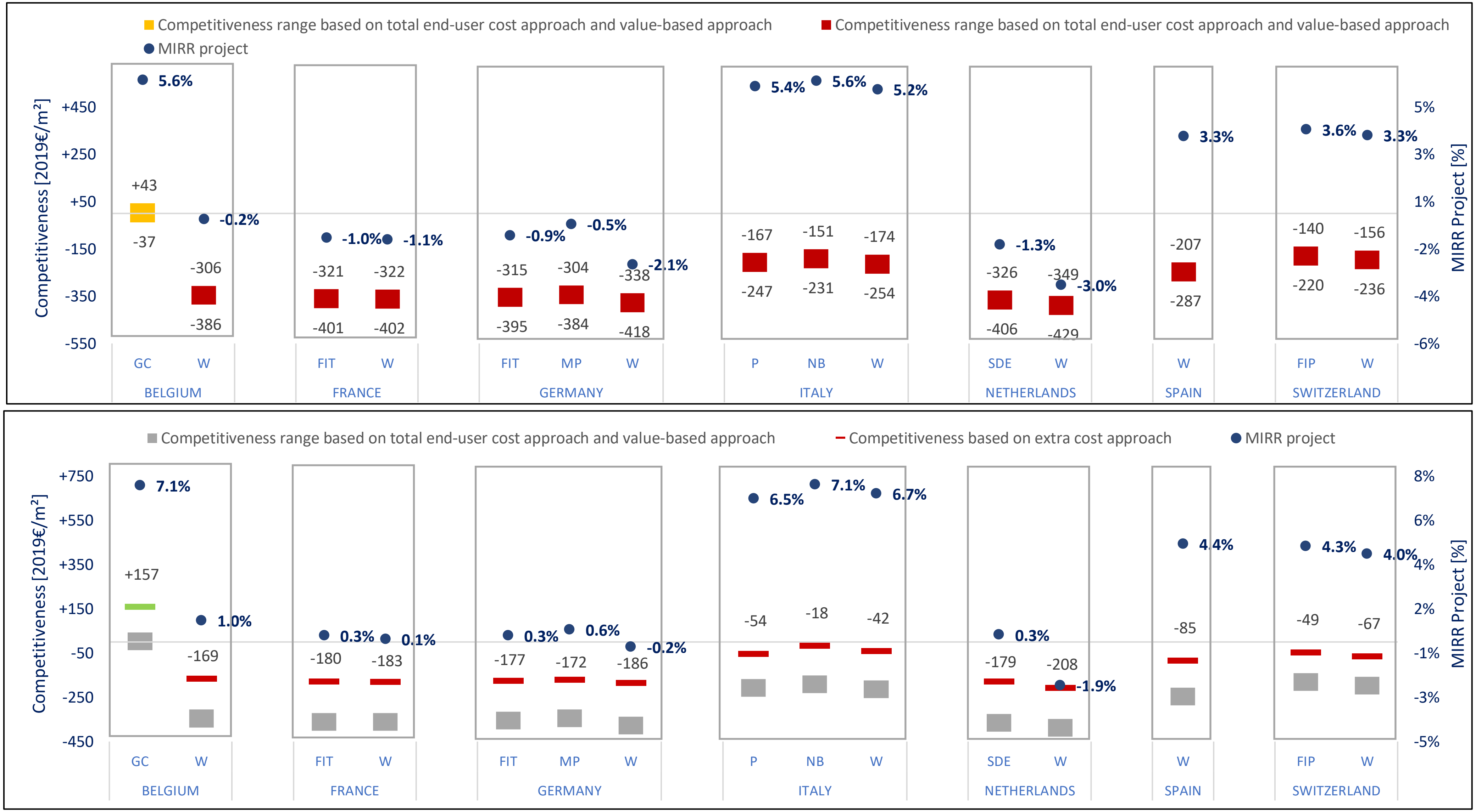

Figure 6.8 Competitiveness of reference case EB_b

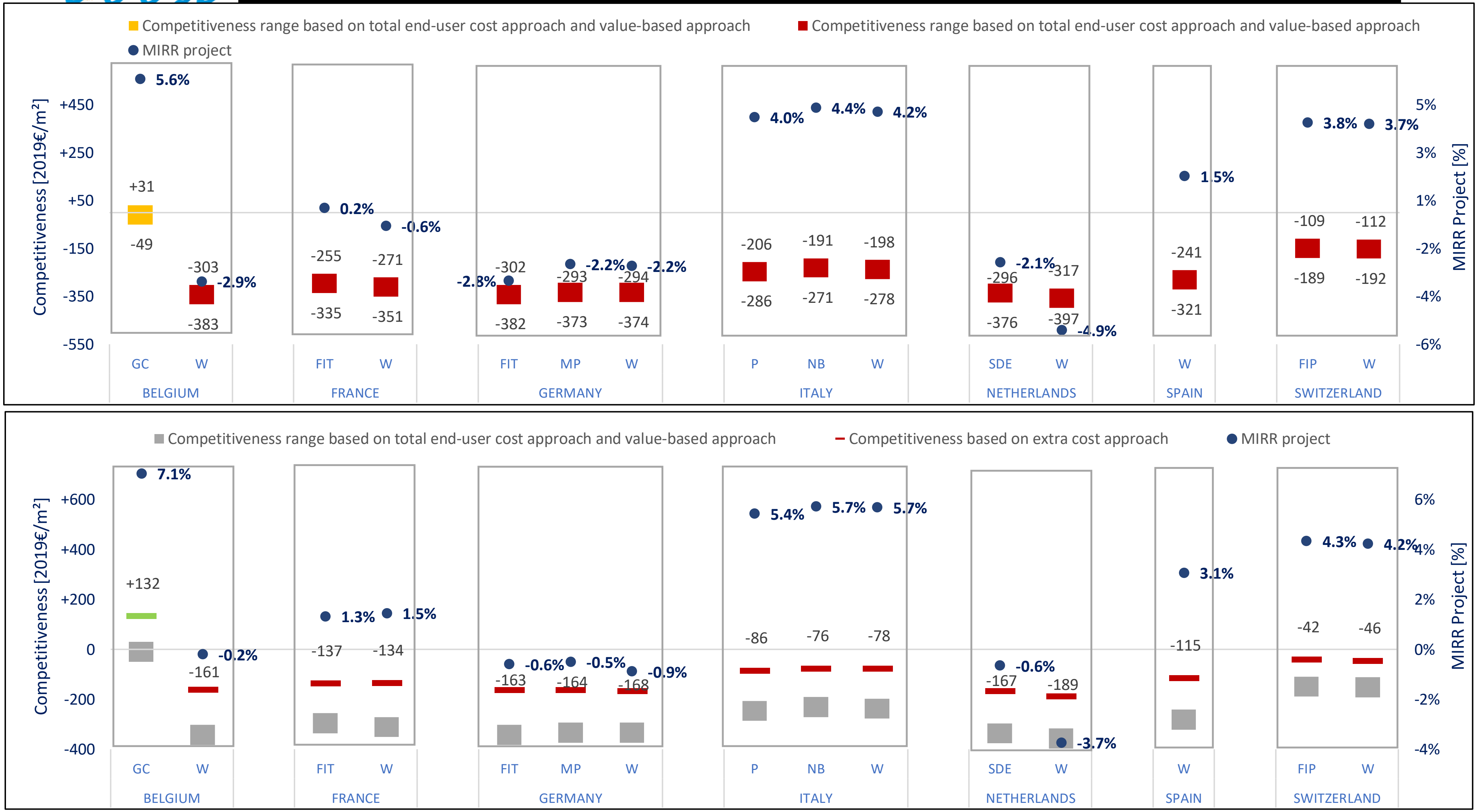

Figure 6.9 Competitiveness of reference case CB_a

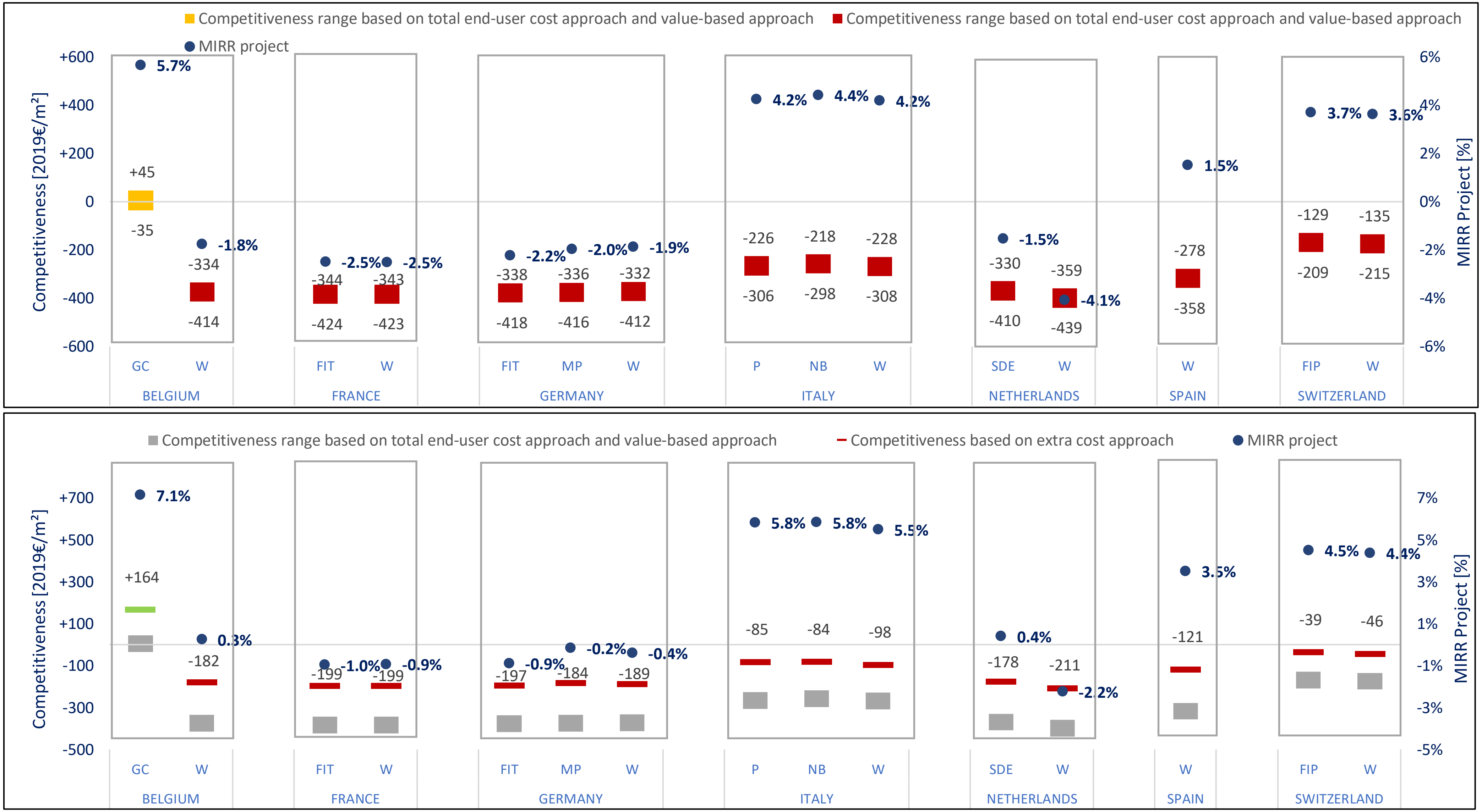

Figure 6.10 Competitiveness of reference case CB_b

Table 6.4 Payback times, in years, of reference cases EB_a, EB_b, CB_a and CB_b

		Belgium		France		Germany			Italy			Netherlands		Spain	Switzerland	
		Green Certificates	Wholesale	Feed-in tariff	Wholesale	Feed-in tariff	Market Premium	Wholesale	Premium	Net-billing	Wholesale	SDE Contribution	Wholesale	Wholesale	Feed-in premium	Wholesale
EB_a	Value-based	26	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!
	Extra cost	15	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!
EB_b	Value-based	25	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!
	Extra cost	15	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!
CB_a	Value-based	26	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!
	Extra cost	15	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!
CB_b	Value-based	26	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!
	Extra cost	15	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!

