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Cost-reduction roadmap for the European BIPV sector

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

Major cost-reductions in the European BIPV sector took place in the past decade, mainly driven by improvements and economies of scale arising from the PV sector. Although crucial, these reductions have not been sufficient to ensure economic attractiveness of BIPV solutions in all configurations and countries, as shown in BIPVBOOST report D1.1 (Competitiveness status of BIPV solutions in Europe"). Hence, all BIPV stakeholders have the willingness to maintain the downward pressure on costs.

This ambition has been formalized at the European level within the SET-Plan, which in 2015 defined strategic objectives but also quantified objectives at the horizon 2025 and/or 2030. The latter are designated in this report as operational objectives. They focus on various key performance indicators of BIPV solutions, namely the total end-user cost and extra cost of BIPV, the module efficiency as well as the system lifetime. These have been partially used to direct and benchmark the investigation conducted in this report, as well as the BIPVBOOST project as a whole.

This report aims at identifying what the future of BIPV in Europe could consist of, cost wise, using a robust methodology. Moreover, it takes the cost-reduction analysis further by taking the "competitiveness"[1] as the key metric to assess the impact of cost-reductions, for various reference cases. It will eventually draw a cost-reduction roadmap for the BIPV sector, with figures until 2030.

The first step in defining the roadmap was to describe and analyse in detail the current situation of the BIPV sector in Europe. For that purpose, the end-user cost status of BIPV, for different configurations, and its detailed structure are presented, based on previous work conducted in the project. [1] Also, a detailed overview of the workflows ongoing in the BIPV value chain is defined, based on D9.1 ("BIPV market and stakeholder analysis") and the activities ongoing in WP6. This process-based segmentation of the value chain will constitute the structure of the cost-reduction roadmap.

Then, an inventory of improvements that could lead to cost-reductions in the BIPV sector has been established. It is based on a thorough literature review, exploring each step of the BIPV value chain from silicon manufacturing to system operation and maintenance (O&M), along with the progress possibly coming from the construction and building industry sectors. This review has been completed by the improvements that should be achieved by the end of the BIPVBOOST project, thanks to partners' expertise. Among the listed improvements, one can mention reduced material consumption, more efficient production lines or optimization of project development. The identified improvements are then categorized based on the type of cost item they influence (direct or indirect costs) and on the process-based segmentation previously defined. They are described qualitatively and quantitatively based on various KPIs along with potential barriers to their implementation, the stakeholders involved, and the time-horizon considered. The distinction is then made between improvements related to technical innovations and improvements associated with market maturation. While the wording, technical innovation improvements, is quite self-explanatory, the notion of market maturation improvements is, in this document, understood as all improvements that are fostering and/or arising from the BIPV market's development.

Once the improvements have been identified and characterized, their maximal potential impact was evaluated, on an individual basis. For this assessment, reference cases have been defined, similarly to what

[1] As defined in BIPVBOOST report See also Appendix 1.

was done in D1.1. These reference cases are representative of the typical applications of BIPV systems. For each reference case, the impact of improvements on two KPIs has been estimated: system end-user cost and competitiveness. From this analysis, it can be said that technical innovation-related improvements have a higher maximal potential impact than market maturation improvements, both on the end-user cost and on competitiveness. Nevertheless, it is important to precise that these latter improvements, by their very definition, are more difficult to quantify precisely or to quantify at all. It can also be concluded from this individual assessment that, for each reference case, multiple improvements have the potential to substantially impact the end-user cost as well as the competitiveness of BIPV solutions, under different configurations. Such observation is promising, as it demonstrates that even the realization of few of the identified improvements has the potential to have a valuable impact on the attractiveness of BIPV solutions.

Following this individual assessment of improvements, a more realistic evaluation was conducted for the different reference cases. In addition to the "best case scenario" in which the maximum potential impact of all improvements is assumed to realize, three alternative scenarios where defined. These scenarios diverge mainly in the magnitude by which the maximum potential impact of improvements would be achieved. This mitigation is based on the analysis of the number of barriers that each improvement could face, their importance, as well as a "time-to-market" factor attributed. For each reference case, a unique combination of relevant improvements is identified their impact on "end-user cost" and "competitiveness" KPIs tested.

In most of the reference cases analysed, the competitiveness threshold is planned to be reached around 2025 under the three "realistic scenarios" ("technology-push scenario", "demand-pull scenario" and "balanced scenario") and values are promising for the 2030 horizon. The competitiveness values reached under the "balanced scenario" amount to 50 $€_{2019}/m^2$ on average for all reference cases (except office building reference cases) by 2030, with most of the positive competitiveness threshold being reached between 2025 and 2030. The residential (SFH_b) reference case, for which positive competitiveness is already achieved just after 2019, could approach 216 $€_{2019}/m^2$ by 2030 under the balanced scenario. Exceptions are the office building reference cases, for which the competitiveness is not foreseen to increase sufficiently to become positive, especially in the case of aSi-based BIPV solutions. These are severely handicapped by high end-user cost and low efficiency values due to the semi-transparency, thus staying between 70 to 250 $€_{2019}/m^2$ away from becoming competitive in the balanced scenario, under the "value-based approach" applied in this report. Nonetheless; the competitiveness relative increase is significant with a 54% increase for the OB_a1 reference case and 73% in the OB_b1 reference case. In addition, it is worth pointing that under an "extra cost approach", the office building reference cases would reach the positive competitiveness threshold by 2030, which is encouraging.

Regarding the end-user costs values, they are foreseen to decrease on average by 47% in the balanced scenario, by 2030 (nominal decrease). The most significant relative decreases can be observed for educational building reference cases based on cSi with a 52-62% relative nominal decrease. In comparison, reference cases such as SFH_b or OB_a1 are characterised by a more moderate, yet still important, end-user cost relative decrease of approximately 40%.

Globally, operational objectives defined by the SET-Plan are foreseen to be reached on time. Most importantly, the planned improvements have the potential to help overreach these objectives, in multiple cases, and to significantly enhance the economic attractiveness of BIPV solutions. This even when their maximum potential impact is reduced in a scenario-based evaluation. As shown here, if technical innovations keep being developed and implemented, and if the market maintains its steady growth and maturation pace backed up by an appropriate regulatory environment, BIPV could become in the medium-term a serious contender to conventional materials in the construction and building sector, for multiple applications.

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1 ABOUT THIS REPORT

1.1 Description of the deliverable content and purpose

This deliverable aims at highlighting all potential improvements along the BIPV value chain, among others planned in the framework of the BIPVBOOST context, as well as gathered through a thorough literature review. These improvements are described both qualitatively and quantitatively. The final target being to translate those improvements in terms of impact on the "competitiveness" metric which will constitute the main KPI and thus the comparison criteria. The impact of improvements on the end-user cost of BIPV systems and other KPIs is also evaluated. Eventually, the cost-reductions will be analysed based on their certainty, the time horizon they are planned for, and the barriers that could hinder their deployment to the whole BIPV market. This will allow to draw a cost-reduction roadmap and to compare the results with specific strategic objectives defined at the European level.

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
T1.1	Used to retrieve data on reference cases and methodology for competitiveness assessment
T9.1	Used to retrieve data on BIPV value chain, project development process and market development
T9.2	Used to obtain data on incentives, tariffs and the valuation of (BI)PV generated electricity
T1.3	Used to characterize reference cases
T6.1	Used to retrieve data on the interactions and stakeholders involved in BIPV project development process
All Tasks from WP2 to WP7	Used to obtain estimated impact of improvements to be developed in the frame of BIPVBOOST

1.3 Reference material

The deliverables published in the frame of the activities mentioned in the table above, i.e. D1.1, D9.1, D9.2 and D1.3.

1.4 Abbreviation list

aSi – Amorphous silicon

BAPV – Building Applied Photovoltaic

BEMS – Building Energy Management System

BIPV – Building Integrated Photovoltaic

BoS – Balance of System

CdTe – Cadmium Telluride

CIGS – Copper Indium Gallium Selenide

cSi – Crystalline silicon

CTM – Cell to Module (Ratio)

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

EB – Educational building

EM – Energy Modelling

EPBD – Energy Performance of Buildings Directive

ESCO – Energy Services Company

EVA – Ethylene vinyl acetate

FBR – Fluidised Bed Reactor

GHG – Greenhouse gases

HJT – Heterojunction

HVAC – Heating, Ventilation and Air Conditioning

IB – Industrial building

IBC – Interdigitated Back Contact

IEA – International Energy Agency

KPI – Key Performance Indicator

LCOE – Levelized Cost of Electricity

MFH – Multifamily house

MPPT - Maximum Power Point Tracking

OCM – Offset construction material

O&M – Operation and maintenance

OB – Office building

PERC – Passivated Emitter and Rear Cell

PV - Photovoltaic

SET Plan - Strategic Energy Technology Plan

SFH – Single family house

2 INTRODUCTION

2.1 Rationale

Building-integrated photovoltaics (BIPV) has been a hot topic in the PV industry for more than a decade [2]. Although, market deployment this technology has so far failed to meet expectations of most stakeholders of the sector [3]. While investigating in detail the roots of this situation is out of the scope of this report, an explanatory element might lie in the subpar competitiveness of BIPV solutions under multiple configurations, which was demonstrated in a previous activity [1]. To overcome this weakness, it is thus crucial to define coherent cost-reduction objectives, eventually allowing to reach competitiveness and possibly triggering a market uptake. However, such resource is currently missing in the literature. In addition, such analysis can contribute to prioritise research and development activities and to evaluate the relevance of capital allocations in the sector. The present roadmap thus aims at filling a blank in the literature and at supporting BIPV stakeholders in their development.

2.2 Scope

In order to achieve this ambition, the present deliverable gathers detailed information on BIPV systems' costs, their structure as well as on processes existing along the BIPV value chain. In other words, the roadmap will describe and investigate all sources of costs eventually making up for the final price paid by the end-user of the BIPV solution. Hence, elements related to the PV characteristic of BIPV will be explored as well, such as efficiency increases at cell levels or cost decreases of inverters, for example. Objectives until 2030 will be presented.

2.3 Strategic objectives

The building sector is the highest energy consumer in the European Union, with about 40% of the total energy demand, and is responsible for significant CO_2 emissions, with about 36% of the total yearly emissions in the EU. For that reason, this is a key point of attention in the different strategies developed at the European level. It was already the topic of a report published in 2010 by the European Commission on "Energy-efficient buildings PPP, Multi-annual roadmap and longer term strategy" or in the SETIS EEI PV ROADMAP More recently, one can cite the recent long-term strategic vision, presented by the European Commission in November 2018, to reduce GHG emissions and achieve climate neutrality by 2050. [4] In this document, seven main strategic building blocks are outlined. Three of them in particular can be highlighted, considering their relevance for the BIPV sector:

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

This ambition is in line with existing regulatory frameworks, such as the revised Energy Performance of Buildings Directive, which entered into force in July 2018. Among others, this aims at accelerating the cost-effective renovation of existing buildings and reach a decarbonised building stock by 2050. In addition, the binding renewable energy target of at least 32% and an energy efficiency target of at least 32.5% by 2030 can also be mentioned as strategic objectives relevant to the BIPV sector.

2.4 Operational objectives

Defining a consistent and relevant cost-reduction roadmap for the European BIPV sector requires to be in line with existing sectorial objectives. Hence, going one step further than in the previous section, operational objectives set at European level are discussed in the following lines. Indeed, the European Commission has already specified clear objectives to be aimed at by the (BI)PV industry, in the framework of the Strategic Energy Technology Plan (SET Plan), published in December 2015. [5]

These SET Plan's objectives cover multiple aspects of PV technologies, among which BIPV applications. Their ultimate goal is to "re-build EU technological leadership and bring down the levelized cost of electricity". These objectives are more detailed than the strategic ones evoked previously, as they are characterised by quantified goals associated with precise means that will allow to reach the strategic targets. The means to achieve this ambition can be summarised, in the case of classical PV technologies, as follows:

1. Increase PV module efficiencies;
2. Reduce system cost;
3. Increase PV module lifetime and minimise their environmental footprint;
4. Improve manufacturing throughput;
5. Enable fast and automated installation processes.

Focusing on BIPV applications, the targets defined in the SET Plan also emphasises multiple aspects. Eventually, these should enable the mass realisation of "(near) Zero Energy Buildings". These are summed up hereafter:

1. Develop multi-functional BIPV elements (i.e. including thermal insulation or water protection);
2. Reduce the additional cost compared to competing solutions;
3. Improve the flexibility of manufacturing processes.

These objectives are quantified, sometimes partially, and have been translated into key performance indicators, related for example to module efficiency, end-user costs or system lifetime. While being relatively vague, these operational targets can still play the role of a compass to guide the definition of the cost-reduction objectives to be presented in the sectorial roadmap.

The SET Plan's objectives expressed in accordance to the KPIs selected for this deliverable are summarised in the following table. The section in blue is specific to BIPV applications.

Table 2.1 KPIs associated to SET Plan's objectives

Key Performance Indicators' details				**Reference value**	**Objective**		
Selected KPI	*Change*	*Unit*	*Trend*	*2015*	*2020*	*2025*	*2030*
Module efficiency	Relative	[%]	↗	N/A	+20%	N/A	+35%
End-user system cost	Relative	[%]	↘	N/A	-20%	N/A	-50%
Module lifetime	Absolute	[years]	↗	N/A	30	35	N/A
Extra cost of BIPV	Relative	[%]	↘	Application dependent*	-50%	N/A	-75%

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

2.5 Research trends

To reach the targets evoked in the previous sections, research activities have already been conducted, through public and/or private financing. The activities ongoing in the BIPVBOOST project of course come to mind. The associated improvements constitute the pillars of the cost-reduction roadmap presented in this report. Furthermore, aspects being investigated in the framework of other research projects can also be mentioned. For instance, modularity and prefabrication of BIPV solutions, as they are part of other H2020 research projects Be-Smart and PVadapt.

As shown below, BIPVBOOST research project's KPIs are not strictly aligned with those expressed in the operational objectives. However, all these targets should be reached, if not surpassed.

Table 2.2 KPIs associated to BIPVBOOST project's objectives

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

*Roof integrated modules = 80-120 €/m²; Roof tiles & membranes = 130-200 €/m²; Semi-transparent facade = 150-350 €/m²; Opaque façade = 130-250 €/m².
**Note that this objective is defined for 2020.

The already mentioned Be-Smart project also has ambitious cost targets, aligned with SET Plan objectives, for different types of BIPV products. These are summarised in the graph below.

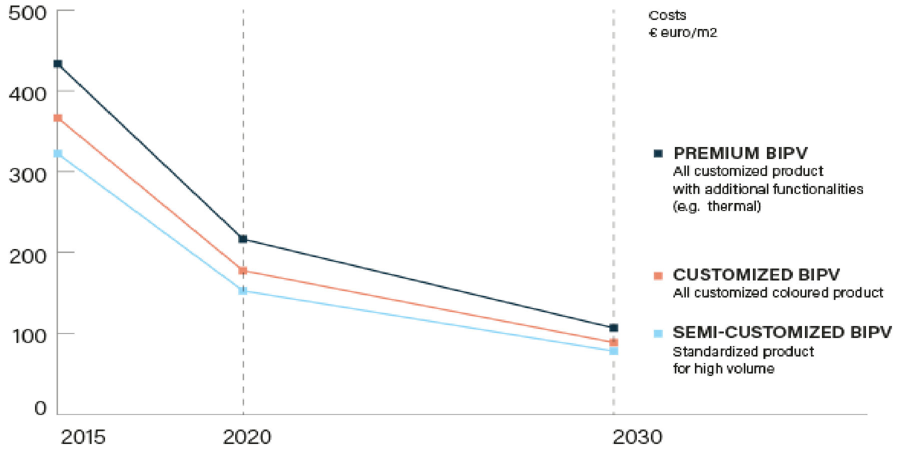

Figure 2.1 Cost-reduction objectives of the Be-Smart H2020 project [59]

All these aspects will be further developed in the cost-reduction roadmap.