Generic and value-based approaches

Following the residential sector, the sector of tertiary buildings is investigated, with the reference cases focusing on educational and commercial buildings.

When it comes to the educational building's reference cases under the two first approaches, except for Belgium, all competitiveness values lie under the zero axes. Indeed, the Green Certificate scheme in Belgium offers a very profitable remuneration which adds to an already relatively high fed-back value, at the wholesale market price, compared to other countries. In addition, the high compensable retail electricity price for IA consumption band allows generous savings on the electricity bill, as in this case a self-consumption rate of 70% is considered. This results in payback times equalling approximately 25 years depending on the reference case taken. Other cases, such as the business model based on net-billing in Italy, feed-in premium in Switzerland or the wholesale market business model in Spain remain close to competitiveness although it does not appear sufficient to pay the investment before the end of its operating lifetime. This can be respectively explained by a favourable fed-back value and by a high wholesale market electricity price. In addition to that, all three countries have quite high retail electricity prices, thus allowing comfortable savings on the electricity bill.

Concerning the commercial building's reference cases, there are a lot of similarities with the EB_a and EB_b reference cases with Belgium being the only competitive case. Although, overall competitiveness results are further away from the positive threshold than in the educational building reference cases. Indeed, in countries where competitiveness was close to zero, new and lower compensable retail electricity apply since the IB consumption band is now used as an assumption. Consequently, savings on electricity bills are reduced. This effect is particularly noticeable in Spain, as retail electricity prices drop by 100% from one consumption band to another.

When it comes to the MIRR of the project, each Belgian competitive case goes along with a MIRR Project higher than the nominal WACC (5,28% in Belgium). On the contrary, almost competitive cases in Italy or in Spain, are linked to a MIRR Project smaller than the nominal WACC (respectively 7,41% and 6,01%) underlying the weakness of the competitivity.

Extra cost approach

By taking an extra cost approach, competitiveness is almost achieved in Italy, Spain and Switzerland. In Belgium the pay back times reach 15 years. But for the remaining cases, taking this further approach is not sufficient to become competitive.

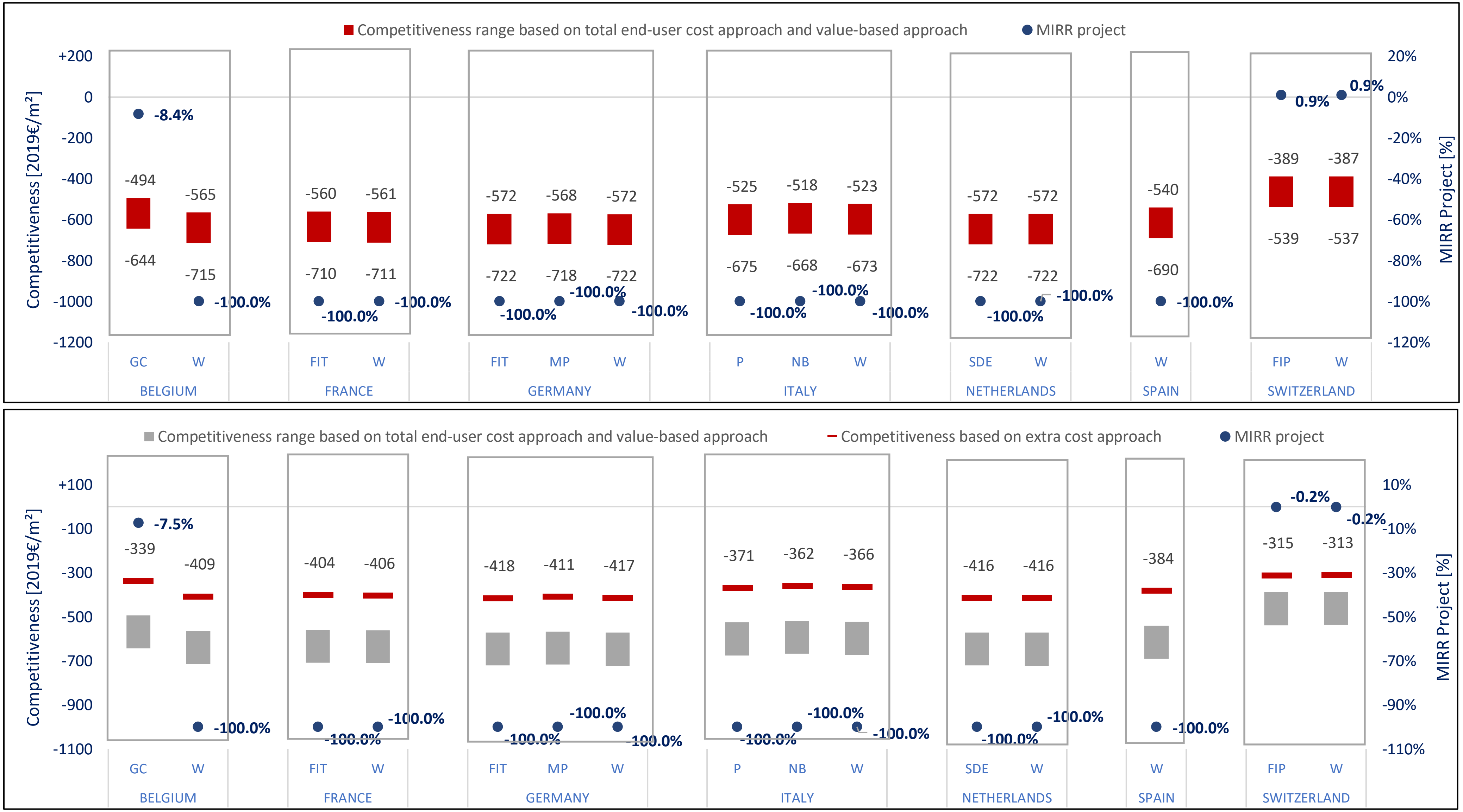

Figure 6.11 Competitiveness of reference case OB_a

Figure 6.12 Competitiveness of reference case OB_b

Generic and value-based approaches

On the two previous pages are depicted the results of the ninth and tenth reference cases, dealing with semi-transparent curtain walls based on aSi and mono cSi PV technologies. All competitiveness results have plummeted towards values between -400 and -700 €/m² and the payback times are always longer than the system lifetime. These are especially negative when the reference case OB_a, based on aSi, is considered. Even the very advantageous remuneration scheme in Belgium did not cope with the very low efficiency of the given technologies. Regarding the MIRR Project values, the very low competitiveness in the OB_a reference case does not allow to compute a realistic MIRR value between -1 and 1. Therefore, the default value of -100% is displayed.

Extra cost approach

As mentioned above, given the very little efficiency values, even the extra-cost approach does not allow to near competitiveness.

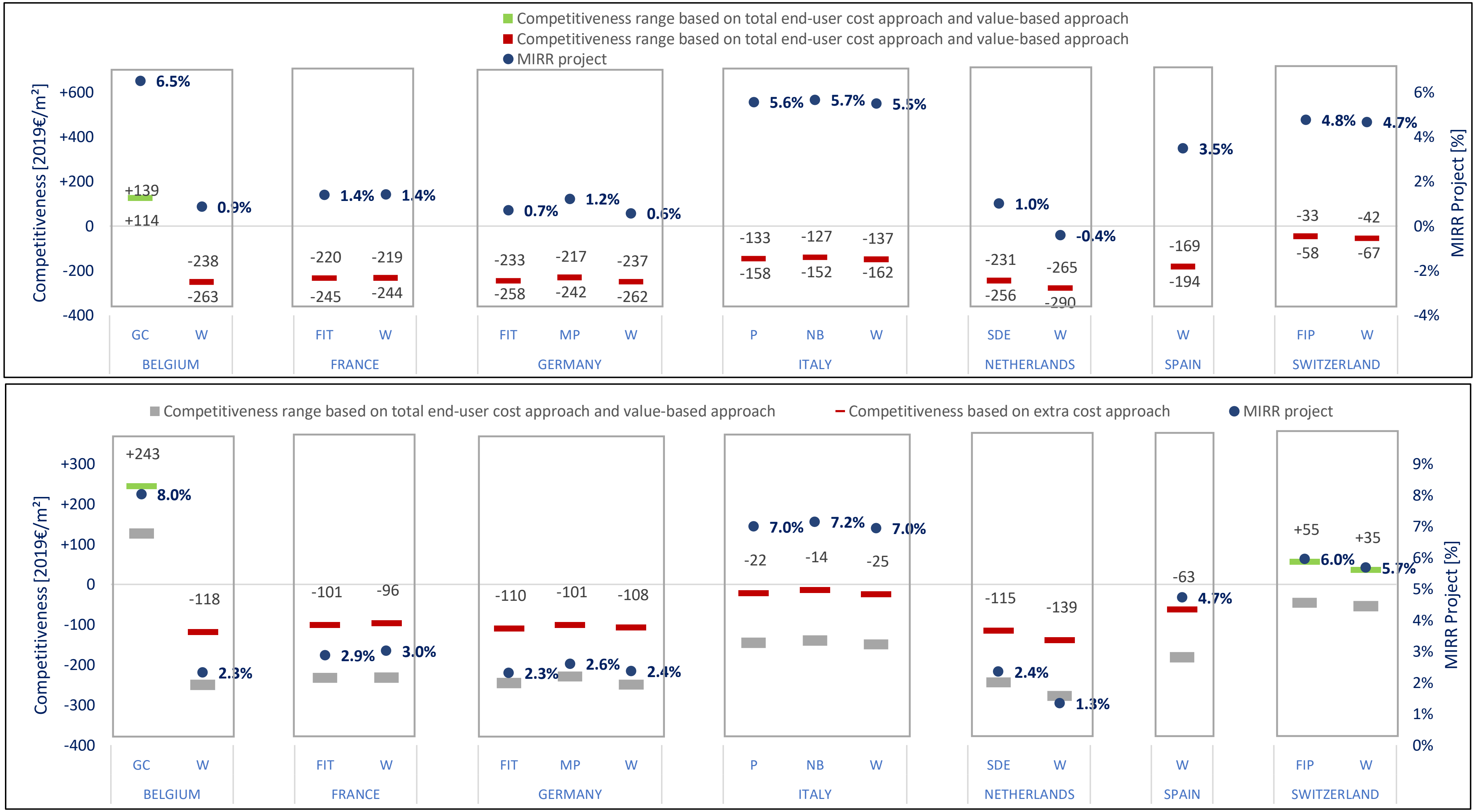

Figure 6.13 Competitiveness of reference case IB (IC consumption band)

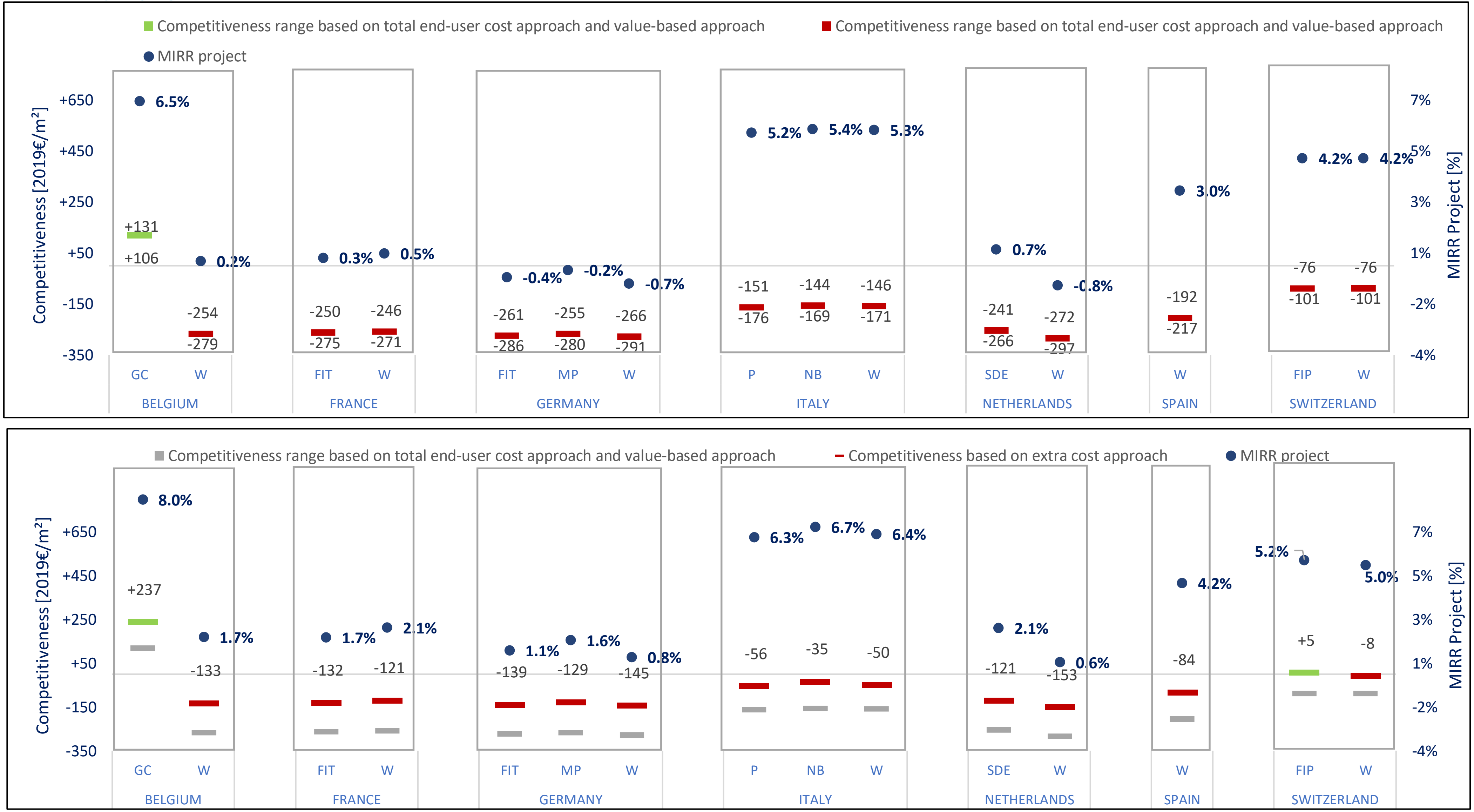

Figure 6.14 Competitiveness of reference case IB (ID consumption band)

Table 6.5 Payback times, in years, of reference case IB for the consumption bands IC and ID

		Belgium		France		Germany			Italy			Netherlands		Spain	Switzerland	
		Green Certificates	Wholesale	Feed-in tariff	Wholesale	Feed-in tariff	Market Premium	Wholesale	Premium	Net-billing	Wholesale	SDE Contribution	Wholesale	Wholesale	Feed-in premium	Wholesale
IB (IC)	Value-based	17	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!
	Extra cost	11	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	15	16
IB (ID)	Value-based	18	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!
	Extra cost	11	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	Not paid back!	23	Not paid back!

Generic and value-based approaches

This last reference case focusing on an industrial building deals with a roof application thus allowing higher yields, lower costs and therefore better competitiveness results. Nevertheless, this favourable framework is offset by two main factors. First, because the building occupant is assumed to be a heavy consumer, retail prices of electricity lies in the IC or ID consumption band. Hence, savings on the electricity bills are limited, even though the self-consumption rate is set to 90%. This can be confirmed by the fact that the results are slightly better in the case of IC consumption band, where compensable retail prices are slightly higher compared to the ID consumption band. Secondly, the high self-consumption rate implies that only a small amount of electricity is fed back to the grid. Therefore, it is not possible to fully take advantage of potential fed-back electricity remuneration’s schemes, even if they are attractive.

As far as Germany is concerned, particularly low values can be observed for the feed-in tariff as well as the wholesale business models. The reason for these values is that the upper installed capacity limit of 100kW to be entitled a feed-in tariff is reached as in the industrial case 180 kW are installed. As for the wholesale business model, Germany has the lowest wholesale electricity price of the seven countries, thus explaining the low competitiveness value.

It can also be added about the relatively good results in Belgium with around 17 years payback period under the value-based approach, that the MIRR Project is bigger than the nominal WACC in this country.

Extra cost approach

Taking an extra cost approach improves the competitiveness results in Italy, in Spain, in Switzerland and in Belgium. Payback time is also improved with 11 years in Belgium and 15 to 23 years in Switzerland. As far as the other countries are concerned, this approach does not change the big picture and the cases remain largely uncompetitive.

7 COST COMPETITIVENESS 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 in terms of end-user cost decreases are needed to achieve 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. A further analysis building on the extra cost evaluation, presented in Section 5.4, allows to determine to what extent the required reduction of end-user costs might have to come from BIPV-related costs.

The figure below and the associated paragraph describe in more detail what information can be drawn from each of the following cost target charts and how they can be interpreted.

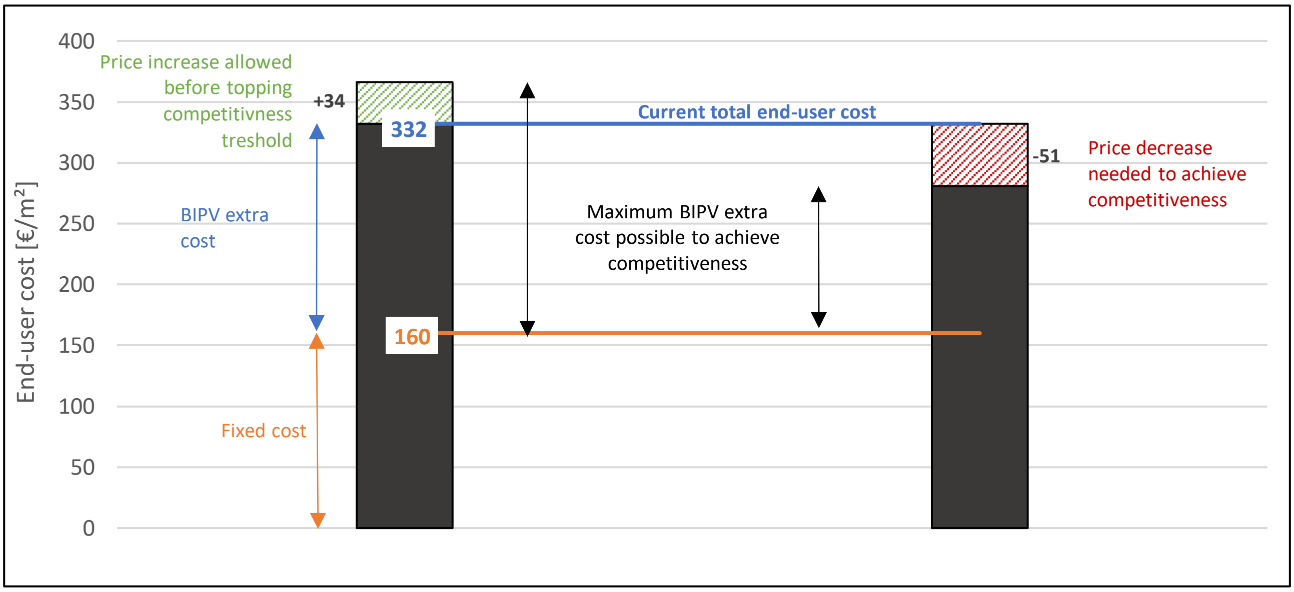

Figure 7.1 Explanatory figure for target end-user cost charts

For each reference case, a straight **blue line** is drawn, indicating the current average total end-user cost of the considered BIPV system. In addition, for every country and business model combination, a histogram presents the maximum total end-user cost that can be reached before the case becomes uncompetitive. This maximum is the cost target to aim at. Furthermore, an indication is also given on the repartition, within this total end-user cost, between fixed costs and the estimated maximum BIPV extra costs allowed in order to respect this threshold. Then, if the current end-user cost (the blue line) is lower than the target end-user cost (the histogram), the latter is represented as a **black column** amounting to the end-user cost value, topped with a **green hatched column**. This hatched area represents the end-user cost increase potentially allowed until the competitiveness threshold is reached, as shown on the left of Figure 6.1. If the current end-user cost is higher than the target end-user cost, the target is represented as a black column topped with a **hatched red area.** This area shows the end-user cost decrease necessary to achieve competitiveness, as shown on the right of Figure 7.1. As presented in Section 5.4, the total end-user cost of BIPV solutions is composed of two main parts: a fixed cost and an extra cost due to BIPV characteristics. These shares depend on the chosen reference case[5]. These two composing elements of the total end-user cost are respectively represented on Figure 6.1 with a **yellow and a blue double arrow**. Due to their nature, it is assumed that t**he estimated fixed costs do not have much room for decrease**, if any at all. Still, some cost items such as packaging or transport could be potential sources of improvement, even if it is limited. Therefore, **the decrease of the total end-user cost will have to be majorly covered by the BIPV extra cost** part. Based on these considerations, the maximum BIPV extra cost that should be aimed at, in order to reach competitiveness, can be deduced. This is shown on the graph with **a black double arrow**.

Note that there is of course a direct correlation between the results of the competitiveness analysis and the end-user cost targets presented here. A highly competitive case allows higher end-user cost, while on the contrary an uncompetitive case would need the end-user cost to decrease in order to become competitive.