3 METHODOLOGY

3.1 Collection of information

To collect the required data on costs, processes or technical characteristics of BIPV products and systems, but also potential improvements and their respective estimated impact, various sources were used. A first screening of publicly available information was conducted, among existing studies and reports. Indeed, as highlighted in the introduction, various roadmaps of relevance for the BIPV sector exist, published by recognised institutional bodies such as the IEA, IRENA or the European Commission. These focus among others on photovoltaics, energy efficiency of buildings or, simply, on energy. [6] [7] [8] [9] [10] [11] [12] In addition, outcomes and results of other research activities, such as the SUNROAD, ZEBRA2020, CoNZEBs, CRAVEzero or PVSITES H2020 projects, were analysed. [13] [14] [15] [16] [17] [18] [19] [20] These were for example used when exploring the processes at play in the planning, development and construction phases of new buildings, as well as their associated costs. Then, elements of the "International technology roadmap for photovoltaics" published annually by VDMA were also used. [21] Furthermore, some national initiatives, in some cases focusing on BIPV (e.g. in The Netherlands), have been investigated. [22] [23] [24] Finally, relevant scientific literature was explored as well. These publications will be referred to in the section dedicated to the description of improvements, when inputs coming from them are used.

Even if few of these publications explore specifically the topic of building integrated photovoltaics and some of them are outdated, they contain various points of interest, which have contributed to establish the present report. Nonetheless, it was highly required to complete the literature review with more precise facts and figures. Hence, the next crucial step was to leverage the experience and expertise of BIPVBOOST partners. For that purpose, all Work Package leaders were questioned about the planned improvements to be developed within the project, at their specific step of the value chain, their estimated impacts and the barriers associated. The insights obtained through this channel constitute the core of this report. The thus constituted improvements inventory constitutes a bottom-up approach. In some relevant cases, this approach was complemented by a top-down approach using learning curve-based estimations.

3.2 Cost-reduction targets

Based on the collected data, a mapping of the improvements was established. To make this mapping more comprehensive, a distinction is made between direct and indirect. Then, sub-categories are defined, based on the sector (PV, BIPV or construction industry) the improvements arise from. Note that the latter can consist in pure technical innovations as well as in modification of procedures or organisation within the sector. In addition, for each improvement, a qualitative and quantitative assessment is conducted on a given time horizon and translated into cost-reduction objectives, considering the impact this improvement has on the previously identified KPIs. Once gathered and completed by an analysis of the barriers to their implementation, the identified improvements allow to define the cost-reduction roadmap. Furthermore, the impact of these improvements on the competitiveness[2] of BIPV solutions is investigated, when taken individually but also in combination. This permits to draw a thorough roadmap for cost-reductions in the

[2] Competitiveness refers to the "total costs and revenues of ownership" competitiveness under the "value-based approach", as defined in BIPVBOOST D1.1

whole BIPV sector on the short- to medium-term and to evaluate the consequences of the mapped cost-reductions in practice, in various situation.

3.3 Key Performance Indicators

A set of twelve KPIs has been defined in order to evaluate the contribution of the inventoried improvements.

The **main KPI** that will be used to measure the impact of cost-reductions will be the competitiveness [€/m²], as defined in Deliverable 1.1 "Competitiveness status of BIPV solutions in Europe". This KPI aggregates in its calculation the other parameters, which will be used as "intermediary KPIs". The choice of this metric can be explained by the fact that the notion of cost is meant to be holistic, i.e. taking the total cost of ownership.

Using **intermediary KPIs** allows to have a first and more adequate quantitative description of an improvement before calculating the associated impact on the main KPI: the competitiveness. Indeed, improvements can impact the direct costs (module cost, end-user cost and O&M) or indirect costs (e.g. workload due to design activities) or they affect the technical performance (module efficiency, system lifetime and performance ratio) or the valuation of the produced electricity (self-consumption rate). Thus, intermediary KPIs will serve as a basis to measure the various improvements more precisely and then to calculate the associated competitiveness value.

Table 3.1 Presentation of intermediary and main KPIs

KPI_id	Parameter	Unit	Targeted impact
Module KPIs			
KPI_1	BIPV module efficiency	[%]	↗
KPI_2	BIPV module cost*	[€/m²]	↘
KPI_3	Degradation rate	[%/year]	↘
System KPIs			
KPI_4	End-user cost**	[€/m²]	↘
KPI_5	Performance ratio	[-]	↗
Project planning KPIs			
KPI_6	Preliminary design workload	[hours]	↘
KPI_7	Technical design workload	[hours]	↘
KPI_8	Installation workload	[hours/m²]	↘
Operational life KPIs			
KPI_9	System lifetime	[years]	↗
KPI_10	O&M cost	[€/m². year]	↘
KPI_11	Self-consumption rate	[%]	↗
Main KPI			
KPI_12	Competitiveness***	[€/m²]	↗

*Cost measured at "factory gate"
** Including all sources of cost, such as planning, materials as well as installation (VAT excluded, except in the residential cases)
*** Competitiveness refers here to the "total costs and revenues of ownership" competitiveness under the "value-based approach", as defined in BIPVBOOST D1.1

3.4 Reference cases

Reference cases presented on the following Table have been defined in order to quantify the impact of the improvements presented in this deliverable on various KPIs, among which the end-user cost, as previously mentioned. These reference cases aim at being the most representative of the technologies used in BIPV projects, without intending to be exhaustive of all technological possibilities. However, these reference cases are not exactly similar to the demonstration sites developed in the frame of the BIPVBOOST project. It is also worth noting that contrary to the PV market, no technology truly dominates the BIPV market. [3]. Hence, as the BIPVBOOST consortium gathers partners using silicon-based and thin-film-based technologies, both types are considered in the conducted cost-reduction analysis.

In addition, both roof and façade applications are considered, with three different technologies (aSi, cSi and CIGS) as well as two optical possibilities (semi-transparent and opaque) and two thermal properties (with and without insulation layer). Most common combinations of application, technology, optical and thermal characteristics for BIPV products are schematically represented in Figure 3.1.

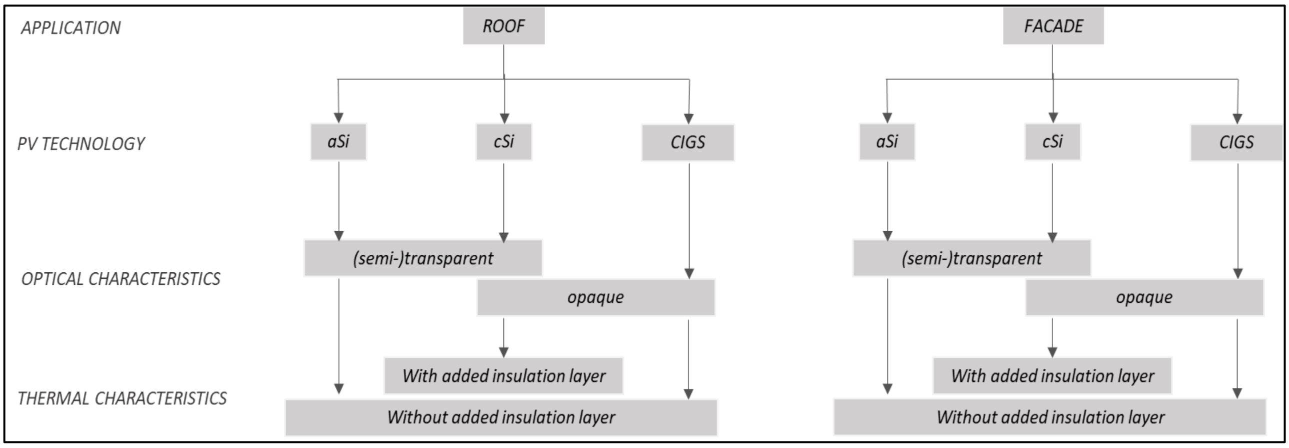

Figure 3.1 Most common combinations of application, technology, optical and thermal characteristics for BIPV products

The definition of a reference case requires to characterize numerous economic and technical parameters for which assumptions, definitions and commentaries were provided in D1.1 “Competitiveness status of BIPV solutions in Europe”. Although, the following table does not list the whole set of parameters. Indeed, it only aims at giving a general description of the chosen reference cases. Insights on other parameters, for example those used in competitiveness calculations, can be found in D1.1 “Competitiveness status of BIPV solutions in Europe”. Reducing the length of the table also allows to enhance readability. Note that base case KPI values for the listed reference cases will be provided in a following section.

Table 3.2 Reference cases [20] [25] [26]

Category of parameter	Parameter	Roof applications		Façade applications						
Technical parameters	***Reference case ID***	**IB**	**SFH_b**	**EB_a1**	**EB_b1**	**EB_b2**	**MFH**	**OB_a1**	**OB_a2**	**OB_b1**
	Building typology	Industrial building	Single family house	Educational building			Multifamily house	Office building		
	Technological system	Lightweight metal roofing	In roof mounting system	Rainscreen façade				Curtain wall		
	Cladding typology	Standing seam metal sheet, opaque, without thermal properties	Glazed, opaque, without thermal properties	Glazed, opaque, without thermal properties	Glazed, opaque, without thermal properties	Glazed, opaque, coloured, without thermal properties	Glazed, opaque, with added insulation layer	Insulated glazing, semi-transparent	Insulated glazing, patterned, semi-transparent	Insulated glazing, semi-transparent
	PV technology	CIGS	Multi cSi	CIGS	Mono cSi	Mono cSi	Mono cSi (IBC)	aSi	aSi	Mono cSi
	Module dimensions	1,6m * 0,5m	1,6m * 0,9m 60 cells	1,587m * 0,664m	1,7m * 1m 60 cells	1,7m * 1m 60 cells	1,7m * 1m 72 cells	1,849m * 1,245m	1,849m * 1,245m	1,650m * 0,85m 36 cells
	Alternative construction material	Metal	Ceramic tiles	Metal	Metal	Coloured metal	Metal	Glazing	Digital printed glazing	Glazing
	Surface available for the system [m²]	1400	50	470			300	270		
Economic parameters	*Electricity consumption band*	IC	DC	IA			DC	IA		
	Cost of alternative material [€/m²] (material only)	25	45	80	80	90	80	150	230	150

3.5 BIPV value chain

The BIPV value chain is very complex, not only due to the number of stakeholders that take part in it but also because, contrary to the construction or the PV sector, there is a need for collaboration between stakeholders that traditionally intervene separately at consecutive steps of the value chain, to work together with a two-way information and work flow. Indeed, as presented on Figure 3.2, showing a generic overview of the main processes ongoing in the BIPV value chain, the manufacturing as well as the project planning phases do not take place consecutively but rather conjointly, requiring from the different involved stakeholders to give feedback on what is possible and what is needed. Then, the process steps that are concerned by BIPVBOOST improvements were highlighted as shown in Figure 3.3. It should be noted that some process steps that are not part of BIPVBOOST research activities, such as PV cells' manufacturing, will be discussed as well in terms of improvements and potential source of cost-reduction for BIPV solutions.

3.6 BIPV processes

To simplify, 5 meta-processes ongoing in the BIPV value chain are presented:

- Preliminary studies & Project planning
- Manufacturing and selection of components
- Construction
- Use
- Decommissioning

These are then decomposed into multiple steps, or sub-processes, which are detailed in Table 3.3 and Table 3.4. In Figure 3.3, the steps of the BIPV value chain that are impacted by improvements planned in the framework of the BIPVBOOST project were highlighted. Nevertheless, the other steps, which are not put forward in Figure 3.3, will also be concerned by improvements described in the following Sections.

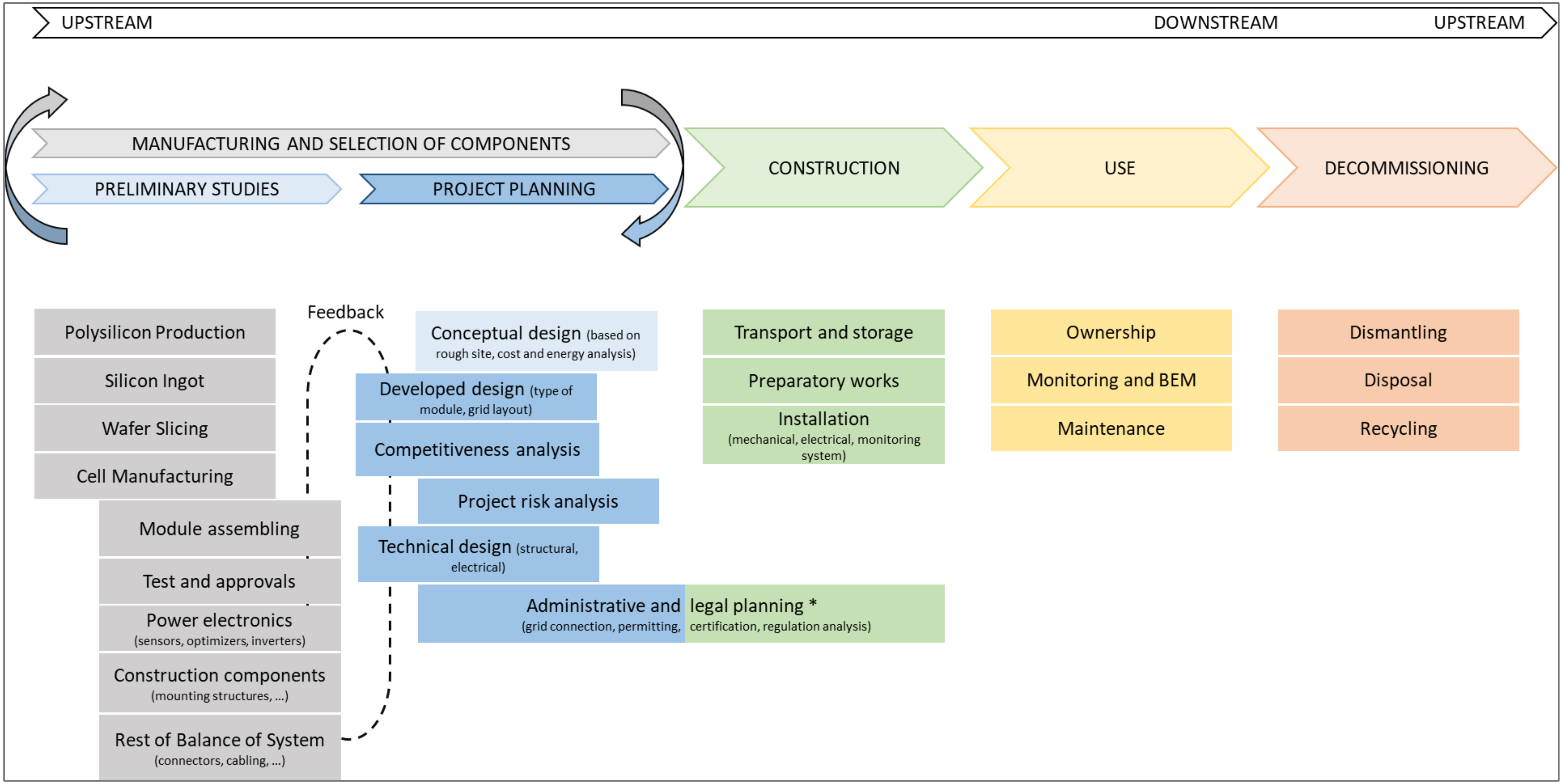

Figure 3.2 Generic overview of the main processes ongoing in the BIPV value chain

* The "Administrative and legal planning" process extends from the project planning phase to the construction phase as represented in the figure above. Nevertheless, in the following tables, figures and sections, it will be attributed to the project planning phase only, for clarity purposes

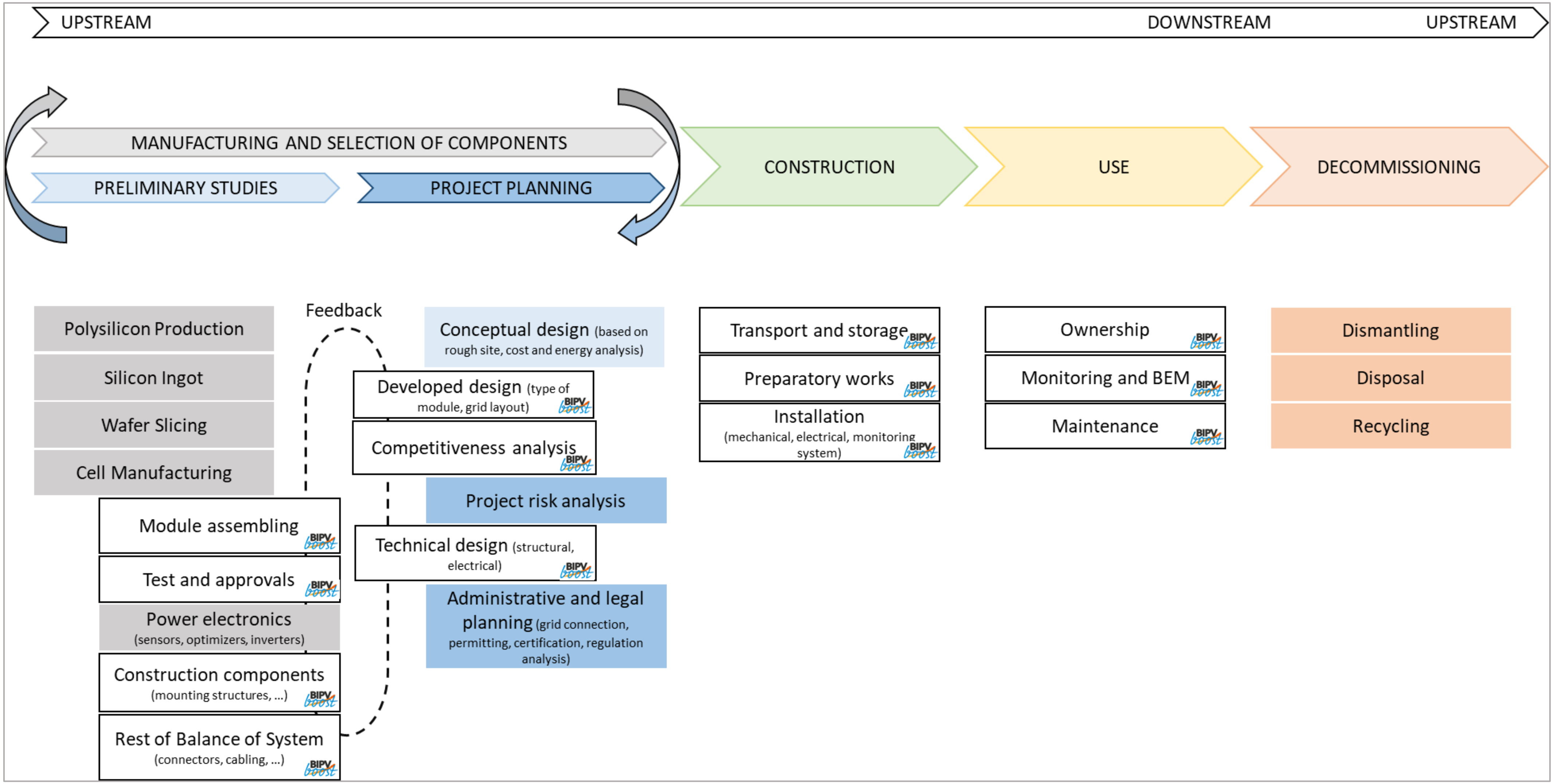

Figure 3.3 Highlight on processes targeted by BIPVBOOST project improvements

Table 3.3 Detailed description of the processes ongoing in the BIPV value chain

Sub-process step	Description	Main stakeholders involved
1 - PROJECT DEVELOPMENT AND PLANNING		
1.1 Conceptual design	Rough site analysis (available surfaces, grid connection possibilities, architectural and historical aspects), cost assessment and energy estimation (solar irradiation, average temperatures)	Architects Engineering and construction company
1.2 Developed design	Determination of type of modules, grid layout, cost evaluation and energy yield assessment	Architects Engineering and construction company
1.3 Competitiveness analysis	Development of business model, financial procedures. Assessment of the project's risks' frequency and gravity and financing	Financers and investors Owner
1.4 Technical (executive) design		
1.4.1 Electrical design	Design of the layout and integration of the different electrical components	Experts on both PV and construction aspects
1.4.2 Structural design	Design of the mounting structure and global mechanical validation	
1.5 Administrative and legal planning	Identification and initiation of required permitting, grid connection and certification procedures	Project manager DSO, Utilities, Regulator(s)
2 - MANUFACTURING AND SELECTION OF COMPONENTS		
2.1 Standard and special module assembling	Manufacturing of the modules	BIPV module manufacturers Testing and Certification Institutions
2.2 Test and approvals	Certification that the installation complies with regulatory standards	
2.3 Power electronics	Selection of adequate power electronics (type, number, …) such as optimizers or sensors	BIPV installers
2.4 Construction components	Selection of adequate mounting structure and other needed construction components	Mounting system manufacturers
2.5 Rest of balance of system	Selection of adequate remaining balance of system elements such as inverters or cablings	BoS manufacturers

Table 3.4 Detailed description of the processes ongoing in the BIPV value chain

Sub-process step	Description	Main stakeholders involved
3 - CONSTRUCTION		
3.1 Transport and storage	Logistic phase including packing, transport and storage	BIPV suppliers BoS suppliers Mounting systems suppliers
3.2 Preparatory works	Needed work before the installation step	Construction company
3.3 Installation		
3.3.1 Structural installation	Construction of the mounting structure, fixing systems, ... according to the structural design.	BIPV installers Construction company
3.3.2 Electrical installation	Construction of the different BIPV system elements (module, inverters, ...) according to the electrical design. Installation of the monitoring system	BIPV installers Electricians
4 - USE		
4.1 Monitoring	Control and monitoring of the BIPV system, alarms, data gathering	BIPV installers or O&M specialised companies
4.2 Building Energy Management	Smart BEMS enhancing BIPV system revenues	BEMS specialised companies
4.3 Maintenance	Corrective and preventive maintenance, cleaning, replacements	BIPV installers or O&M specialised companies
5 - DECOMMISSIONING		
5.1 Dismantling	Equipment removal and replacement with new system or alternative building product	BIPV installers or construction companies
5.2 Disposal	Disposal of the BIPV system	Companies specialised in recycling of PV and/or construction elements, or their subcontractors
5.1 Recycling	Recycling of the BIPV system's material	

4 COST STATUS OF BIPV

4.1 Past cost reductions

One of the obstacles to the deployment of BIPV from a niche market to a significative market segment is the cost competitiveness issue. [3] Until recently, BIPV remained in most cases uncompetitive compared to conventional construction products or BAPV systems, even though products have been existing for many years. [27] [28] Nevertheless, a drastic cost per Wp decrease of PV systems' components, such as PV cells, occurred in the recent years. Various factors can explain this trend, such as economies of scale, technical innovation, increasing efficiencies, or intense competition. Not only has there been efficiency improvements for existing PV technologies, but new products have also entered the market, offering promising prospects to reach even higher efficiencies.

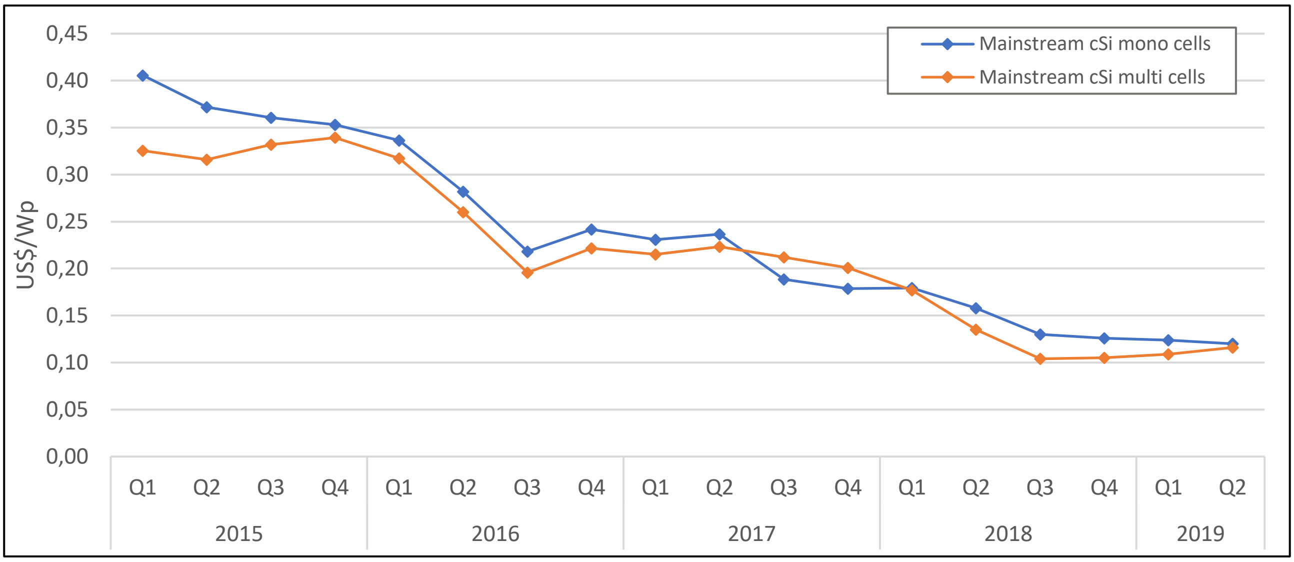

Figure 4.1 Cell prices' evolution (end of quarter average spot prices) [29]

Eventually, these factors have also benefited BIPV products and systems. Indeed, the tremendous cost decreases and performance improvements in the PV sector have resulted in significant competitiveness improvements of BIPV in the last years. Studies tracking the prices of BIPV systems in time have shown that the prices of BIPV systems have dropped from 8.000 €/kWp (or 950 €/m²) on average in 2004 to 3.300 €/kWp (or 400 €/m²) on average in 2015. [30] Even if these reductions are encouraging, they seem to have been stagnating in the last years. Indeed, there was no significant price drop to be noticed between 2015 and 2017, when it comes to BIPV products. [28]

4.2 Overview of current costs

4.2.1 End-user cost

This section aims at giving a brief overview of end-user cost for different BIPV applications. A longer discussion and quantified details can be found in Deliverable 1.1. [1]

In Section 4.1, the decreasing price of BIPV in the last decade has been evoked. A more detailed overview, i.e. making a distinction between the different existing technologies, on today's BIPV end-user cost is depicted here and put into perspective with the end-user cost of building envelope solutions using conventional construction materials (tiles, glass, concrete, stone …). As a reminder, the total end-user cost of BIPV not only considers the cost of BIPV modules, but also all other sources of cost, as it is defined as the final cost to be borne by the investor. Among others, it includes the cost of the fastening system, inverters, cabling or the labour costs associated with planning, installation and administrative work.

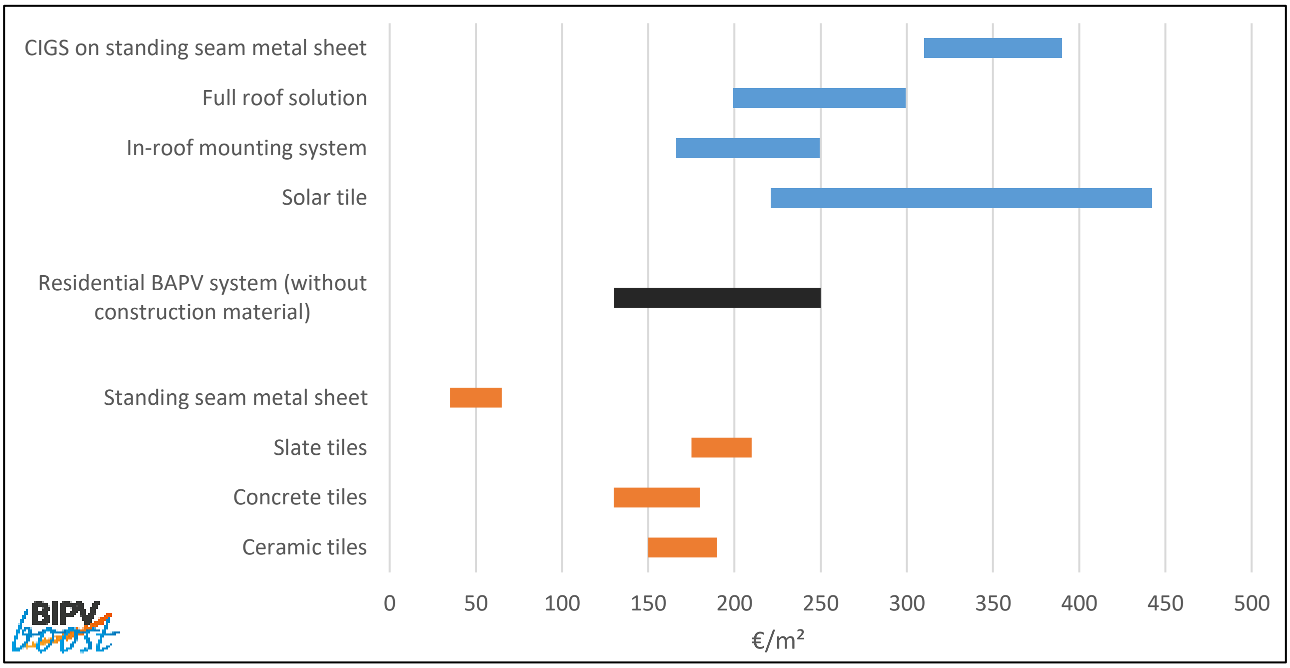

Figure 4.2 Comparison of the end-user cost of various roofing solutions, as of 2019

First, the end-user cost of BIPV in the case of roof application is examined and compared with its equivalent among traditional construction materials. The low prices of standing seam metal sheet, mostly used in the industrial sector, makes it difficult for BIPV to be competitive. As far as the different residential roofing solutions are concerned, the simplest solutions such as in-roof mounting systems can be, in some cases, more competitive than some type of tiles, on a pure cost basis. Full-roof solutions are slightly more expensive and are therefore less competitive. Then, the most expensive active roof solutions are solar tiles or seam metal roofing with an active layer, which are still far from being able to compete with conventional roofing systems. However, it is worth noting that the latter product is not at the same level of maturity as the other products, thus substantial cost reductions are still possible and expected only due by increased market penetration.