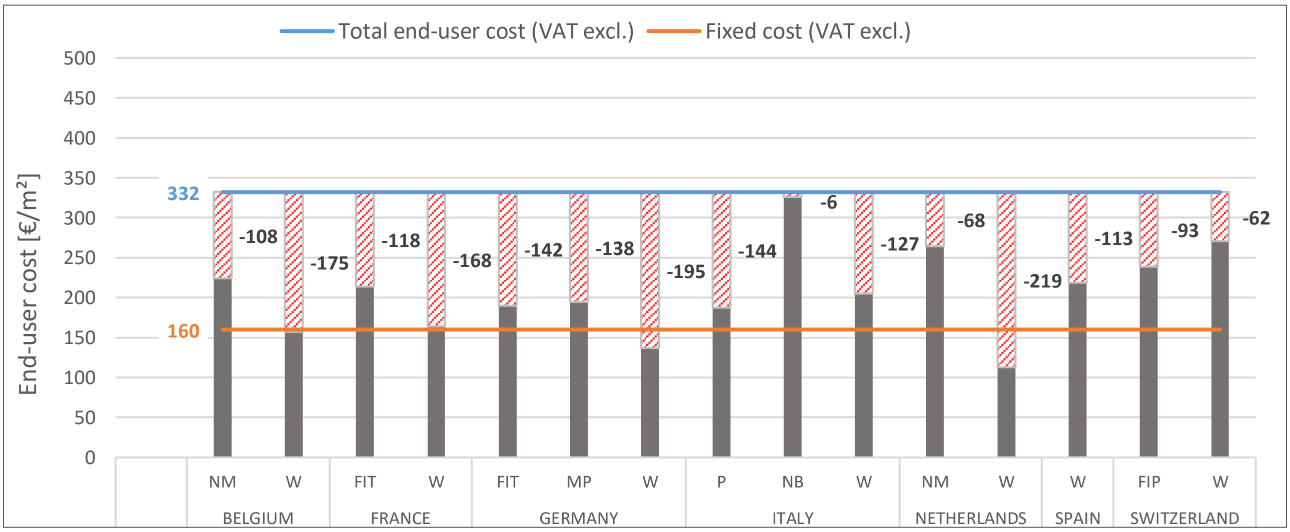

Figure 7.2 End-user cost target of reference case SFH_a

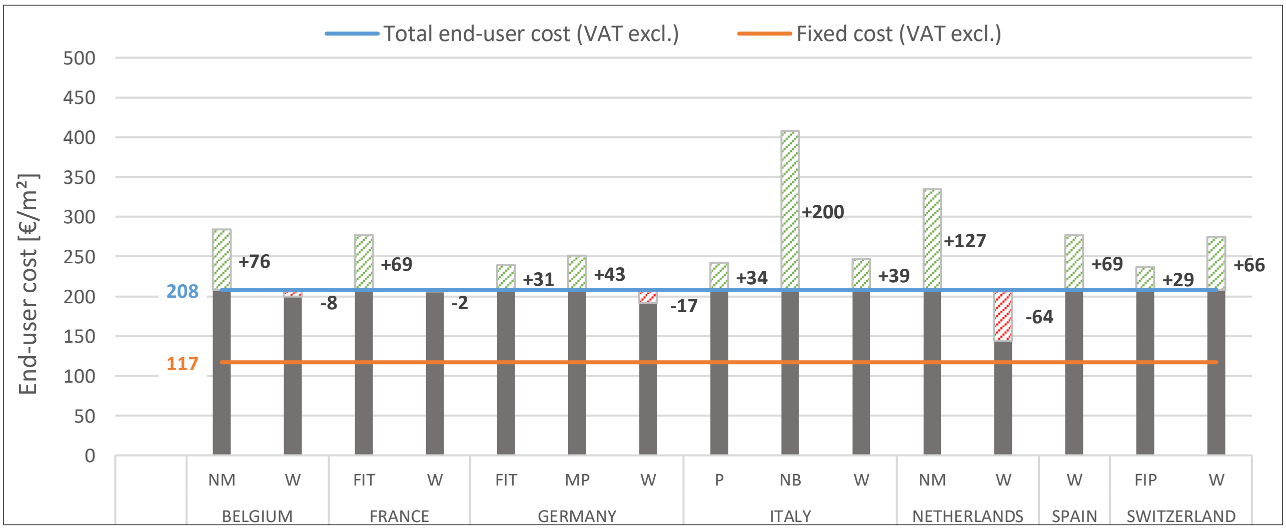

Figure 7.3 End-user cost target of reference case SFH_b

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[5] As evoked already, these shares are estimations, based on the typical cost structure of various studied reference cases, representative of the situation as of today. By definition, these estimations are not frozen and can certainly vary from one country or project to another. They will also likely evolve in the future.

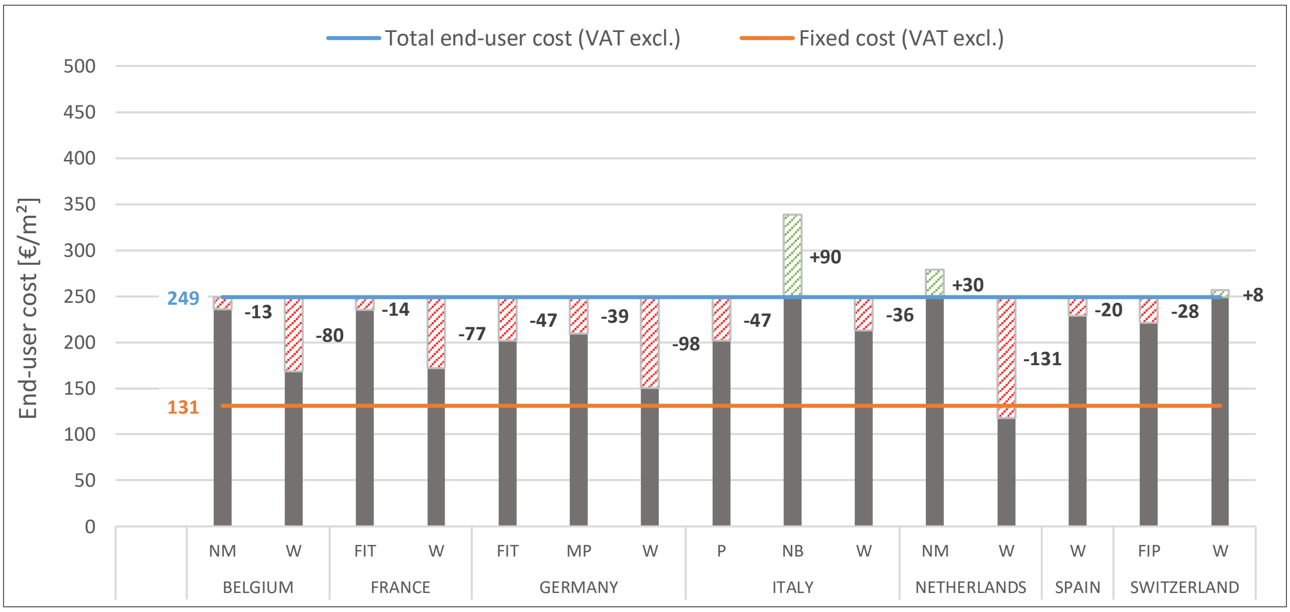

Figure 7.4 End-user cost target of reference case SFH_c

Overall, in these three first residential cases, an important number of end-user cost targets are already achieved and by far for some very competitive cases such as the net-billing business model in Italy. For the SFH_a reference case, some additional efforts concerning are required. However, as the required end-user cost decreases are quite comparable to or smaller than BIPV extra cost, the targets can often possibly be achieved by only partially reducing the extra cost due to BIPV. For the two remaining cases, namely the wholesale model for the Netherlands, Belgium and Germany, the needed end-user cost decreases exceed, or are close to, the estimated BIPV extra cost. Therefore, the target can only be reached if the fixed costs also diminishes, in addition to the extra cost due to BIPV. Nonetheless, given the fact that the cost targets for the classic business models are already achieved, or can be achieved with limited difficulty, competitiveness under these three wholesale business models appears as not crucial the attractiveness of the analysed BIPV solutions.

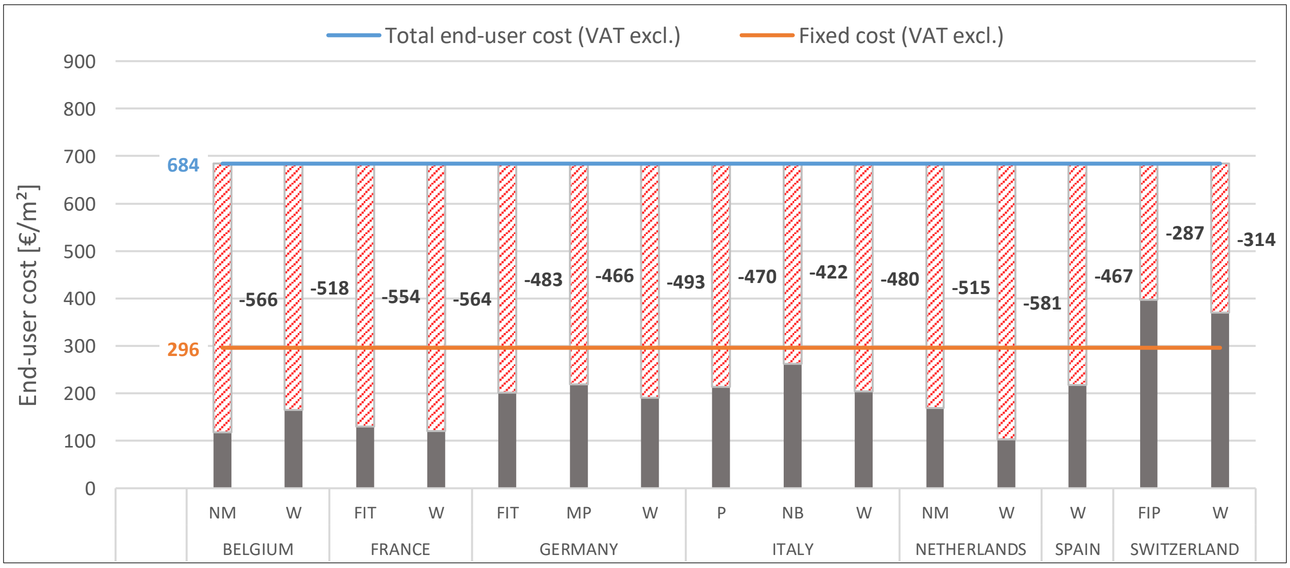

Figure 7.5 End-user cost target of reference case MFH

In line with the results found for competitiveness values, the end-user cost targets for MFH reference case are realistically unachievable. Indeed, their values are close to or even under the fixed cost value meaning that in order to achieve competitiveness there should be no or nearly no BIPV extra cost and even, for the cases with the lowest competitiveness results, a decrease of the fixed costs. Consequently, the reduction of the CAPEX cannot be the main and only lever to achieve competitiveness for the MFH reference case. Other aspects, such as module efficiency must imperatively be improved as well, in order to bring the competitiveness metric to positive values.