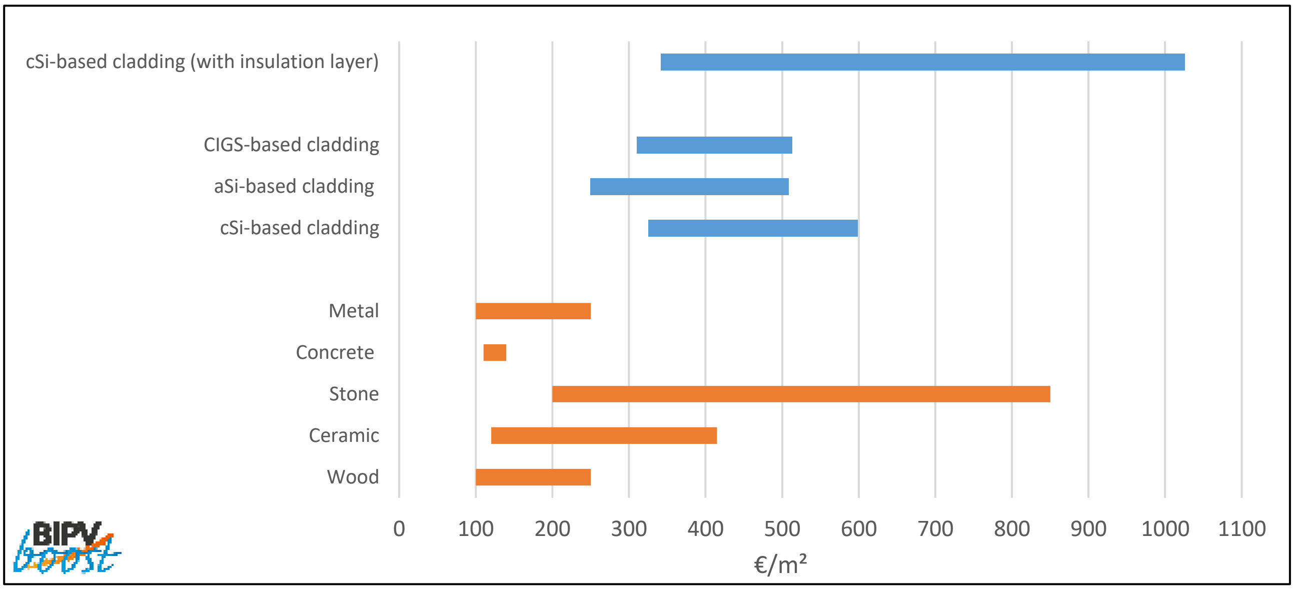

Figure 4.4 Comparison of the end-user cost of various ventilated façade (rainscreen façade) solutions, as of 2019

When it comes to rainscreen façade systems, in a vast majority of cases active solutions remain more expensive than conventional construction materials except in the case of stone and ceramic where the cost can range up to very expensive options. Other materials, such as glass, could also be part of the comparison but were not added here because of the lack of robust and precise data.

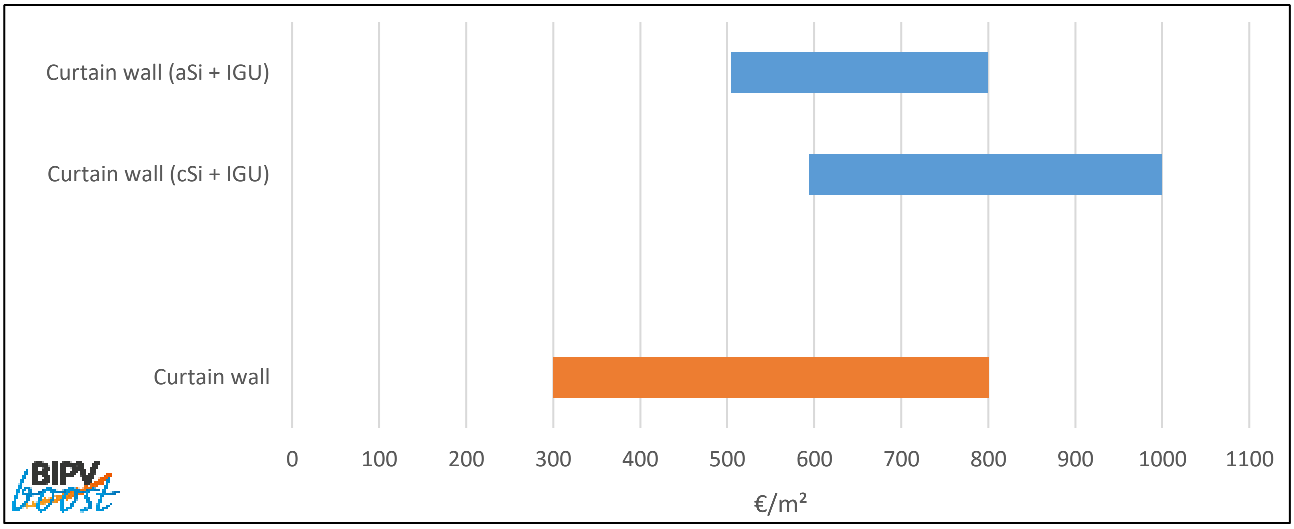

Figure 4.3 Comparison of the end-user cost of non-ventilated façade (curtain wall) solutions, as of 2019

Then, in the case of curtain walls, the gap between traditional construction systems and BIPV systems is more moderate. Indeed, the active solution can compete on a cost level with its non-active equivalents, under certain conditions.

Even if some important cost-reductions have already been achieved as presented in Section 4.1, BIPV is still globally more expensive than conventional building envelope solutions. Nevertheless, the gap is not insurmountable and, in some cases, BIPV solutions can under certain conditions already reach similar cost than some non-active solutions.

4.2.2 Structure of the end-user cost

The cost structure of the end-user cost of a BIPV solution (including manufacturing, development and installation) is showed on Figure 4.5 and Figure 4.6. The manufacturing process, resulting in the BIPV module cost, is the most important component of the end-user cost[3]. The remaining cost is divided quite equally between the planning and the construction processes, each of them accounting for 15 to 20% of the end-user cost. It can also be noted that the process steps that were highlighted in Section 3.6 (steps of the BIPV value chain that are impacted by improvements planned in the framework of the BIPVBOOST project), account for almost 90% of the total end-user cost.

This cost distribution between the different meta-processes and sub-processes will be used throughout the rest of the document to make assumptions on the impact on the end-user cost of an improvement at the scale of a given process step. This split is based on the data collected in the frame of BIPVBOOST Task 1.1 and was partially introduced in report D1.1 “Competitiveness status of BIPV solutions in Europe” already. These figures are in line with what can be witnessed in adjacent segments of the building sector, such as the construction of NZEB. [18] [15]

[3] Note that the detailed cost structure of “module assembling” step is not provided, for confidentiality reasons

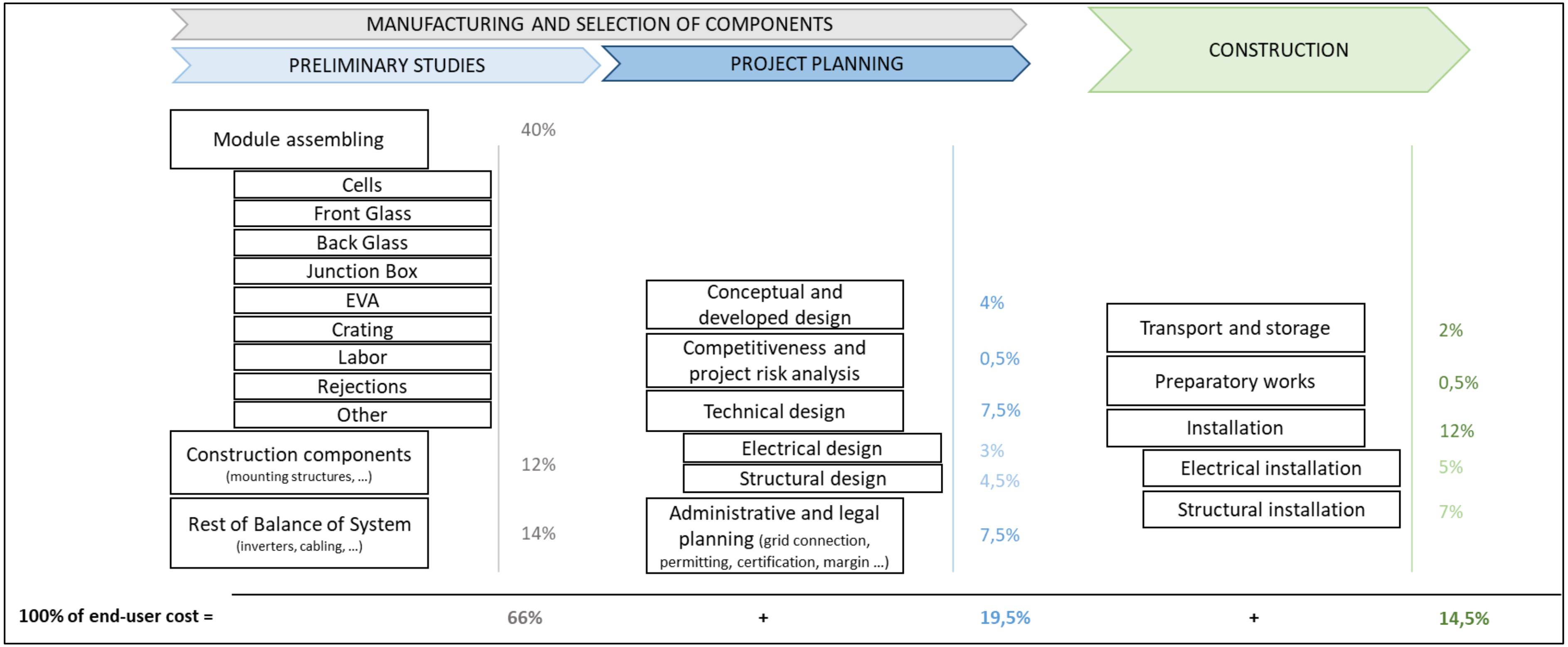

Figure 4.5 Indicative structure of the end-user cost for a typical roof application

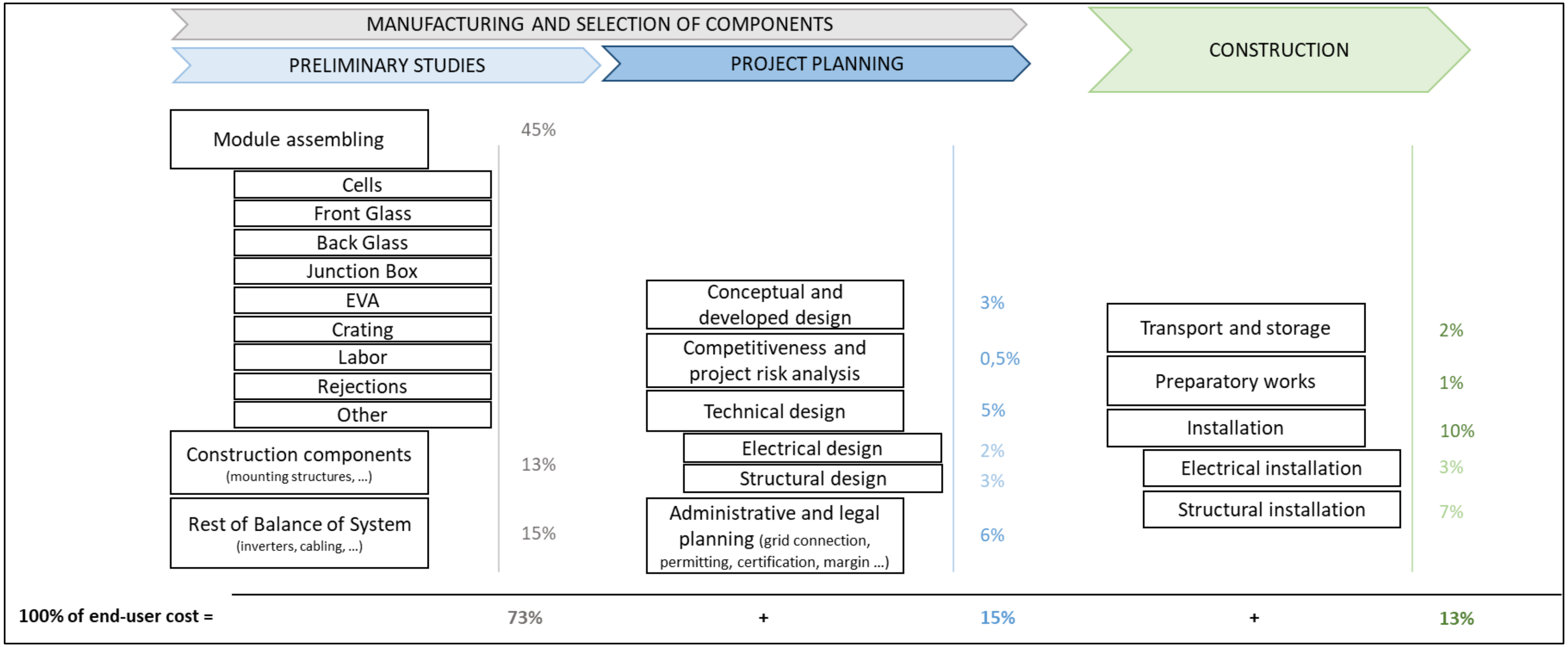

Figure 4.6 Indicative structure of end-user cost for a typical façade application

4.3 KPI values for each reference case

Seven reference cases are defined in Section 3.4 and will be the basis for the cost-reduction roadmap. They are characterised with 12 KPIs, which were presented in a previous section. In order to quantify both the improvements and their associated cost-reductions, the current values of these KPIs are defined in Table 4.1.

The intermediary KPIs' values have been collected or estimated first. Some values were defined based on the reference cases' characteristics from BIPVBOOST D1.1. Nevertheless, to define the reference cases' values of the remaining chosen KPIs, especially those related to installation or design times, some further pieces of information or assumptions were needed. To that end, BIPVBOOST project partners that are acquainted with these topics provided the missing information. Then, the competitiveness was calculated for each reference case based on the intermediary KPIs' values.

Table 4.1 Reference cases' KPI values

KPI_Id	Parameter	Unit	IB	SFH_b	EB_a1	EB_b1	EB_b2	MFH	OB_a1	OB_a2	OB_b1
KPI_1	**BIPV module efficiency***	[%]	15,1	18	15,1	16,6	16,6	17,5	2,7	2,7	10,5
KPI_2	**BIPV module cost****	[€/m²]	140	85	150	240	311	350	260	260	295
KPI_3a	**Degradation rate (year 1)**	[%/year]	0,7	1,8	0,7	1,8	1,8	1	1	1	1,8
KPI_3b	**Degradation rate (from year 2)**	[%/year]	0,7	0,5	0,7	0,45	0,45	0,25	1	1	0,45
System KPIs											
KPI_4	**End-user cost*****	[€/m²]	350	220	412	462	543	725	652	652	797
KPI_5	**Performance ratio**	[/]	0,8								
Project planning KPIs											
KPI_6	**Preliminary design time**	[h]	Only relative changes are considered								
KPI_7	**Technical design time**	[h]									
KPI_8	**Installation time**	[h/mod]									
Operational life KPIs											
KPI_9	**System lifetime**	[year]	20								
KPI_10	**O&M cost**	[€/m²*year]	2		5						
KPI_11	**Self-consumption rate**	[%]	90	30	70			60	70		
Main KPI											
KPI_12	**Competitiveness******	[€/m²]	-243	-45	-286	-321	-392	-559	-550	-470	-630

* Note that for reference cases based on semi-transparent solutions (OB_a1, OB_a2, OB_b1), BIPV modules are assumed to have a 50% transparency level. Therefore, an equivalent opaque solution would have an efficiency value twice as big.
** Cost measured at "factory gate"
*** Including all sources of cost, such as planning, materials as well as installation (VAT excluded, except in the residential cases)
**** Competitiveness refers here to the "total costs and revenues of ownership" competitiveness under the "value-based approach", as defined in BIPVBOOST D1.1

5 COST REDUCTION ROADMAP

5.1 Presentation

This section aims at presenting an inventory of the improvements which are foreseen to have an impact on the cost and competitiveness of BIPV solutions. They will form the basis of the cost-reduction roadmap, once classified per time-horizon and process step. For that purpose, distinction is first made between direct and indirect costs, then between BIPV-related, PV-related and construction-related improvements. Direct costs are related to materials and components, while indirect costs refer to other sources of cost such as labour, design or administrative and legal planning. Then, BIPV-related improvements are classified in function of the process step, presented at Section 3.6, they refer to. Regarding the chosen time-horizon, it is based on the scheduling of BIPVBOOST project (end of the project in 2022) and the timing defined in the SET Plan (goals set at 2025 and 2030). In the different sources identified thanks to the literature review, the impacts of various improvements are only known for specific years. In addition, the introduction of a certain improvement on the market can follow different paths (continuous or discontinuous). Therefore, when the impact was only known for year N, it was assumed that before year N no impact would be seen.

It is important to note that all the cost-reductions values are expressed in nominal terms. Concerning improvements that are planned in the frame of the BIPVBOOST project, their grey heading ribbon is highlighted in the following sub-sections, with the project's logo. For those improvements, the cost impacts are based on the information provided by project partners, thus explaining the absence or lack of references in related paragraphs. For each improvement, a general description is given, describing the improvement and explaining how it can be achieved, as well as which market segments (products, technologies, …) are concerned by the impacts. Then, the impacts on associated KPIs are listed and quantified. The different relative KPI increases or decreases are defined based on 2019 base case values. Finally, the potential barriers to implementation of those improvements are presented, along with the involved stakeholders.

5.2 Direct costs improvements

5.2.1 PV related

BIPV is a market segment of the PV sector as much as it can also be considered as a market segment of the construction sector because of its double function of electricity generator and construction material. As mentioned already, it has largely taken advantage of innovations and cost-reductions introduced to increase the competitiveness of PV systems. Moreover, the PV sector is still a breeding ground for even further improvements that will benefit the BIPV sector. This applies mostly to direct costs such as raw materials (such as silicon) and basic components (cells, inverters) which are used for both PV and for BIPV even though some minor adjustments might apply some cells' type, for example, might be more relevant for one or the other application. Therefore, it is relevant to study here what improvements are likely to be implemented in the PV sector, and what associated cost-reduction can be expected.

5.2.1.1 Silicon and wafers

Silicon and wafer represent respectively 28% and 38% of a solar cell price. Silicon is the material representing the highest share in the total cell cost. [31]

IMPROVEMENT IN SILICON CRYSTALLISATION

Description:

To achieve lower cost of silicon crystallisation, two main improvements can be cited. The first being the production of bigger ingots. The current common size of a multicrystalline silicon ingot is 1100 kg and it could reach 1500 kg in 2030. As far as monocrystalline silicon is concerned, a more moderate increase should take place, with 250 kg ingots in 2019 expected to reach 350 kg in 2030. As crystallisation is a batch process, it is relevant to increase the quantity of material processed per batch and thus, the unit costs. Indeed, long preparation times for charge and discharge are required for each batch, representing and important cost. Then, the mainstream processes that are used to produce silicon are the Siemens process for multicrystalline silicon and the Czochralski process for monocrystalline silicon. These processes are all highly energy intensive and therefore the reduction of the energy consumption during the crystallisation process is an additional improvement that will lead to cost-reductions. This could be achieved by transitioning to a FBR (Fluidised Bed Reactor) process for multicrystalline silicon. While energy consumption for monocrystalline silicon ingots is expected to drop from 32 kWh/kg in 2019 to 25 kWh/kg in 2030, multicrystalline silicon ingots should remain at their 2019 level of 6-7 kWh/kg. [12] [32] [33]

Cost impact:

As these improvements concern any PV technology using silicon, which still concerns an major share of available BIPV products on the market and as the module cost remains the biggest cost item of the total end-user cost, they are relevant to explore in the framework of this BIPV cost-reduction roadmap. The relative cost-reductions compared to 2019 values are summarised in Table 5.1. By taking into account the estimated share of silicon cost in the solar cell cost and the approximate share of cell cost in the BIPV module cost, the impact of this improvement on the KPI module cost can be calculated. [31]

Table 5.1 Silicon and BIPV module relative cost-reductions until 2030

	Unit	*2022*	*2025*	*2030*
Mono Si	/	-11,1%	-11,1%	-16,7%
Multi Si	/	-15,7%	-21,1%	-23,2%
Mono Si based BIPV module cost	€/m²	-1%	-1%	-1,5%
Multi Si based BIPV module cost	€/m²	-1,4%	-1,9%	-2,1%

Barriers to implementation:

Purification levels of the FBR and metallurgical solar grade silicon still have to be demonstrated. [32]

Stakeholders involved:

Silicon ingot and wafer manufacturers

IMPROVEMENT IN WAFERING TECHNOLOGIES

Description:

The wafering process includes wire sawing, cleaning, sorting and testing. The improvements related to the wafering process will mainly concern improved slicing and kerf losses reduction, better handling (to avoid breakage) and better process control (fewer defects). This should be mainly reached through thinner and even ultra-thin wafers (down to 100 microns). Current wafer thicknesses lie around 175-180 µm. While p-type multi and mono for Al-BSF cells should reach 160 µm in 2029, p-type multi and mono for PERx cells could even fall to 140-145 µm. As far as HJT or IBC technologies are concerned, thickness values nearing 125-135 µm for n-type mono wafers can even be expected. [12] [32] [33] One can also mention the tendency to progressively increase wafer sizes. These allow to maximize output will using existing production lines. Various commercial products are already equipped with 158,75 mm², 161,75mm² or even 166 mm² cells, and their market share are projected to rapidly increase. [21] Some key actors of the solar PV sector have already committed to adapt 100% of their wafer production lines in the medium-term, such as LONGi Solar. [34]

Cost impact:

These improvements materialise through wafer cost reduction as summarised in Table 5.2, among others by permitting to reduce the average consumption of silicon per Wp. By taking into account the share of wafer cost in the solar cell cost of 38% and the share of cell cost in the BIPV module cost, the impact of this improvement on the "BIPV module cost" KPI can calculated. [31]

Table 5.2 Wafer and BIPV module relative cost-reductions until 2030

	Unit	*2022*	*2025*	*2030*
Mono Si based wafer cost	€/Wp	-10,8%	-16,2%	-21,6%
Multi Si based wafer cost	€/Wp	-18,4%	-21,1%	-21,1%
Mono Si based BIPV module cost	€/m²	-1,3%	-2%	-2,6%
Multi Si based BIPV module cost	€/m²	-2,2%	-2,6%	-2,6%

Barriers to implementation:

Manufacturing processes will have to be adapted to make sure breakage rate do not increase as thickness decreases and that coating and metallization can be applied uniformly even though wafer size increases. Although these still appear as limited barriers. [35]

Stakeholders involved:

Wafer manufacturers

5.2.1.2 Cells

IMPROVEMENT OF OVERALL EQUIPMENT EFFECTIVENESS OF CSI CELL PRODUCTION TOOLS

Description:

A solar cell manufacturing line is decomposed into front-end (thermal and chemical) processes and back-end (metallisation and classification) processes. The individual cells are manufactured in the front-end process while the assembly takes place in the back-end process. In order for the production lines to function in an optimal way, the throughputs of both processes should have similar capacity. Currently, front-end processes have a capacity around 5000 wafers/h. Currently metallisation tools have a throughput of around 6000 wafers/h, while wet chemical processing is leading with 8000 wafers/h. Thermal processes have lower throughputs. [33] [36]

Cost impact:

The improvement of equipment effectiveness of both processes will impact the module cost positively. By considering the respective shares of the front-end and the back-end process in the cell cost of 65% and 35%, and then the share of cell cost in the total module cost , and under the assumption that a relative increase of equipment effectiveness will lead to a symmetric relative decrease on the cell cost, the impact on the module cost can be quantified. **[33] [31]**

Table 5.3 BIPV module cost relative decrease by 2030

	Unit	*2022*	*2025*	*2030*
Overall equipment effectiveness of cell production tools for front end process (chemical and thermal)	Wafers/h	+4,4%	+4,4%	+6,9%
Overall equipment effectiveness of cell production tools for back end process (metallisation and classification)	Wafers/h	+4,4%	+4,4%	+4,9%
BIPV module cost	€/m²	-1,4%	-1,4%	-1,9%

Barriers to implementation:

Limited

Stakeholders involved:

Manufacturers of PV cells production equipment, PV cells manufacturers

IMPROVEMENT OF METALLISATION COSTS

Description:

The metallisation pastes which use aluminium and silver represents the highest non silicon material cost, thus making it a relevant field for improvement. Lower cost can be achieved through new pastes recipes that require less aluminium and silver such as adhesive pastes or mixed ones. If the mass contribution of aluminium is 2 to 10 times more important than silver, the cost of silver surpasses by far the cost of aluminium thus making it the predominant material cost in the metallisation process. In addition, the price of silver is highly dependent to the global market. [31] [33]

Cost impact:

The foreseen reduction of aluminium and silver quantities used per cell are gathered in Table 5.4. These reductions are likely also valid for n-type cells, but lack of sources makes it difficult to quantify. Therefore, they are not presented here. By considering the share of metallisation pastes cost in the solar cell cost of 9%, the respective contribution of aluminium and silver in the metallisation cost of 23% and 77% and the share of cell cost in the BIPV module cost, the impact of this improvement on the “BIPV module cost” KPI can be calculated. [31]

Table 5.4 Silver, aluminium and BIPV module relative cost-reductions until 2030

	Unit	*2022*	*2025*	*2030*
Aluminium use for monofacial cells	kg	-17,9%	-20,5%	-30,3%
Silver use for p-type monofacial cells	kg	-22,2%	-33,3%	-44,4%
Monofacial p-type based BIPV module cost	€/m²	-0,6%	-0,9%	-1,2%

Barriers to implementation:

Limited

Stakeholders involved:

Manufacturers of PV cells production equipment, PV cells manufacturers, metallisation paste manufacturers

IMPROVEMENT OF CELL EFFICIENCIES

Description:

Even if in the last decades cell efficiency values have highly increased, there is still potential for all technologies to improve their performance. Cells based on n-type wafers, in particular, are expected to show a higher efficiency increase potential, as compared to p-type cells which have already reached a more advanced level of maturity.

Cost impact:

The cell efficiency increases are gathered in Table 5.5. Under the assumption of a constant cell-to-module power ratio, the relative increase of cell efficiency can be applied to the KPI module efficiency. These efficiency increases have an impact on the competitiveness of a BIPV solution by increasing the electricity production.

Table 5.5 Cell and BIPV module relative efficiency-increase until 2030

	Unit	*2022*	*2025*	*2030*
Multi Al BSF cell efficiency	%	+2,1%	+3,1%	+4,1%
Mono Al BSF cell efficiency	%	+2%	+3,4%	+4,9%
IBC cell efficiency	%	+2,9%	+4,6%	+5,8%
Multi Al BSF based BIPV module efficiency	%	+2,1%	+3,1%	+4,1%
Mono Al BSF based BIPV module efficiency	%	+2%	+3,4%	+4,9%
IBC-based BIPV module efficiency	%	+2,9%	+4,6%	+5,8%

Further examples of cell efficiency values that will be reached in 2030 for different technologies such as multi and mono PERC can be added. Average multi PERC and mono PERC cells' efficiencies would respectively reach 21,9% and 23,5% in 2030, according to VDMA. HJT cells would hit an impressive 25,4%. [33] As far as perovskites-based cells are concerned, they should enter the market in the coming years in tandem with conventional n-type cSi cells, with efficiencies above standard figures and have the potential to increase up to even 30% in the medium-term. [37] Although, the impact on module efficiency for those technologies will not be here presented in detail as they are not studied in the reference cases.

Barriers to implementation:

Limited

Stakeholders involved:

Manufacturers of PV cells production equipment, cell manufacturers, researchers.

5.2.1.3 Module

REDUCED DEGRADATION OF SYSTEM'S PERFORMANCE

Description:

A further element worth adding, even if it only has a marginal effect, is the improvements in terms of average degradation rate of performances per year. The impact of such technical improvement on yearly degradation rate values can be estimated to lie between 5% and 15%, in relative terms. Improvements are considered to start plateauing around 2025. [21] These are highly dependent of the PV technology considered but, in this case, a general average has been considered.

Cost impact:

As shown through the sensitivity analysis conducted in the framework of BIPVBOOST D1.1, a 20% relative decrease of yearly degradation rate (which is not even what is expected to be reached by 2030) would only result in a 4,5% relative increase of competitiveness.

Table 5.6 Yearly degradation rates' relative decrease until 2030

	Unit	*2022*	*2025*	*2030*
Average yearly degradation rate	%	-5%	-12,5%	-15%

Barriers to implementation:

Limited

Stakeholders involved:

Cell and module manufacturers, researchers, manufacturers of cell and module production equipment.

IMPROVEMENT OF THE CTM[4] POWER RATIO

Description:

The cell-to-module ratio can be optimised through two main means. The first one is by improving the light management and to reduce optical losses. This can be achieved by diminishing the surface of inactive areas (spaces between cells, busbars, …) and by making the inactive areas participate in the light distribution within the module by increasing their reflectance. Smaller inactive areas can be achieved through ribbons with smaller widths, whereas higher inner reflectance can be reached with the use of round or textured tabs which reflect the light partially back to the cells, or by using reflective material such as white backsheet or even

[4] Cell-to-module

white EVA on the rear side of the module. The second way to increase CTM ratio is to decrease resistive losses. Resistive losses increase with longer distances travelled by the current and decrease with higher cross sections. Smaller travelled distances can be achieved through increased number of busbars which has the side-effect of increasing inactive surfaces. Thus from 3 busbars in 2015 an optimum seems to be currently reached with 5 busbars. Higher cross sections seem a priori contradictory with the previously mentioned need for smaller ribbon width to diminish shaded areas. The solution is to reduce the width while increasing the height thus remaining at a constant cross section. This allow in some cases to even reduce the total area of the cell covered, even if the number of busbars, is increased. [38] [39] One can also mention the multi-busbars or multi-wires solutions, which can go up to 12 busbars/wires.

Cost impact:

The impacted KPI by improvements related to the CTM power ratio, is the module efficiency. This impact is evaluated to amount to a 0,5% relative increase by 2022 and 3% by 2030 for cSi as shown in Table 5.7. [38] [39]

Table 5.7 BIPV module efficiency relative increase until 2030

	Unit	*2022*	*2025*	*2030*
BIPV module efficiency - cSi	%	+0,5%	+1,5%	+3%
BIPV module efficiency – CIGS	%	+10%	+20%	+33,3%

Barriers to implementation:

Limited

Stakeholders involved:

Module manufacturers, manufacturers of module equipment production line

ADVANCED MODULE DESIGN AND TOPOLOGY

Description:

In line with the previous improvement’s target of obtaining the highest module efficiency with a given cell efficiency, advanced module design aims at optimizing cell layout and placement onto the module. The two main innovative techniques currently explored and implemented by the industry are half-cut cells and shingling, although the first one is more widespread due to easier implementation in factories. Shingling consists in making cells overlap each other. The connection which is traditionally provided by ribbons placed on the cells is, in the case of shingled cells, made with a conductive adhesive on the overlap. Thus, the space between cells is reduced to almost none and the inactive surface due to ribbons is avoided. As far as half-cut cells are concerned, resistive losses are directly tackled. Resistive losses increase proportionally with the square of the electrical current. Another important factor in the case of BIPV is the improve aesthetics of shingled modules, compared to traditional module configuration based on full or even half-cells. [38] [40] [41]

In addition, by improving the module topology, the power output can be optimised when some cells are shaded or partially shaded. Indeed, the technical challenge lies in the fact that cells connected in series in the same string must have the same current. In case of partial shading, some cells can only produce a certain share of the maximum power, ideally proportional to the non-shaded surface. Current techniques consisted in either bringing all the cells of a same string to a lower current and therefore making them work in the active part, despite losing some power (the mismatching losses), or to drive full current through the cells that are not shaded and to “switch off” the shaded cells (this is usually not possible in standard modules). New techniques consist in MPPT (Maximum Power Point Tracking) for example which allow based on smart algorithms to get maximum power available in the PV module, thus reducing the mismatching losses. The results of those algorithms are enhanced by optimised stringing. Such improvements are particularly important in the case of BIPV, as shading is a major issue, especially in urban environments. [24] [39]

Cost impact:

Enhanced module design impacts positively the module efficiency, while an improved module topology allows a higher power output over the system’s lifetime in different light conditions, materialised through the KPI performance ratio. Absolute losses due to shading represent around 5% in BIPV systems thus making improvements with regards to this matter a further source of cost-reductions.