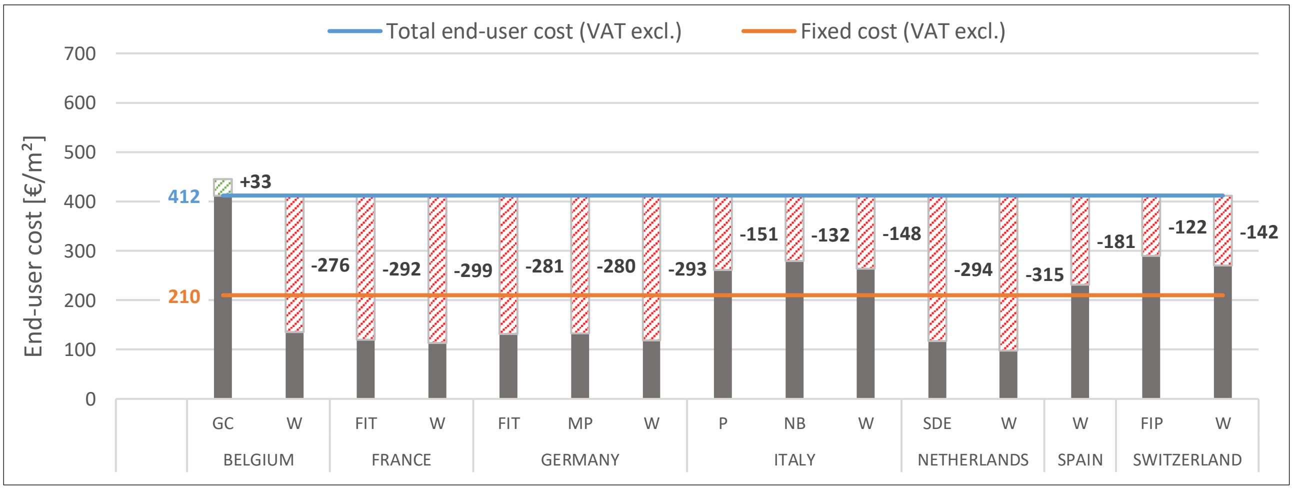

Figure 7.7 End-user cost target of reference case EB_a

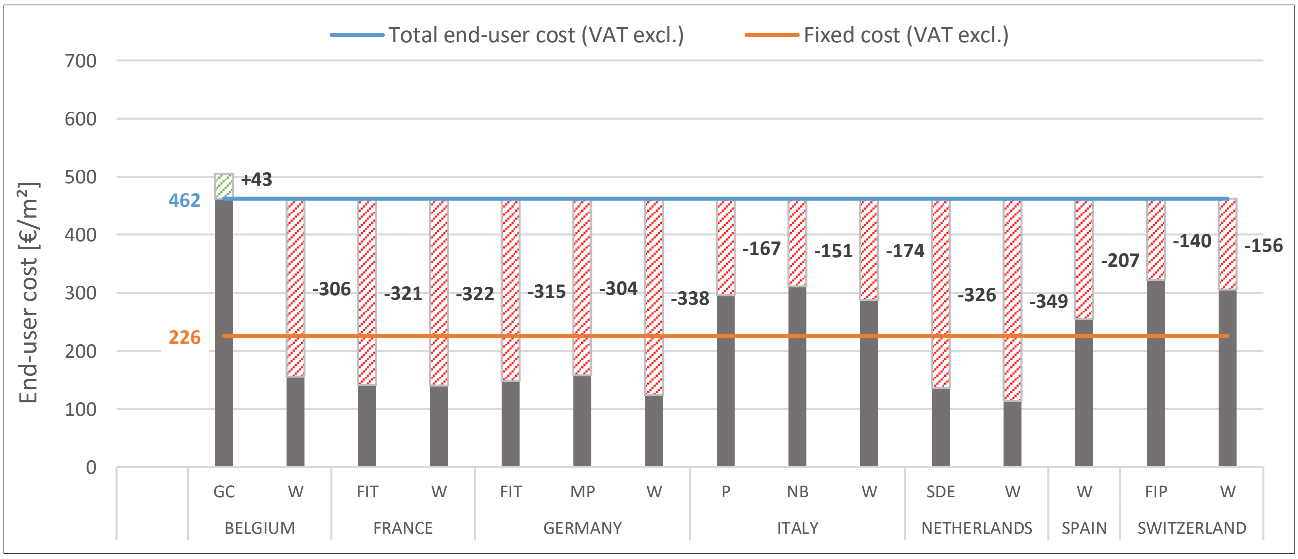

Figure 7.6 End-user cost target of reference case EB_b

The educational, commercial and industrial cases are analysed together in the following paragraph. As far as the IB reference case is concerned, the calculations have been made with both the IC and ID consumption band as both are possible for industrial buildings.

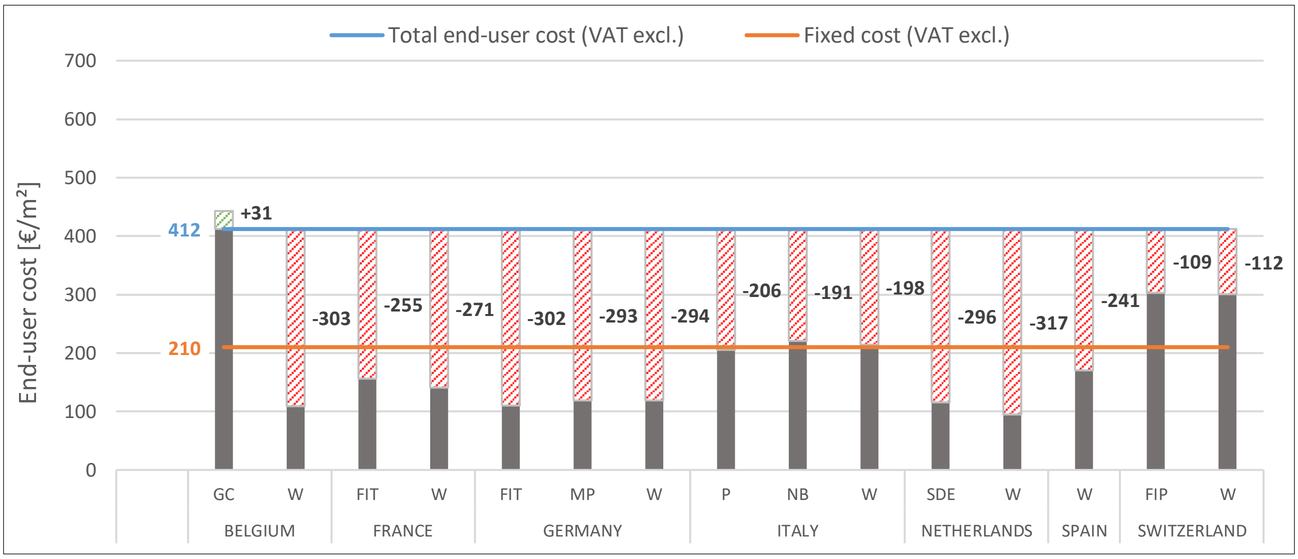

Figure 7.8 End-user cost target of reference case CB_a

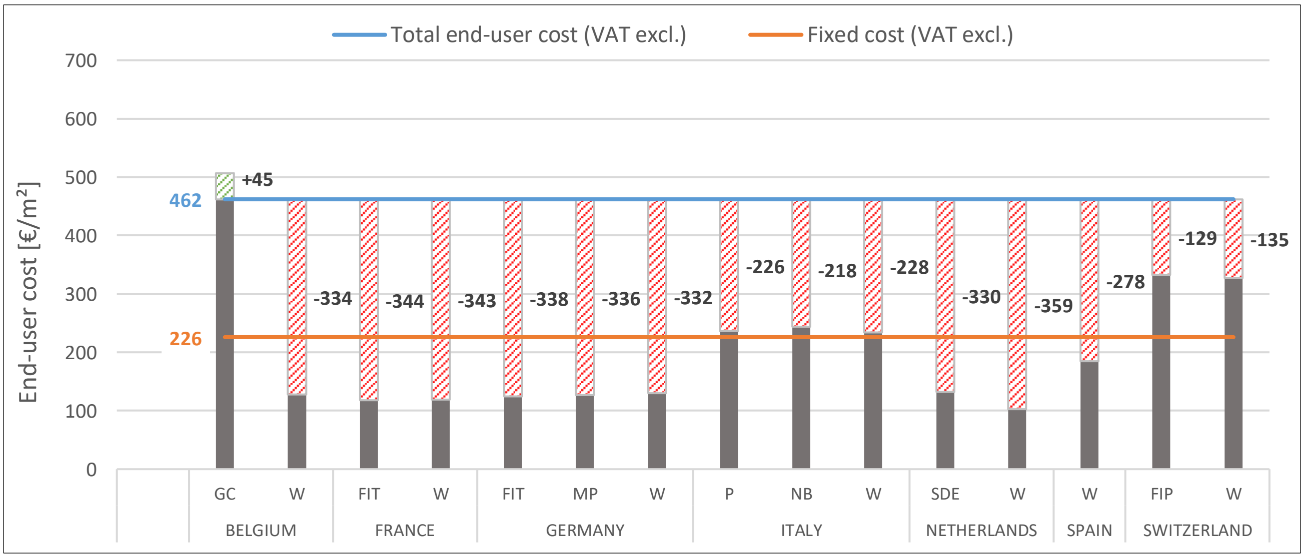

Figure 7.9 End-user cost target of reference case CB_b

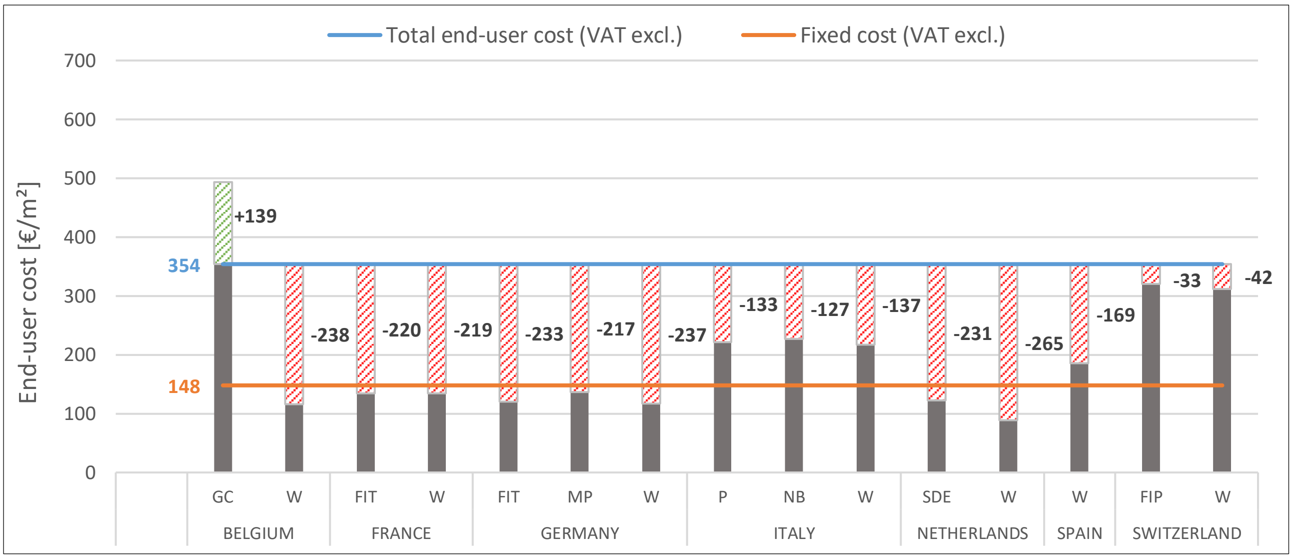

Figure 7.10 End-user cost target of reference case IB (IC consumption band)