Table 5.8 BIPV module efficiency relative increase until 2030

	Unit	*2022*	*2025*	*2030*
BIPV module efficiency – cSi cells	%	+0,5%	+2,5%	+10%
Performance ratio	/	+1%	+2,5%	+5%

Barriers to implementation:

Production methods for shingled cells are more complex and imply higher costs. Indeed, shingling cannot be made with current production lines even if updated. Nevertheless, these higher costs are compensated by higher module power outputs. The half-cut technology requires few further steps, the main one being the cell cutting.

Stakeholders involved:

Cell and module manufacturers, researchers, manufacturers of cell and module production equipment.

INNOVATIVE ENCAPSULANT MATERIALS

Description:

Currently the main encapsulant material that is used in the PV industry is EVA (ethylene vinyl acetate). Other materials with facilitated treatment properties, reduced energy needs and efficiency increase potential have been examined as alternatives to EVA. Silicon could be this alternative material. [32] Polyolefin-based encapsulants, are also explored as possible low-cost, more stable alternatives (i.e. with reduced or no yellowing).

Cost impact:

The end-user cost reduction that can be assimilated to this improvement is shown in Table 5.9.

Table 5.9 End-user cost relative reductions by 2030

	Unit	*2030*
Total end-user cost	€/m²	-0,88%

Barriers to implementation:

Stability and durability, especially in terms of aesthetics, which is crucial in BIPV

Stakeholders involved:

Researchers, polymer manufacturers

IMPROVED MODULE DURABILITY

Description:

The development of more flexible and automated production lines will allow higher precision and quality levels and consequently longer BIPV system lifetimes. The development of such equipment for cSi and IBC cells is part of the BIPVBOOST project and are presented into more details as far as efficiency increase and end-user cost decrease are concerned in Section 5.2.3.1. Only the improved module durability allowed by these innovations is addressed in this paragraph. The improvement is applicable to any cell technologies but not relevant for all of them. Indeed, reaching longer system lifetime for technologies such as cSi, IBC or CIGS can increase the competitiveness. On the contrary, the improvement is not relevant for aSi based BIPV modules as they are characterised by important degradation rates and low efficiency which with extended lifetimes do not allow to generate sufficient electricity volumes to generate positive cash flows.

Cost impact:

The BIPV system lifetime is projected to increase by 25% until 2022 and by 50% by 2030.

Table 5.10 System lifetime relative increase until 2030

	Unit	2022	2025	2030
System lifetime (cSi, IBC, CIGS)	years	+25%	+40%	+50%

Barriers to implementation:

Intrinsic technical limitation due to the stability of materials. Great variety of operating conditions. Risks due to improper installation.

Stakeholders involved:

Cell and module manufacturers, researchers, manufacturers of cell and module production equipment, PV modules' and systems' components manufacturers

5.2.1.4 Inverters

IMPROVEMENT OF INVERTERS

Description:

Most current inverters have an operational lifetime of 15 years at most, which implies that they must be replaced during the BIPV system's lifetime at least once. Through the use of new materials and components which will allow reduced stress on components and improved reliability, the lifetime of inverters is expected to reach 30 years, thus matching the one that BIPV installations will typically have by 2030. In addition, with the help of monitoring, potential faults could be detected earlier, thus easing the maintenance.

A further technological improvement will consist in higher bus DC allowing a bigger AC connection and thus a higher power in the inverter, which can contribute to reduce the cost per Wp.

Then, economies of scale are worth mentioning for inverters as the market keep expanding. [42] In addition, the increasing global market will continue to stimulate inverter cost-reductions. [32] [12]

Cost impact:

The above-mentioned improvements will lead to both reduced costs on operation and maintenance processes, through increased lifetime and reliability as well as to reduced inverter cost. The latter will consequently lead to reduced end-user costs. By considering the share of operation and maintenance costs associated to inverters' replacement in the total O&M costs, which approximately equals 35%, the cost-reductions impacting O&M costs can be quantified. The estimated share of inverter cost in the total end-user cost of 8,4% allows to determine the end-user cost-reduction. Both cost impacts are summarised in Table 5.11. [1] These estimated figures are in line with the historical learning rates.

Table 5.11 Inverter, end-user and O&M relative cost-reductions by 2025

	Unit	*2025*
String inverter cost	€/Wp	-20%
Micro inverter cost	€/Wp	-18%
Total end-user cost for string inverter-based systems	€/m²	-1,66%
Total end-user cost for micro inverter-based systems	€/m²	-1,51%
O&M cost	€/m²*year	-35%

Barriers to implementation:

As economies of scale will drive cost-reductions for this improvement, market barriers can be cited.

Stakeholders involved:

Inverter manufacturers

5.2.1.5 Rest of BoS

IMPROVEMENT OF REST OF BOS

Description:

Balance of system's improvements, aside of those related to inverters, encompass for example cabling, racking and mounting. As far as cabling cost-reductions are concerned, they could be achieved through smaller cable distances thanks to higher module efficiencies. Indeed, with higher efficiencies and for an equal installed capacity, the installation volumes can be reduced, and thus the total cabling length. For instance, a 15% per-watt cable cost reduction can be expected with a relative module efficiency increase of 20%. Smaller cable diameters achieved thanks to higher voltage could also contribute to cabling cost-reductions. With regards to mounting structures, their adequate dimensioning and optimization could also help decrease BoS costs. For the remaining BoS elements, plug and play cabling connections, material usage reductions, better optimisation can be cited as contributors to the overall cost-reduction. [12]

Cost impact:

Learning curves for balance of system costs lie around 89%. This corresponds to a progress ratio of approximately 11% by considering an average scenario for the PV market development. [43] [44] Compared to other studies, this value can be considered as slightly aggressive. [45] All in all, this value would correspond to a 17% BoS cost-reduction and a 6% end-user cost reduction by 2025.

Table 5.12 End-user cost relative reductions by 2025

	Unit	*2025*
Total end-user cost	€/m²	-6%

Barriers to implementation:

Limited

Stakeholders involved:

BIPV products manufacturers and installers, Manufacturers of mounting, wiring, connectors, …

5.2.2 Construction industry related

PREFABRICATION AND MODULARITY OF BUILDING ENVELOPE ELEMENTS

Description:

Shifting a part of the on-site installation to the manufacturing process through the development and usage of prefabricated and modular building envelop elements, has multiple advantages. Indeed, as the on-site assembly is shortened, labour costs are proportionally diminished. [15] Other benefits such as lower dependency on weather conditions, which can cause delays, can also be mentioned.

Cost impact:

The KPI that monitors this improvement is the installation time, which eventually impacts the end-user cost. Indeed, installation costs account for 12% in the case of typical roof applications (10% for typical façade applications) of the total end-user cost. The assumption is made that a X% installation time reduction will impact the total end-user cost by $12\% * X\%$, as installation cost is directly related to the associated duration. This assumption is made possible by the fact that labour costs in this process step are important as compared to material costs. [15]

Table 5.13 Installation time and end-user cost relative decrease until 2030

	Unit	*2022*	*2025*	*2030*
Installation time	hours/m²	-10%	-30%	-50%
End-user cost-reduction – Roof application	€/m²	-1,2%	-3,6%	-6%
End-user cost-reduction – Façade application	€/m²	-1%	-3%	-5%

Barriers to implementation:

Prefabrication and modularity can still present some technical challenges. Nevertheless, prefabrication is possible even for small quantities, therefore allowing many possibilities for product personalisation.

Stakeholders involved:

BIPV product manufacturers, BIPV installers.

5.2.3 BIPV related

5.2.3.1 BIPV module assembling

ECONOMIES OF SCALE AND INDUSTRIALISATION

Description:

A substantial source of cost reduction in manufacturing is economies of scale. This allows among others to spread fixed costs on larger production output, or to benefit from more advantageous cost conditions when supplying some input materials. This trend and its impact on PV module cost have been studied and quantified, in link with the evolution of the global PV market. [46]

Cost impact:

Between 2001 and 2012, module costs have decreased by 73%. Among those 73%, 46% were related to economies of scale. Consequently, the module cost decrease, on this 11-year period, that was assignable to economies of scale amounts to -34%. As 11 years is the duration of the 2019-2030 period studied within this deliverable and assuming that the BIPV market could have comparable growth rates between 2019 and 2030 as the PV market did between 2001 and 2012, considering as a best-case, it can be estimated that economies of scale will contribute to module cost-reductions to the same extent. [46]

Table 5.14 BIPV module cost relative decrease until 2030

	Unit	*2022*	*2025*	*2030*
BIPV module cost	€/m²	-5%	-20%	-30%

Barriers to implementation:

The impacts of this improvement could be hindered by a market barrier as the improvement is completely dependent on the PV market growth.

Stakeholders involved:

BIPV module manufacturers, real estate investor, general construction companies

AUTOMATIC AND FLEXIBLE BIPV PRODUCTION LINES FOR CSI CELLS

Description:

This improvement relates to the manufacturing process of BIPV products based on crystalline silicon cells. It consists in increasing the automation degree without lowering flexibility. The string lay-up which was until now manually executed is going to be automated. Thus, a higher position precision can be achieved as well as reduced cell breakage. In addition, high-resolution electroluminescence quality control machines will enable to detect crack early in the process thus avoiding extra reworking. Overall, manpower needs will be reduced by a two-fold and scraps by a five-fold factor.

Cost impact:

The position precision, which is made possible with the automated string placement, allows to use thinner strings which, because they reduce the covered cell surface, improve module efficiencies. Then, the reduction of cell breakage reduces the total module cost. Finally, by improving the crack detection, the module cost but also system durability and therefore lifetime is increased. These impacts are summarised in terms of KPI on Table 5.15.

Table 5.15 Module efficiency relative increase & module and end-user relative cost-reduction for 2030

	Unit	*2022*	*2025*	*2030*
BIPV module efficiency	%	+10%	+14%	+25%
BIPV module cost	€/m²	-12%	-19%	-25%
Total end-user cost – Roof application	€/m²	-5%	-8%	-10%
Total end-user cost – Façade application	€/m²	-5%	-9%	-11%

Barriers to implementation:

Limited

Stakeholders involved:

Manufacturers of BIPV module production equipment, BIPV module manufacturers.

AUTOMATIC AND FLEXIBLE BIPV PRODUCTION LINES FOR BACK-CONTACT CELLS

Description:

The prices for back-contact cells-based module are relatively high compared to products based on mainstream cSi cells. This is due to the higher price of IBC cells itself but also because the cells-to-string welding process is manual, requiring high manpower costs and hindering the manufacturing process from reaching higher production rates, reasonable delivery times, and low rejection rates. With the development of an automated and flexible BIPV production line for back-contact cells, in parallel with the abovementioned improvement, which would make it the first automated welding machine for back-contact cells compatible with glass-glass lamination in the industry, significant cost-reductions should be achieved. The main cost-reduction drive will be the significant reduction of manpower costs, which could be more than halved. As for the automatic and flexible production lines for cSi cells, higher module efficiencies should be achieved.

Cost impact:

The impact is similar to the one of the abovementioned improvements. Therefore, higher cell efficiencies will be achieved as well as lower modules costs through the reduction of cell breakage and reduced manpower costs. These impacts on KPI are summarised in Table 5.16.

Table 5.16 Module efficiency relative increase and module and end-user relative cost-reduction for 2022

	Unit	*2022*
BIPV module efficiency	%	+14%
BIPV module cost	€/m²	-21,4%
Total end-user cost – Façade application	€/m²	-9,6%

Barriers to implementation:

Limited

Stakeholders involved:

Manufacturers of BIPV module production equipment, BIPV module manufacturers.

DEVELOPMENT OF A PORTFOLIO OF GLASS-GLASS AESTHETICALLY ADVANCED COLOURED SOLUTIONS

Description:

Some of currently used colouring solutions such as mass-coloured glass, impact the module efficiency because the colouring is applied in front of the cells, thus reducing the energy harvested. On the other hand, in the case of ceramic frits or powder paint alternatives, the colouring is behind the cell, thus preserving the cell efficiency as is. The improvement therefore consists in using techniques that combine both the advantage of not affecting the cell efficiency and reducing costs (in the case of powder paints). Indeed, low cost powder paints for opaque coloured solutions reduce the cost of ceramic frits by 70%. This improvement is of high relevance as BIPV serves also the function of a building element, which creates expectations in terms of aesthetics, including colours.

Cost impact:

The impact on the end-user cost can be deduced based on the extra cost of material (powder paint) and manufacturing process steps.

Table 5.17 End-user cost relative decrease until 2030

	Unit	*2022*	*2030*
End-user cost – Façade application (coloured)	€/m²	-28%	-41%

Barriers to implementation:

Limited

Stakeholders involved:

Manufacturers of BIPV module production equipment, BIPV module manufacturers.

DEVELOPMENT OF A PORTFOLIO OF GLASS-GLASS AESTHETICALLY ADVANCED PATTERNED SOLUTIONS FOR ASI BASED MODULE

Description:

For amorphous silicon modules to achieve certain levels of transparency (typically 10% to 30% transparency), the technic used is to remove the aSi layer with a laser following a homogenous pattern along all the module surface. This technique could be used to remove the aSi layer following a specific pattern (stripes, squares …). By removing a comparable amount of aSi layer thus achieving similar transparency levels, the efficiency would also be unaffected.

Cost impact:

As explained above, this improvement will not impact the module efficiency. This solution should be fully cost competitive with digital printing for non-active solutions. This improvement, as the one described above on coloured solutions, is particularly relevant for the BIPV sector because it will make aesthetic and customised solutions more affordable thus making BIPV more attractive to consider for architects for example. The impact of this improvement can be measured with the end-user cost.

Table 5.18 End-user cost relative decrease until 2030

	Unit	*2022*	*2030*
End-user cost	€/m²	-32%	-45%

Barriers to implementation:

Limited

Stakeholders involved:

Manufacturers of BIPV module production equipment, BIPV module manufacturers.

MULTIFUNCTIONAL BIPV FAÇADE CLADDING SYSTEM WITH INTEGRATED INSULATION

Description:

This improvement consists in the development of a BIPV prefabricated façade element that will fulfil multiple functions such as thermal insulation, noise protection and electricity generation. This solution will be suited both for any type of BIPV module. For this solution to be affordable, manufacturing processes will be optimised, and easy mounting systems will be developed to reduce both production costs and installation time.

Cost impact:

This improvement has a particular interest for the BIPV sector because it will help BIPV systems to contribute to nZEB regulations while remaining at reasonable prices. Both the reduction of installation time and production costs will contribute to the decrease of end-user costs over time as summarised in Table 5.19.