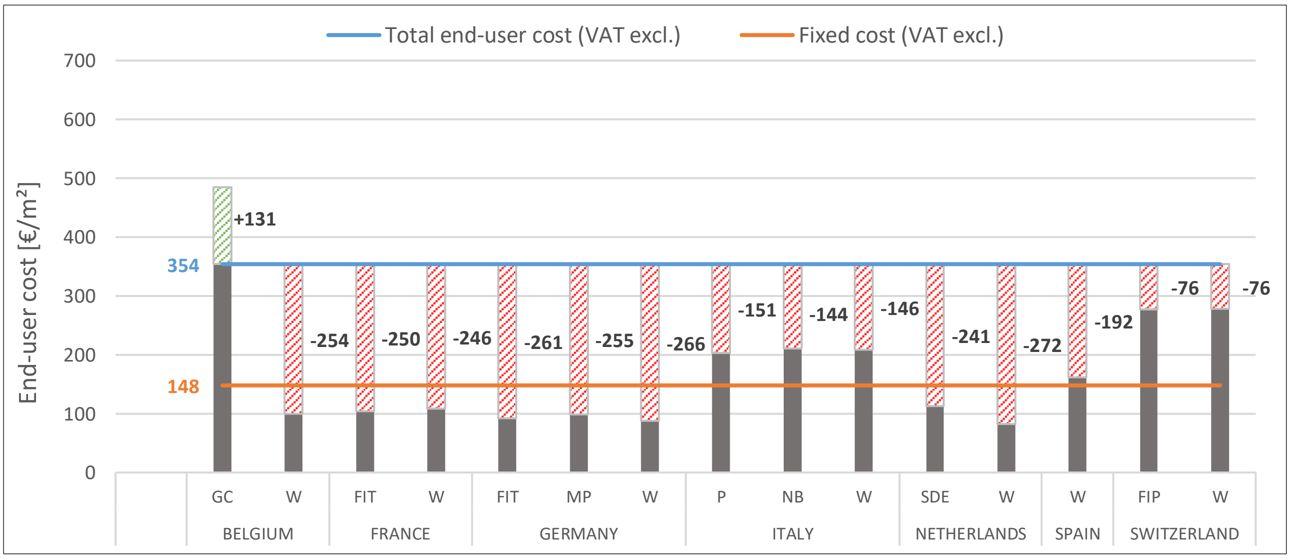

Figure 7.11 End-user cost target of reference case IB (ID consumption band)

For the educational building, the commercial building as well as the industrial building reference cases, it can be noted that, except for the most southern countries (Spain, Italy and Switzerland) and the competitive case of green certificates in Belgium, the end-user cost targets lie all below the fixed cost part and can thus not be realistically reached. Additional improvements, aside of a reduction of the total end-user cost, are required.

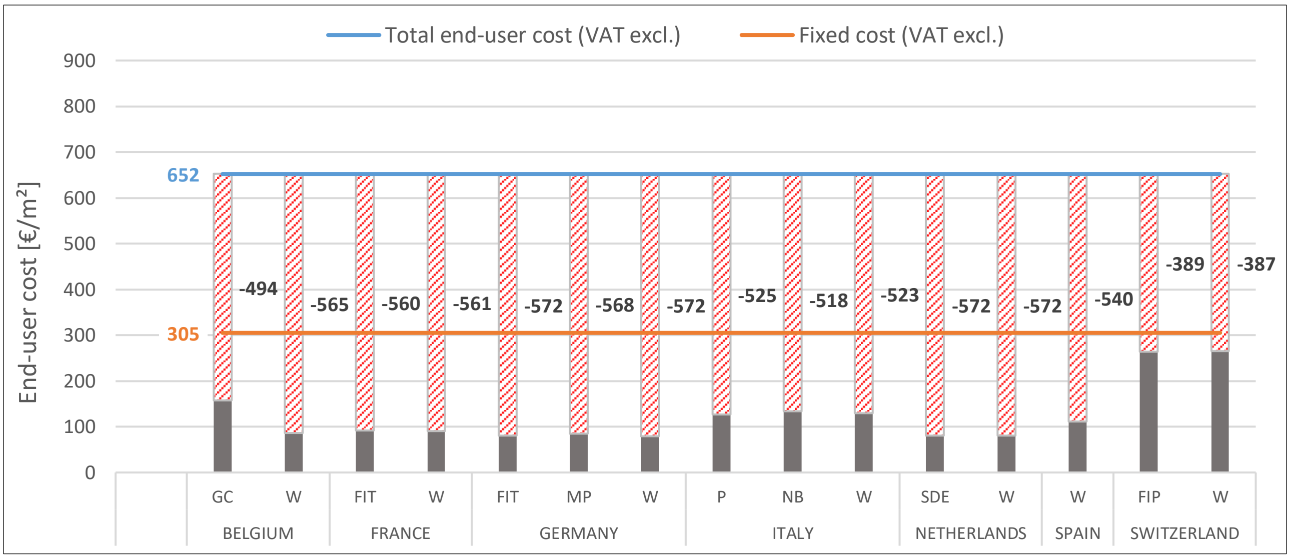

Figure 7.12 End-user cost target of reference case OB_a

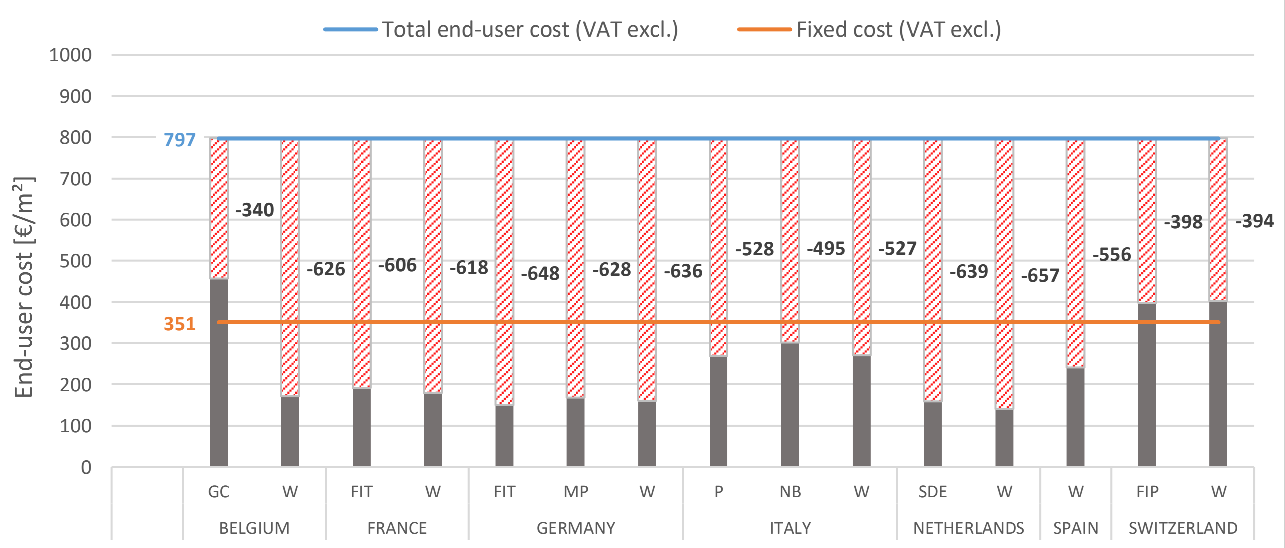

Figure 7.13 End-user cost target of reference case OB_b

Concerning the office building reference cases, no end-user cost target seems to be reachable. The fact that these targets are extremely far from the current end-user cost can be explained by, on one hand, the high end-user cost of BIPV curtain walls, and on the other hand, the limited conversion efficiency values of modules under such configuration, no matter the considered PV technology (2,7% for aSi and 10,4% for mono cSi), due to their semi-transparent characteristics. These targets can therefore hardly be interpreted as real targets for manufacturers or other stakeholders. These results also demonstrate, as highlighted previously, that potential cost reductions absolutely need to be combined with technical improvements in order to reach competitiveness.

8 KEY INFLUENCING PARAMETERS

In order to understand how main parameters affect the competitiveness results, a sensitivity analysis has been conducted. Then, few parameters have been selected and studied per pair, to analyse how they can possibly impact competitiveness when they are combined. They have been chosen as these will be likely influenced by outcomes of BIPVBOOST's activities. The influence of the evolution of electricity prices has also been studied as this parameter can significantly alter project's competitiveness. This has been underlined for example by results shown in previous sections and the striking differences between some countries. Eventually, this sensitivity analysis will also allow to highlight which parameters are the most important to work on, in order to improve the competitiveness of BIPV systems.

8.1 General sensitivity analysis

The analysis has been conducted taking as base reference case the SFH_b in Belgium. The competitiveness assessment is conducted taking a total end-user cost approach, under the wholesale market business model. The values of the eight analysed parameters have been modified by relative steps of 10%, one by one, while other parameters remain fixed, to assess their influence individually. The choice of the reference case is mostly arbitrary as only the relative effects on competitiveness will be commented on. Nevertheless, the choice of a wholesale business model allows to have a neutral base case, where the relative effect of the self-consumption rate on competitiveness can be better evaluated. Note that the eight parameters chosen for the analysis are parameters which will likely evolve in the coming years, thanks to technology innovation and performance improvements, as well as to increased experience of actors of the BIPV sector.