Table 5.19 End-user cost relative decrease until 2030

	Unit	*2022*	*2025*	*2030*
End-user cost – Façade application	€/m²	-28%	-31%	-37%

Barriers to implementation:

Different barriers may affect the development or expected impact of this improvement. First, technological barriers should be considered. Indeed, the presented product gathers different technologies (thermal insulation, noise protection, fire safety, …) which are not necessarily well-suited to be combined. For example, the selection of a material due to its ability to fulfil a certain function might not be suitable for another function. Furthermore, the addition of electric installation to the currently used installation systems products could imply some difficulties and risks.

Then, barriers related to the market or to communication and dissemination can also represent a threat for the impacts to be reached as planned especially on the medium to long-term (2025 to 2030). Indeed, good results rely on an increasing market demand as well an on an efficient communication on the new product. Therefore, reaching targets beyond 2022 has medium certainty of being achieved.

Stakeholders involved:

BIPV module manufacturers, façade installers, façade elements manufacturers, BIPV installers

5.2.3.2 Construction components

ENHANCED, COST EFFECTIVE ROOF SYSTEM BASED ON LIGHTWEIGHT CIGS ON METAL

Description:

This improvement consists in developing a BIPV roof system based on lightweight CIGS on metal. The cost-reduction will be driven by lower manpower and transport costs thanks to lower weight thus making the handling and mounting easier.

Cost impact:

It is expected to reach up to 34% of end-user cost-reduction by 2022 and up to 55% by 2030. This improvement is particularly relevant for buildings with lightweight requirements due to mechanical constraints and typical big roof surfaces.

Table 5.20 End-user cost relative decrease by 2030

	Unit	*2022*	*2030*
End-user cost – Roof application	€/m²	-34%	-55%

Barriers to implementation:

The typical building typology for this improvement are industrial buildings which represent large surface. It thus favours economies of scale and make the price competition fierce. Therefore, it can be considered that the major barrier for this improvement is a market entry barrier.

Stakeholders involved:

BIPV module manufacturers, roof installers, roofing elements manufacturers, BIPV installers, mounting structure manufacturers.

LOW COST CLICK & GO SUBSTRUCTURE FOR BIPV MODULES

Description:

This improvement consists in developing an easy mounting structure with upgraded design for glass façade applications. By improving the design, the number of components can be reduced while enhancing the aesthetical aspect. In addition, standardised designs and certification at European level can be developed. [22] Through the easier installation, cost-reduction can be achieved by reducing the necessary time of this step. In addition, by using lighter mounting structures, further labour cost-reduction can be reached as well as cost-reduction with regards to transport and crating. Finally, the mounting structure assembly line is being upgraded to reduced significantly gluing and overall assembly times. [12]

Cost impact:

The impacted KPI is the mounting structure cost which includes the rear frame glued to the PV modules, the mounting rail system on the building and their installation (material, labour, transport). By considering the share of the mounting cost in the total end-user cost of approximately 30%, the impact on this second KPI can be deduced.

Table 5.21 Mounting system and end-user costs relative decrease until 2030

	Unit	*2022*	*2030*
Mounting system cost	€/m²	-33%	-54%
End-user cost – Façade application	€/m²	-10%	-16%

Barriers to implementation:

A first barrier to the implementation of this improvement is technological. Indeed, the trend is to use heavier PV glass modules (4/4mm or 3/3mm) instead of lightweight modules (2/2mm) as higher glass-thicknesses are current standards and are more suitable for coloured glass. Yet, most of the cost-reductions (labour costs, transport costs and installation costs) are weight dependent and apply for 2/2mm modules. Then, the cost-reduction is particularly significant in the case of standard modules. Even if further efforts are made to enable customised solutions to also benefit from this improvement, only limited cost-reductions will be achieved as the cost-reduction is dependent on scale and quantity. Finally, an additional barrier is related to the market maturation and consequent adaptation of manufacturing processes. With increasing maturity and learning by experience, the mounting system gluing will take place in the PV manufacturing line and not by a mounting manufacturer thus avoiding extra transport and crating cost as well as benefiting from cost-savings thanks to automated gluing machines. The impacts on the end-user cost have been quantified based on the assumption that the last barrier will not be overcome before 2030.

Stakeholders involved:

Mounting structure manufacturers, BIPV module manufacturers, façade installers, façade elements manufacturers, BIPV installers

IMPROVED VENTILATION OF BIPV SYSTEMS TO MAXIMISE PERFORMANCES

Description:

The yield of a photovoltaic installation depends on climate conditions like temperature and solar irradiance. More precisely, the temperature of the module impacts the energy output. Therefore, improving ventilation at the back of the modules will enable to reach higher performance ratios and thus, higher yield values. [24] [47] [48] [49] [50]

Note that such improvement is of high interest for façade installation, which suffer from lower solar irradiance and thus lower yield values. In addition, the improvement is particularly relevant in the case of cell technologies that have non-optimal temperature coefficients such as multi and mono crystalline silicon as opposed to some thin-film technologies which perform relatively better under higher temperatures.

Cost impact:

By improving the ventilation and consequently diminishing the impact of temperature on the total yield, the competitiveness of BIPV will be increased. The effect for BIPV rooftop installations amounted to a 2,6% higher yearly electricity generation in an experimental investigation conducted in the Netherlands in 2017 [24] [47]. [48] [49] [50]

Table 5.22 Performance ratio relative increase until 2030

	Unit	*2022*	*2025*	*2030*
Performance ratio	-	+0,5%	+1%	+1,5%

Barriers to implementation:

Limited

Stakeholders involved:

BIPV installers, façade and roof designers, BIPV products manufacturers, mounting structures manufacturers

5.3 Indirect costs improvements

5.3.1 PV related

IMPROVEMENT OF REGULATORY FRAMEWORKS

Description:

In order to favour the development of the BIPV market it is crucial to stimulate and guarantee the competitiveness of BIPV systems. In that aspect, the situation of BIPV is not different from other PV applications, and an appropriate and secure legal environmental is key. [51] To guarantee economic attractiveness, it is both necessary for system owners to be able to value the non-self-consumed generated electricity through an advantageous business model, and to increase the share of self-consumed electricity. As far as advantageous business models are concerned, it is crucial that regulatory frameworks establish favourable conditions in the case of tenantship. Indeed, owners can be reluctant to invest in (BI)PV as it is the tenants that will benefit from it through savings on their energy bill. A possible solution, although difficult or impossible to implement in most cases due to unadapted legal framework, which does not allow to increase rents in accordance with the initial capital investment. [3] [52] [53] The second element consisting in increasing self-consumption rates will be allowed through development and/or reinforcement of schemes such as collective self-consumption and the creation of energy communities, or the installations of EV charging stations. [16] [14] Finally, the uniformization of building regulations in Europe could contribute to a faster development of the BIPV market. In particular, EPBD (Energy Performance of Buildings Directive) could go further by strengthening nZEB and making on-site renewables compulsory. Such possibilities are discussed as part of an improvement presented further below in this document.

Cost impact:

The impact on the competitiveness can be quantified by estimating the impact on the self-consumption rate which is possible for improvements such as collective self-consumption. Depending on whether a typical residential of a typical commercial case is considered, it is assumed that self-consumption rates can be relatively increased by 10 to 50%.

Table 5.23 Self-consumption rate relative increase for 2030

	Unit	*2019 (base case)*	*2022*	*2025*	*2030*
Self-consumption rate – typical residential case	€/m²	30%	+10% (33%)	+25% (37,5%)	+50% (45%)
Self-consumption rate – typical commercial case	€/m²	70%	+10% (77%)	+20% (84%)	+30% (91%)

Barriers to implementation:

Barriers are of medium importance. On the one hand, the possibilities mentioned here are already part of the set of recommendations published by the European Authorities in the frame of various directives. Nevertheless, the introduction of new regulatory elements is a slow process and some stakeholders can be reluctant to see changes applied, which can hinder the fast development of the BIPV market. [52]

Stakeholders involved:

Tenants/Users; building owners; public authorities and policymakers, DSOs; municipalities; citizen groups/NGOs; utility companies.

5.3.1 Construction industry related

IMPROVED KNOWLEDGE ON BIPV AND INFORMATION FLOWS

Description:

The lack of companies able to address both the building element and PV module related installations increases end-user costs. Indeed, BIPV projects, and especially BIPV façade projects, involve a large number of specialists who did not yet acquire sufficient experience and knowledge on BIPV, thus increasing the overall duration and cost of these projects. The collective awareness and knowledge of the different stakeholders of the construction and building value chain can be improved by increased integration. This can be achieved by optimizing the circulation of information between the stakeholders. In addition, the development of guidelines regarding BIPV for the construction and building sector for which this technology is quite new and not always considered would help the stakeholders becoming better acquainted with this hybrid solution. [7] [13] [15]

Cost impact:

In the sense that it can favour the selection of a BIPV solution during the construction of renovation process, the impact of these improvements is quite comparable to the development of BIM solutions along the value chain. The main impact would be seen on the end user-cost as described Table 5.24. [15]

Table 5.24 End-user cost relative decrease until 2030

	Unit	*2022*	*2025*	*2030*
End-user cost	€/m²	-0,5%	-1,5%	-5%

Barriers to implementation:

The achievement of the improvement impacts could be hindered by communication and dissemination barriers if information and good practices are not exchanged among the different stakeholders along the value chain. Resistance to change could also appear.

Stakeholders involved:

Trade associations and chambers of commerce, public authorities

SIMPLIFICATION OF ADMINISTRATIVE AND LEGAL PROCEDURES

Description:

Administrative and legal procedures including permitting, certifications or grid connection can represent long time periods, hindering a project to reach more rapidly the next steps. Through more transparency, standardisation and allowed online permitting, the time gain could be significant. [54] [55] In the same idea of gaining in work efficiency, by engaging dialogue with local urbanistic authorities, the building and urban layout could be optimised. Indeed, by organising the buildings' zoning and orientation, having already in mind the possibility of a solar project (BIPV project), the competitiveness of future onsite-installed BIPV systems could be increased. [11] [16] [56]

Cost impact:

As far as permitting, certification, and grid connection are concerned, the time gain is expected to be 50% by 2030. Administrative and legal planning costs account for 6% to 7,5% of the total end-user cost (depending on whether a typical roof or a typical façade application is considered). In those 6% (or 7,5%), 50% can be assignable to permitting, certification and grid connection costs. Thus, the impact on the end-user cost can be quantified and summarised as in Table 5.25.

Table 5.25 End-user cost relative decrease until 2030

	Unit	*2022*	*2025*	*2030*
End-user cost – Roof application	€/m²	-0,75%	-1,1%	-1,88%
End-user cost – Façade application	€/m²	-0,6%	-0,9%	-1,5%

Barriers to implementation:

The periodic renewal of political representatives can interrupt or slow down the dialogue with authorities thus, representing barrier to the development of this improvement.

Stakeholders involved:

Public authorities and policymakers (local, regional, national), trade associations, citizen groups

IDENTIFICATION OF THE ADVANTAGES OF BIPV SYSTEMS IN COMPLYING WITH NZEB REGULATION

Description:

The introduction of nZEB regulations in the building sectors implies the need for various solutions to both reduce buildings' energy consumption and produce renewable energy. BIPV in this sense is a good fitting to comply with nZEB regulations by assuming those two functions (thermal insulation and electricity production). By putting forward the quantified advantages of BIPV with regards to these regulations, BIPV will become a trusted solution considered by architects and building owners thus promoting its market development. A parallel effect of the introduction of energy efficient buildings regulations is that to comply with those regulations, traditional building materials will need to have improved thermal, acoustic characteristics while meeting environmental constraints. Thus, the extra cost of BIPV as compared to traditional building elements will shrink. In addition, by recognising BIPV as a key and relevant solution for energy efficient renovation or building construction, cheap loans can be released, and projects can benefit from financial support as part of country-specific long-term national building renovation strategies. Thus, lower discount rates can be reached through either increased share of debt or lower interest rates. Spotlighting, in a quantified manner, the advantages of BIPV in complying with nZEB regulations, should also contribute to building occupants perceiving the increased value of a BIPV installation, and thus agreeing with higher associated rents. [7]

Cost impact:

While an increased perceived value of buildings with BIPV installations is difficultly quantifiable in terms of impact on a KPI or on the competitiveness, the access to cheaper loans can impact the discount rates. In Belgium, in a non-residential reference case, a 1% to 15% reduction can be expected until 2030.

Barriers to implementation:

Only new buildings are required to comply with nZEB regulations and as the construction sector, except for France where the sector is quite dynamic, is hindered by a gloomy economic situation in Italy and Spain, as well as to a lesser magnitude in Belgium and in the Netherlands. Indeed, their construction sectors are conservative and cost-sensitive thus limiting the annual construction rates. Nevertheless, an adapted regulatory framework could stimulate the construction sector. Therefore, it can be considered that (building industry) market barriers and political and legal barriers have to be taken into account for this improvement.

Stakeholders involved:

Researchers, trade associations

5.3.2 BIPV related

5.3.2.1 BIPV module assembling

DEVELOPMENT OF ENVIRONMENTAL AND TECHNICAL CODES AND STANDARDS

Description:

The quantity of modules to recycle has not reached a critical level yet. Thus, investments in recycling processes and infrastructures hardly justifies, neither for the recycling companies nor for the PV plant owners. Nevertheless, in the coming years, the economy behind disassembly and recycling stages, the recovery and reuse of components from used (BI)PV modules will strengthen and develop as it becomes either a legal obligation to comply with environmental policies and/or economically profitable. Thus, the systematising of eco-design approaches could lead to lower module costs, once their dismantling and recycling cost will be taken into account (as a net positive value).

In addition, the development of technical codes and standards at the scale of multiple countries or at the EU scale, could also harmonise the product offer and could contribute to help architects or building owners become more familiar with and confident about BIPV products. [22]

Cost impact:

Those improvements are worth mentioning but are hard to quantify, as this is a longer-term issue. Therefore, they will not be assessed in terms of impact on competitiveness in the following section.

Barriers to implementation:

Adopting an eco-design approach in the manufacturing processes can be challenging as it could force industrial actors to profoundly adapt their usual practices. Thus, barriers could be major. But there are few doubts that these will be overcome if eco-design guidelines become compulsory. Indeed, manufacturers will not have much choice if they want to access the market. It is important to note that it will also have an impact on the disassembly and recycling of modules as well as the recovery and reuse of the material after their system lifetime, which currently lies around 25 years. Therefore, the benefits of eco-design approaches will only be observable on BIPV competitiveness values on the long-term.

Stakeholders involved:

Module manufacturers, researchers, manufacturers of module production equipment as well as stakeholders in the sectors of dismantling, sorting, recycling, and reuse.

IMPROVEMENT OF BACK-END LOGISTICS AT BIPV PRODUCTION FACILITIES BY ENHANCED CRATING

Description:

Currently, the direct cost related to crating represents a small share of the total BIPV module cost. By optimising the wood thickness and robustness, by allowing compatibility with larger modules, while developing a set of standard crate dimensions, this cost item could end up being reduced by 20% by 2022. Note that even if this number only takes into account on site crating, but this improvement represents further benefits along the logistics chain.

Cost impact:

Based on the share absolute difference represented by crating in the total cell cost before and after the relative improvement, on the share of cell cost in the total module cost and on the share of the module cost in the total end-user cost, it can be determined what impact this improvement will have on the end-user cost. The results are shown in Table 5.26.