Table 8.1 Sensitivity analysis - Base case parameters values

	Yield	Self-consumption rate	End-user cost	O&M cost	Offset Construction Material Cost	Degradation Rate	Module Efficiency	System Lifetime
Unit	*[kWh/kWp]*	*[%]*	*[€/m²]*	*[€/m².year]*	*[€/m²]*	*[%/year]*	*[%]*	*[years]*
Base case value	863	30	220,5	2	45	0,5	18	30

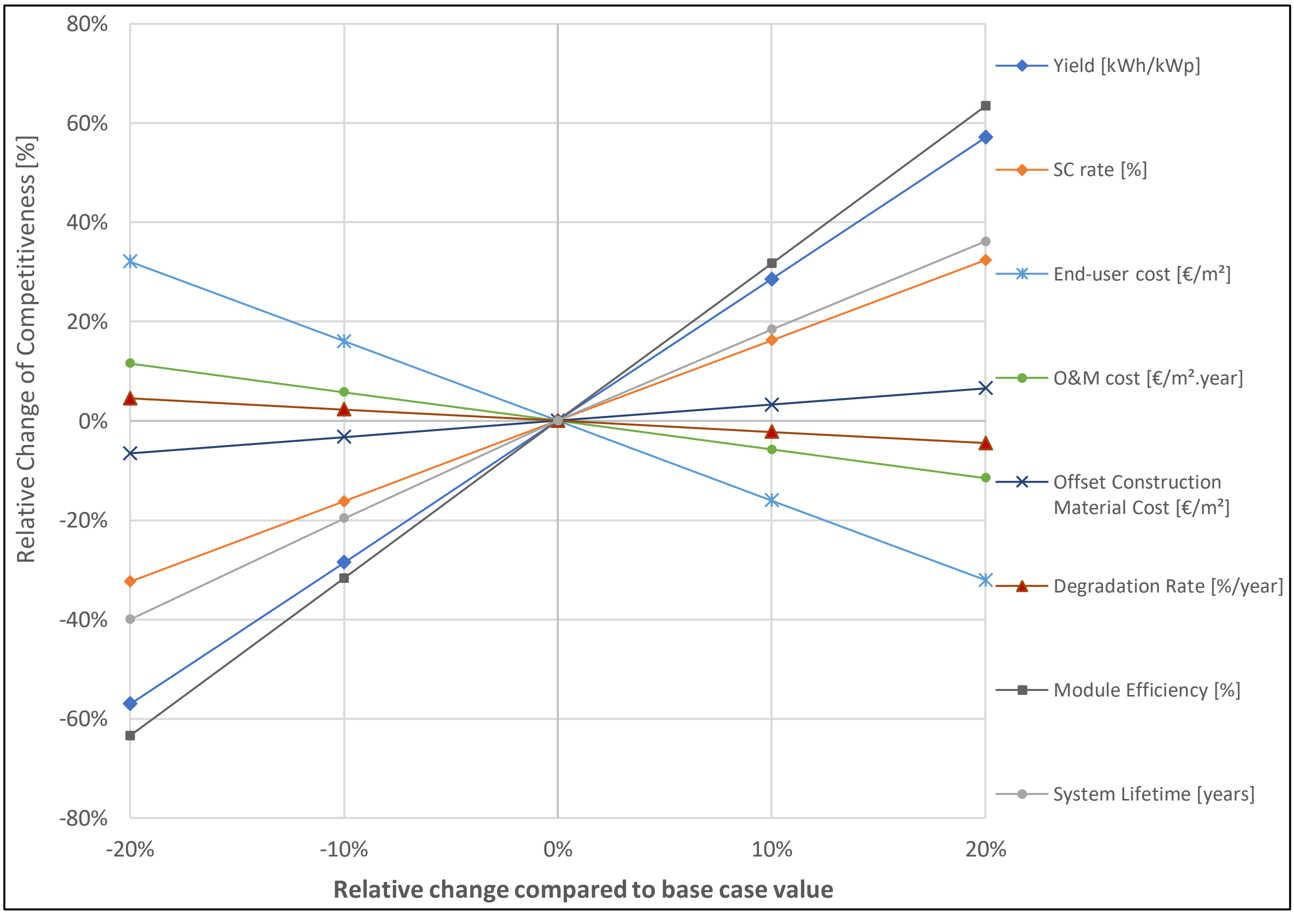

Figure 8.1 Sensitivity analysis on single parameters

The most influential parameters among the eight chosen ones are the module efficiency and the yield. Their increase logically affects competitiveness in a positive way as they induce a higher electricity production. The next most impacting parameters are the initial total end-user cost and the self-consumption rate. While a higher initial end-user cost obviously decreases the competitivity, a higher self-consumption rate on the other hand means more revenues in the form of savings on the electricity bill and, consequently, a better competitiveness.

The system lifetime comes right after and shows that increasing operational lifetime leads to an improvement of project's competitiveness. It is interesting to set the system lifetime as a parameter in this sensitivity analysis as the competitiveness results have been computed with a system lifetime set to 30 years. Thus, it can be seen to what extent a longer system lifetime would affect the competitiveness. This is of special interest as the lifetime of conventional building envelope solutions is usually longer than 30 years.

The three remaining parameters, namely the annual degradation rate of performances, the OCM and the yearly O&M cost, affect the competitiveness by 4 to 12% when changed by 20% compared to their base case value. These moderate effects can be explained by various elements. One can mention the fact that the base case values of these parameters are quite low and therefore, making them vary by 10 or 20% does not affect much the ending result. Indeed, the degradation rate, for example, of the base case is 0,5% per year. Even by making it vary by 20%, it still does not reach the degradation rates of CIGS, for example.

8.2 Influence of electricity prices' evolution

Then, the influence of the yearly variation rates of the compensable retail electricity price and of the wholesale market price have been analysed. For this purpose, two methods have been used for each price. First, the base case variation rate was changed by steps of 10% while simulating a random evolution of prices following a normal distribution law, as presented in part 6.1. Curves presented on Figures 8.2 and 8.3 for this stochastic variation result from a hundred calculations, made for each 10% step. Secondly, the variation rate was changed by steps of 10% while simulating a constant annual price variation.

Table 8.2 Sensitivity analysis - Base case parameters values

	Variation Rate of the Compensable Retail Electricity Price	Variation Rate of the Wholesale Electricity Price
Unit	[%]	[%]
Base case value	3,5	2

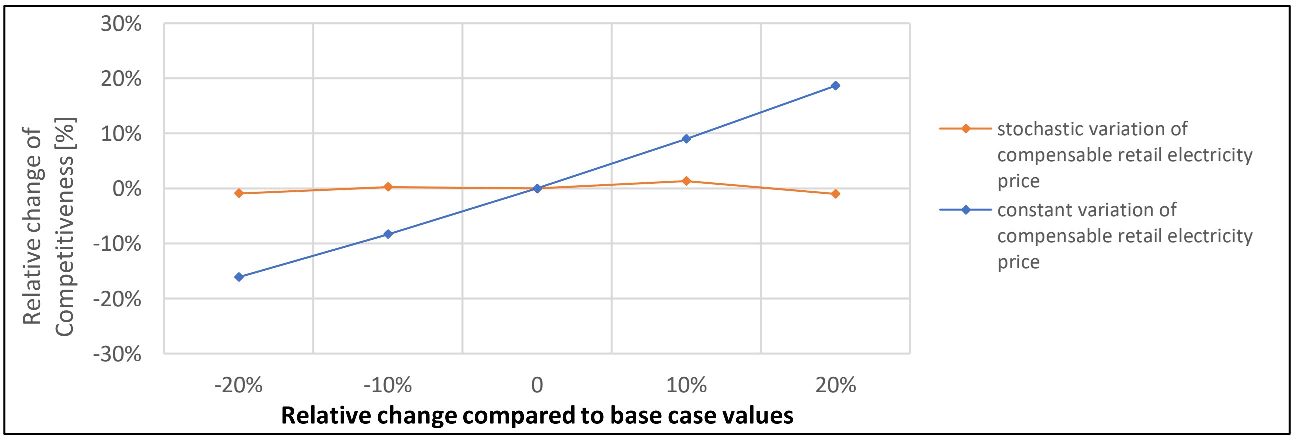

Figure 8.2 Sensitivity analysis on single parameter compensable retail price's variation rate

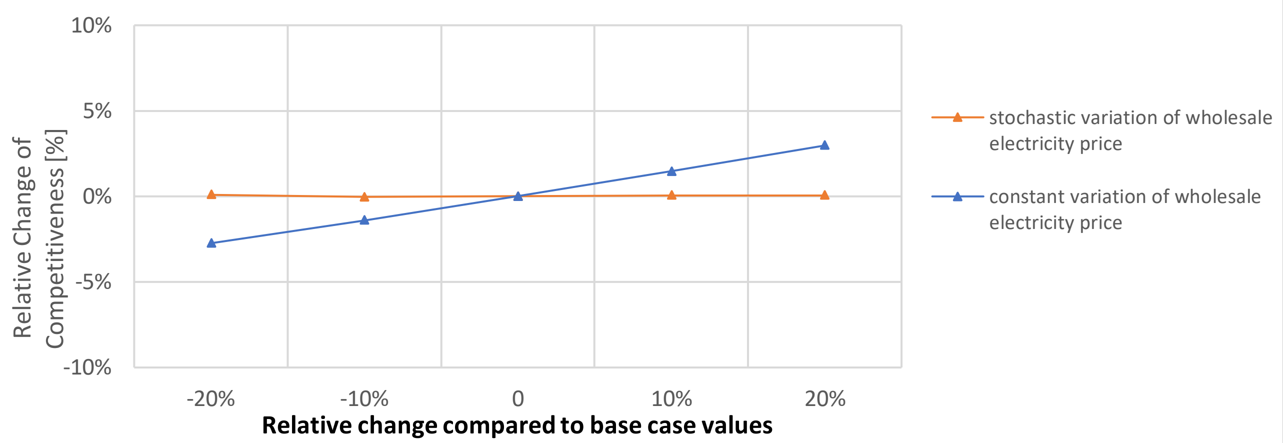

Figure 8.3 Sensitivity analysis on single parameter wholesale market price's variation rate

Considering the stochastic approach, the results show that changing the variation rate only has a negligible impact on the competitiveness. Indeed, as the variation of the range is moderate and as, in the stochastic approach, variation rates can be negative or positive, the effect on the competitiveness is not significant. On the other hand, the results in the case of a constant, linear, yearly variation rate show that the effect on the competitiveness is, on the contrary, substantial. Thus, it demonstrates that such an approach to simulate price evolution could have led to unrealistic results, considering that forecasting an accurate evolution of electricity prices is impossible. Assuming a linear yearly variation rate of electricity price can lead to overoptimistic or overoptimistic competitiveness results and should be thus avoided.

8.3 Study of paired parameters

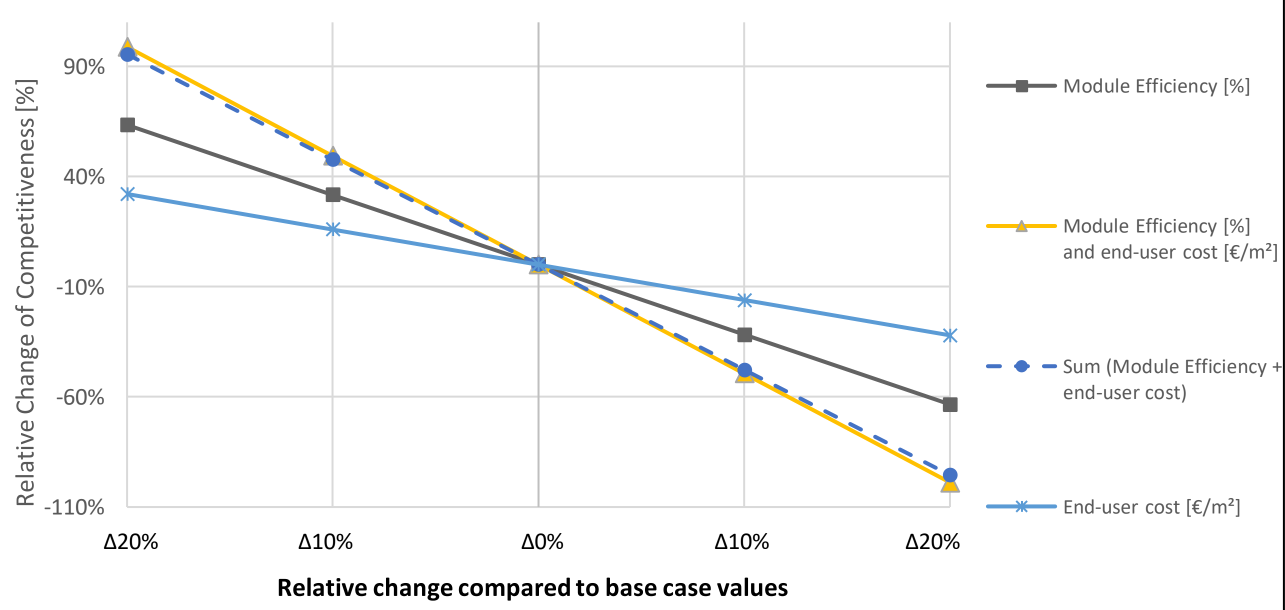

Figure 8.4 Sensitivity analysis on coupled parameters "Module efficiency" and "End-user cost"

The purpose of the coupled parameters' sensitivity analysis is to determine whether some of the parameters are dependant from each other. In other words, whether the effect on competitiveness of the first parameter can increase the effect on competitiveness of the second parameter. The chosen parameters for the coupled parameters' sensitivity analysis are factors which have turned out to be among the most influential ones from Figure 8.1. Furthermore, they are parameters for which there is an improvement potential that will be specifically worked on in the framework of the BIPVBOOST project.

Firstly, the end-user-cost and the module efficiency variations positively impacting competitiveness (i.e. an end-user-cost decrease and a module efficiency increase) have been combined, and symmetrically, the end-user-cost and module efficiency variations negatively impacting competitiveness (i.e. an end-user-cost increase and a module efficiency decrease) were also associated. For example, the Δ20% variation on the left of the chart is the case in which the end-user-cost is increased by 20% and the module efficiency is decreased by 20%. The result is then compared to the sum of the previously found effect in Figure 8.1. What can be drawn from the chart, as both straight lines almost overlap, is that module efficiency and end-user-cost can be considered as two independent parameters with regards to their respective influence on the competitiveness. In any case, these two parameters should be prioritized, considering that a relative change of Δ10% of their value (i.e. module efficiency from 18% to 19,8% and an end-user cost variation from 220,5€/m² to 198,5€/m², while other parameters remain unchanged) can significantly improve competitiveness, up to 50%.

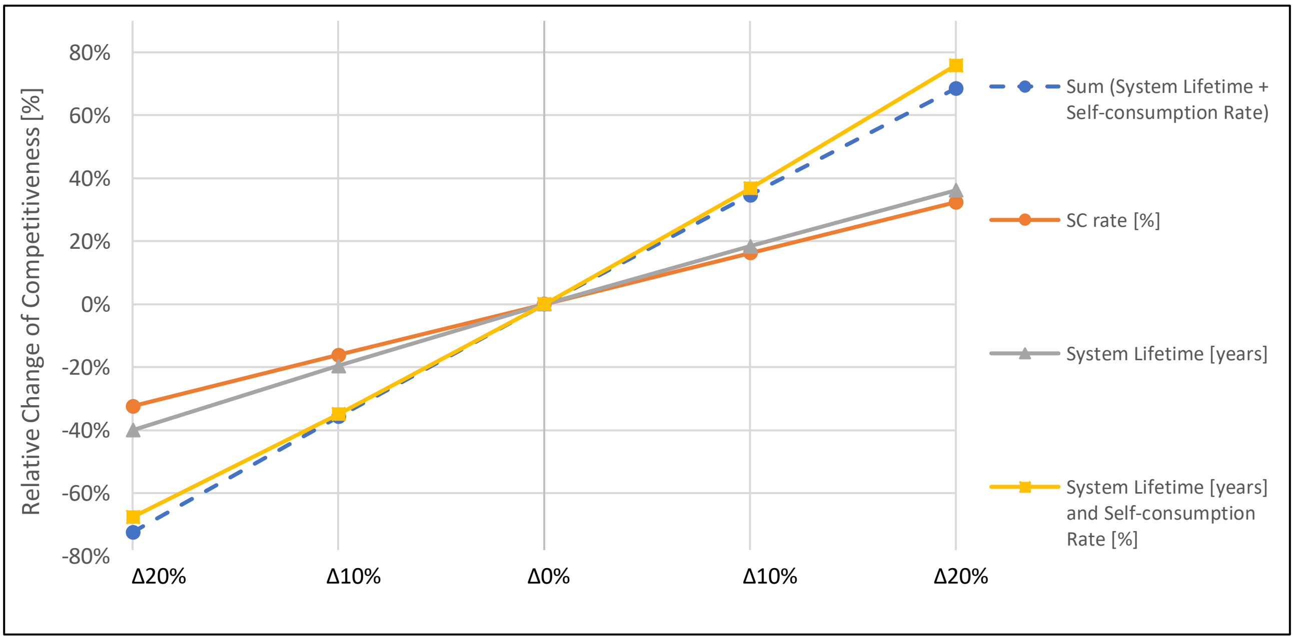

Figure 8.5 Sensitivity analysis on coupled parameters "Self-consumption rate" and "System lifetime"

Following the same approach as for the module efficiency and the end-user-cost, a sensitivity analysis has also been conducted on the self-consumption rate and system lifetime together. It appears from the chart above that these two parameters are slightly dependent, as their respective effects reinforce each other. Indeed, it appears that when combined, they permit to improve competitiveness to a larger extent than what the sum of their individual influences could have led to think. It had been drawn from Figure 8.1 that these two parameters were influential on their own. This analysis allows to identify that this influence can even be stronger. It means that improving self-consumption rate from 30% to 33% and system lifetime from 30 to 33 years only (other parameters remaining equal) competitiveness can progress by approximately 40%. It is also interesting to note that a growing self-consumption rate and an increased system lifetime are two plausible and compatible scenarios for BIPV. Therefore, taking advantage of this dependency is likely to become a reality.

On the basis of this sensitivity analysis, the most influential parameters can be identified. On a technical level, the yield, the efficiency and the lifetime of the system are unsurprisingly very influential parameters. From an economical point of view, end-user-cost has also a major influence on the competitiveness. This was already confirmed by the very different competitiveness results found with the extra cost approach compared to the value-based and generic approach. Finally, from a technical but also regulatory framework perspective, the self-consumption rate has a significant effect on competitiveness and even more with growing lifetimes. As regulatory framework will likely evolve from an exclusive individual, single house scale self-consumption to the authorization of collective schemes (at the scale of a building or even of a whole neighbourhood), self-consumption rate will be able to progress by tens of percent, thus considerably improving competitiveness.

9 CONCLUSIONS

As BIPV solutions are multifunctional, their competitiveness was studied through various aspects and approaches in this report. Even if, because of its additional electricity generating function, BIPV as a building component is hindered by quite uncompetitive end-user costs in comparison with traditional construction materials and solutions, when examining competitiveness with a dynamic point of view, i.e. on the entire operating lifetime, economic attractiveness can be observed in multiple cases. For the two latter types of competitiveness assessment, the three different approaches developed aim at adapting economic evaluations to the BIPV singularity and offering a fair competitiveness assessment. These approaches have resulted in showing that, as electric generating units, BIPV systems can be competitive. Indeed, LCOE values are quite comparable to the compensable retail electricity prices and even inferior to it in numerous cases, except for the office building reference cases.

Then, the holistic competitiveness assessment of BIPV 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, the Belgian case, with its “green certificate”-based business model for commercial cases or the Italian case with its net-billing scheme for residential cases, have shown some positive competitiveness values. On the other hand, in other countries, like the Netherlands, competitiveness was rarely achieved, due to the combination of unfavourable factors, as explained. That being said, BIPV appears already 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 still far from being competitive, except where support schemes for PV and/or irradiation are particularly generous, such as in Belgium, Italy or Spain. This can be explained by the still relatively high cost and the sub-optimal performances of the system due to the vertical tilt, among others.

Nevertheless, 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 the negative results presented here. Also, considering that total end-user costs will continue to decrease as this technology will mature, some of the defined cost targets will likely be reached in the future. Indeed, except for the office building reference case, the cost targets seem reasonably achievable in most countries and cases. Moreover, other parameters, apart from cost, can significantly contribute to improve competitiveness. This was identified thanks to the conducted sensitivity analysis. As technological improvements hit the market, embodied in improved module efficiencies or lengthened system lifetime, BIPV competitiveness will be possibly reached in multiple countries and for various applications. Significant competitiveness improvements can be reached even with a 10% increase compared to the current values, as pointed out in the sensitivity analysis. As far as the module efficiency is concerned this consist in only 1 or 2 percent points increase, which is within reach. In addition, 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. Many of these aspects will be among the researched topics within BIPVBOOST project.

Last but not least, other elements can also contribute to nuance the quite weak competitiveness of some reference cases. They include for instance the fact that, thanks to the green image or the unique aesthetical aspect that BIPV can give to a building, rents, building sale’s prices and occupancy rates can be increased, thus contributing positively but indirectly to BIPV competitiveness. They also cover the fact that reduced heat transfers and reduced permeability to solar radiation can be achieved thanks to BIPV surfaces (roofs and façades). But these elements are difficult to model as part of reference cases, because they highly depend of local project's conditions. Globally, it should be reminded that it is essential to assess each case individually to conduct a relevant and precise BIPV attractiveness analysis.

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APPENDIX 4: Definition and description of the technological systems considered in the reference cases (based on [33])

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

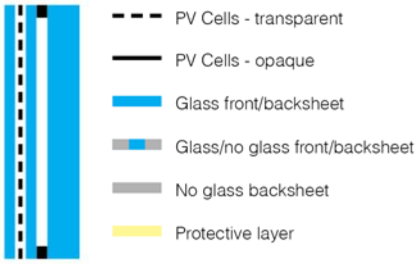
- Curtain wall façade: external not ventilated and continuous building skin system, totally or partially glazed, composed by panels supported by a substructure. A curtain wall system is an outer building envelope system in which the outer walls are non-structural. The curtain wall façade does not carry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

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

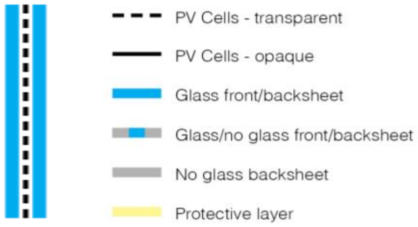
APPENDIX 5: Definition and description of the cladding typologies considered in the reference cases (based on [33])

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

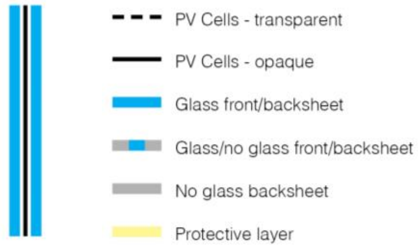
- Group 1 - Glazed transparent solution with thermal properties. This solution is typical for skylights and curtain walls.



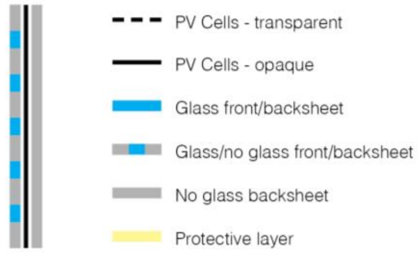
- Group 2 - Glazed transparent solution without specific thermal protection performances. This solution is typical for canopies, external pane of double skins facades and walkable floors.



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



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



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