Table 5.26 End-user cost relative decrease by 2022

	Unit	*2022*
End-user cost – Roof application	€/m²	-0,8%
End-user cost – Façade application	€/m²	-0,9%

Barriers to implementation:

Limited

Stakeholders involved:

Module manufacturers, crating manufacturers

5.3.2.2 Other indirect costs

REDUCTION OF CUSTOMER ACQUISITION COSTS

Description:

As the BIPV market is still a niche market, architects or building owners do not consider systematically BIPV installations as a possibility for a renovation or a new construction. Therefore, the need for and the costs associated with the promotion of BIPV products are high. Not only are there bigger efforts to be made in terms of convincing and promoting BIPV products from the BIPV manufacturers and installers' side, but it requires also and extra time; and thus cost; for architects, general construction companies or simply the public, such as building owners, if they consider a BIPV system. Indeed, the little availability of catalogues, guidelines or knowledge transmission in this new sector, can represent a significant impediment. [54] [3]

Cost impact:

Improvements that will lead to a better communication around BIPV products and their promotion should contribute to a reduction of customer acquisition costs. What is understood here under acquisition costs are both the costs for BIPV manufacturing and installation companies associated to the promotion of their product catalogues as well as the extra time needed for the purchasing decision process for architects or building owners if they consider a BIPV installation. Thus, by considering the average share of acquisition costs in the total end-user cost to be about 2,5%, the impact on this KPI can be quantified as summarised in Table 5.27. [54]

Table 5.27 End-user cost relative decrease until 2030

	Unit	*2022*	*2025*	*2030*
End-user cost	€/m²	-0,5%	-1,26%	-2,5%

Barriers to implementation:

The expected impact for this improvement relies on a good communication about existing products, completed with an efficient dissemination of promotion and education material.

Stakeholders involved:

BIPV manufacturers, BIPV installers, building owners, architects, trade associations.

5.3.2.3 Design and preparatory works & installation

BIM-BASED SW TOOL SUPPORTING THE BIPV DESIGN AND INSTALLATION PROCESS

Description:

BIM-based tools are commonly used by professionals for traditional roof and façade solutions. Multiple digital solutions for the mainstream architecture, engineering and construction sectors exist such as AutoDesk or the AEC suite. The improvement in the framework of the BIPVBOOST project consists in extending the performances of BIMSolar®, a software developed by ENERBIM, from a tool dedicated to BAPV and BIPV preliminary design to BIM compatibility and energy modelling (EM). These two functionalities represent key factors in the cost-reduction strategy within the modernised building industry. The software will eventually serve the purpose of a collaborative platform. The compatibility of this tool allows it to dialogue with the software currently used by the building industry. In addition, the energy modelling can be used as input in energy models and simulation solutions to compute optimal solutions based on numerous parameters. This is of important relevance for BIPV projects as, because of relative high investments costs, price is often the main driver in the decision-making process, thus possibly leading to non-optimal performing projects. This tool will enable to have access to BIPV related data, fuelled by BIPV manufacturers, in all BIM supported design and construction stages. [12] [15]

Cost impact:

Time savings within the overall process and mitigation of technical risk are the main key elements for cost-reduction. Thus, this improvement will have a positive impact on the design time and to a lesser extent on the installation time. As shown in the total end-user cost breakdown presented in Figure 4.5 and Figure 4.6, design and installation represent respectively 11,5% and 12% for typical roof applications and 8% and 10% for typical façade applications. As for a previous improvement which impacted the installation time, the assumption is made that a X% design time reduction (respectively installation time reduction) will impact the total end-user cost for roof applications by $11{,}5\% * X\%$ (respectively $12\% * X\%$). This assumption is made possible by the fact that labour costs in those process steps are important as compared to material costs. These impacts are quantified in Table 5.28. Overall, reducing installation time, thanks to this improvement, is both less significant and less certain than reducing design time. [15]

Table 5.28 Design & installation time and end-user cost relative decrease

	Unit	*2022*	*2025*	*2030*
Preliminary design time reduction	h	-10%	-20%	-30%
Technical design time reduction	h	-10%	-15%	-20%
Installation time reduction	h/m²	-5%	-10%	-15%
End-user cost-reduction – Roof application	€/m²	-0,69%	-1,34%	-1,99%
End-user cost – Façade application	€/m²	-0,55%	-1,08%	-1,60%

Barriers to implementation:

Different barriers could hinder the introduction of this improvement on the BIPV market. The first barrier is technological. Indeed, BIM compatibility and energy modelling in the building sector are still limited in number, technical area-specific and not systematically compatible with each other. A further barrier that could hinder BIM tools for BIPV to be widely used is related to the BIPV market. The deployment and use of BIPV BIM tools will depend on the market uptake of this sector. Even in the large building and construction market, only a minority of stakeholders use BIM tools. The importance of this second barrier will decrease with time as the BIPV market becomes more mature and a progress is made in BIM adoption by the different stakeholders. Then, the third barrier that could also slow down the spreading of BIPV BIM tools is an economical and financial barrier. Introducing a BIM solution constitute an additional cost for professionals because it requires training, updates and maintenance. Most concerned companies are small companies and are therefore not economically and financially strong enough to support this additional cost. [3] This barrier will lose importance with time because new generations of professionals will be more familiar with digitised solutions and tools in general. Finally, the issue of having a great number of stakeholders taking part in the decision-making process, thus encumbering the design and installation processes, cannot be compensated significantly by the introduction of BIM tools.

Stakeholders involved:

Designers, architects, BIPV installers, construction companies, installers of mainstream building envelope solutions.

5.3.2.4 Monitoring and maintenance

PREDICTIVE ENERGY MANAGEMENT SYSTEM

Description:

The improvement consists in ensuring an optimised energy operation of buildings equipped with BIPV systems. This will lead to a better grid integration, maximising the overall value of BIPV generation by increasing self-consumption rates through demand-side management. Indeed, some devices (various appliances, heating, lighting, …) are already capable of being controlled remotely, thus allowing to reduce the mismatch between electricity consumption and production. If these devices do not have such built-in characteristics, they can be easily equipped with appropriate chips. Moreover, when technically possible and allowed by the local electricity market design, additional revenues can also be generated. For example, through load-shifting to take advantage of time-of-use tariffs or power capacity peak-shaving if a battery system is added. [16] It should be noted that the impacts of this improvement vary highly depending on the project and on the occupation profiles of the building.

Cost impact:

The impact of this improvement should be perceived on the self-consumption rates that can be achieved. Indeed, through the management of demand side loads to match PV electricity production, the self-consumption rates could be increased, in relative terms, by 10%. As evoked, such improvement could also require additional investments, this increasing the end-user cost. Although this is highly case dependent and it was assumed here that it was not necessary.

Table 5.29 Self-consumption rates relative changes by 2022

	Unit	*2022*
Self-consumption rate	%	+10%

Barriers to implementation:

A first barrier than can be cited is a technological barrier. Indeed, the lack of standardisation of communication protocols for PV inverters, storage systems and manageable loads makes the realisation of a predictive energy management system tool more complicated. Then, a further barrier that can be noted is an economic and financial barrier as a predictive energy management system represents a higher up-front cost. Which can be due to the necessary upgrade of the appliances or the addition of battery storage systems. For such reasons, the involvement of an ESCO can be an asset. Finally, political and legal barrier should also be paid attention to, as investment in storage and energy management systems is highly dependent on the regulatory framework as well as the energy market conditions, unfortunately very volatile.

Stakeholders involved:

Asset owners and managers in charge of ensuring the building's long-term financial performance.

FAILURE DETECTION AND DIAGNOSIS TOOL

Description:

The development of a failure and diagnosis (FDD) tool is based on data mining techniques. The improvement consists in alerting about potential failures before they impact the energy generation performances. In addition, by giving detailed information on the type of failure and the measures needed, it will facilitate preventive and corrective maintenance and thus reduce associated costs. [11] [16]

Cost impact:

The expected impacts should be perceived on the yield by up to +5%.

Table 5.30 Yield relative increase by 2022

	Unit	*2022*
BIPV system yield	kWh/kWp	+5%

Barriers to implementation:

Technological barriers for this improvement are worth mentioning as available datasets have poor quality, thus making them more difficult to analyse. As far as new technologies are concerned, the datasets to be exploited by the FDD tool are, in addition, not large enough to draw robust conclusions. Nevertheless, technological barriers are expected to be overcome by the end of the BIPVBOOST project. Then, there is a lack of public awareness on the benefits of FDD tools for the performance ratio, as well as a need for qualified personal to use them, thus representing a communication and dissemination barrier.

Stakeholders involved:

Building owners, tenants/users, construction company, public authorities, planners, asset managers and ESCOs.

5.4 Summary

Table 5.31 gives and overview on the different improvements that were presented in Section 5.2 and Section 5.3. Moreover, improvements are classified into two meta-categories: market maturation and technical innovation. A parameter is also included to highlight if they are part of the BIVPBOOST project. Under the technical innovation meta-category are gathered all the improvements taking place in and/or impacting one or the other manufacturing process (more efficient production lines, use of less and other materials or introduction of new techniques, …). The other meta-category gathers improvements that are fostering and/or arising from the BIPV market's development (enhanced communication and collaboration between stakeholders, development of back office support and software, development of a supporting legal framework, economies of scale or need for environmental and technical standards, …). The colour code used in the table is the same as in the presentation of the steps and sub-steps of the BIPV value chain. Thus, grey represents the manufacturing and selection of components, blue represents the preliminary studies and project planning, construction steps are represented in green and operation and maintenance steps in yellow. The cells that were left white cannot be assigned to one and only process step.

				BIPVBOOST	Technical innovation	Market maturation
Direct costs	PV related	Silicon & wafers	Improvement in silicon crystallisation		x	
			Improvement in wafering technologies		x	
		Cells	Improvement of overall equipment effectiveness of cell production tools		x	
			Improvement of metallisation costs		x	
			Improvement of cell efficiencies		x	
			Reduced degradation of system's performance		x	
		Module	Improvement of CTM Power ratio		x	
			Advanced module design and topology		x	
			Innovative encapsulant materials		x	
			Improved module durability		x	
		Inverters	Improvement of inverters		x	
		BoS	Improvement of BoS		x	
	Construction industry		Prefabrication and modularity of building envelope elements			x
	BIPV related	BIPV module assembling	Economies of scale and industrialisation			x
			Automatic and flexible BIPV production lines for cSi cells	x	x	
			Automatic and flexible BIPV production lines for back contact cells	x	x	
			Portfolio of glass-glass aesthetical advanced coloured solutions	x	x	
			Portfolio of glass-glass aesthetical advanced patterned solutions	x	x	
			Portfolio of glass-glass, low-cost, large format and large thickness glass-glass bifacial cell modules	x	x	
			Multifunctional BIPV façade cladding system with integrated insulation	x	x	
		Construction component	Enhanced, cost-effective roof system based on lightweight CIGS on metal	x	x	
			Low-cost click & go substructure for BIPV modules	x	x	
			Improved ventilation of BIPV systems to maximize performances		x	
Indirect costs	PV related	Regulation	Improvement of regulatory framework			x
	Construction industry		Improved knowledge and information flows			x
			Simplified administrative and legal procedures			x
			Identification of the advantages of BIPV systems in complying with nZEB regulation	x		x
	BIPV related	BIPV module assembling	Development of environmental and technical codes and standards			x
			Improvement of back-end logistics at BIPV production facilities by enhanced crating		x	
		Administrative and legal planning	Reduction of customer acquisition costs			x
		Design and preparatory works & installation	BIM-based tool supporting the BIPV design	x		x
			and installation process	x		x
		Monitoring and maintenance	Predictive energy management system	x		x
			Failure detection and diagnosis tool	x		x

Table 5.31 Summarising table of improvements

5.5 Roadmap

The roadmap represents all the studied BIPVBOOST improvements as well as the other identified improvements, all gathered in the two presented meta-categories (technical innovation and market maturation). They are presented according to which process step they impact and according to the time horizon at which they are planned to enter into force. In addition, the quantified impact on the relevant KPIs, for each improvement, are represented. Again, it is worth noting that these impacts should be interpreted as best-case results.

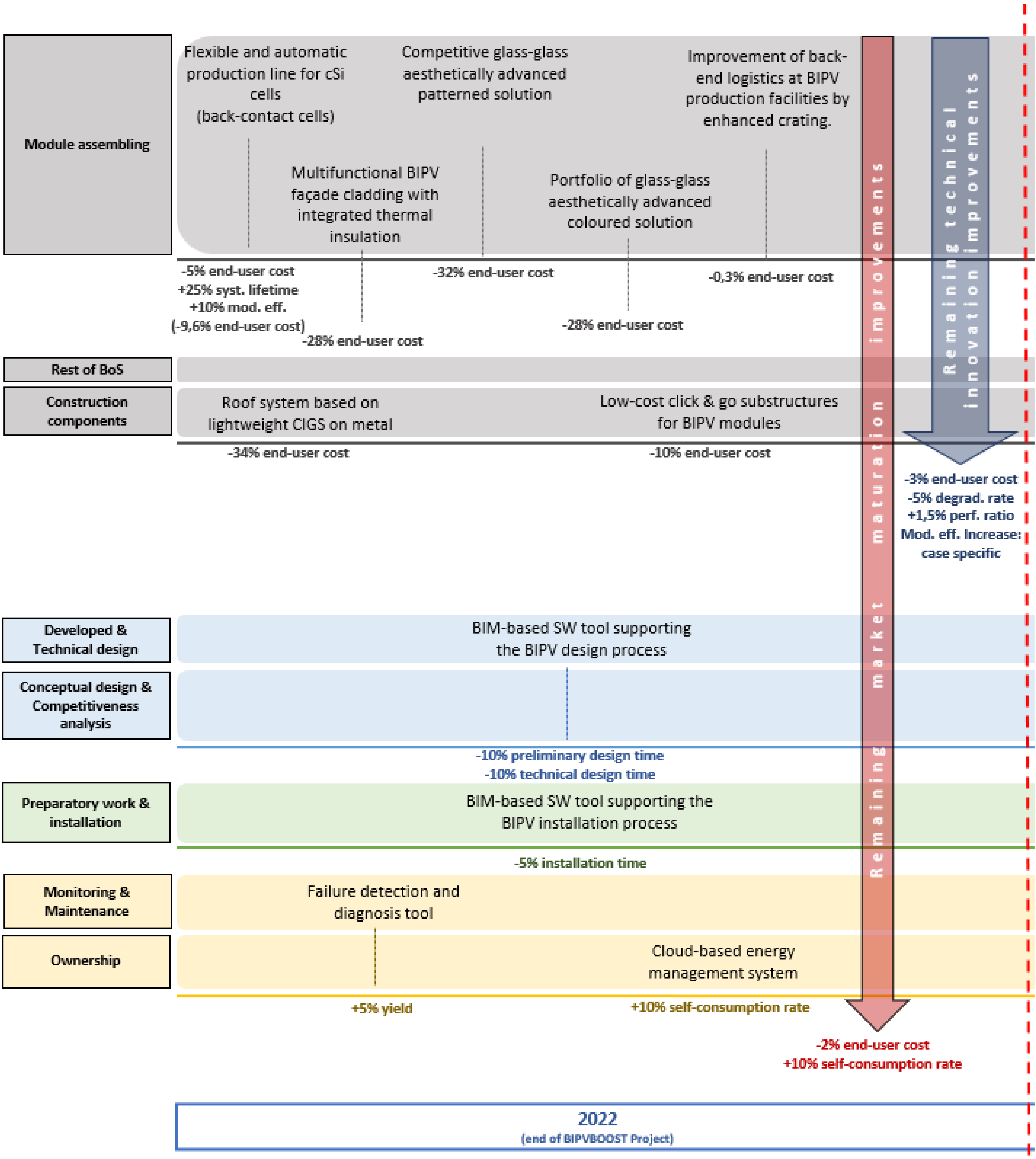

Figure 5.1 Cost-reduction roadmap proposed by BIPVBOOST project

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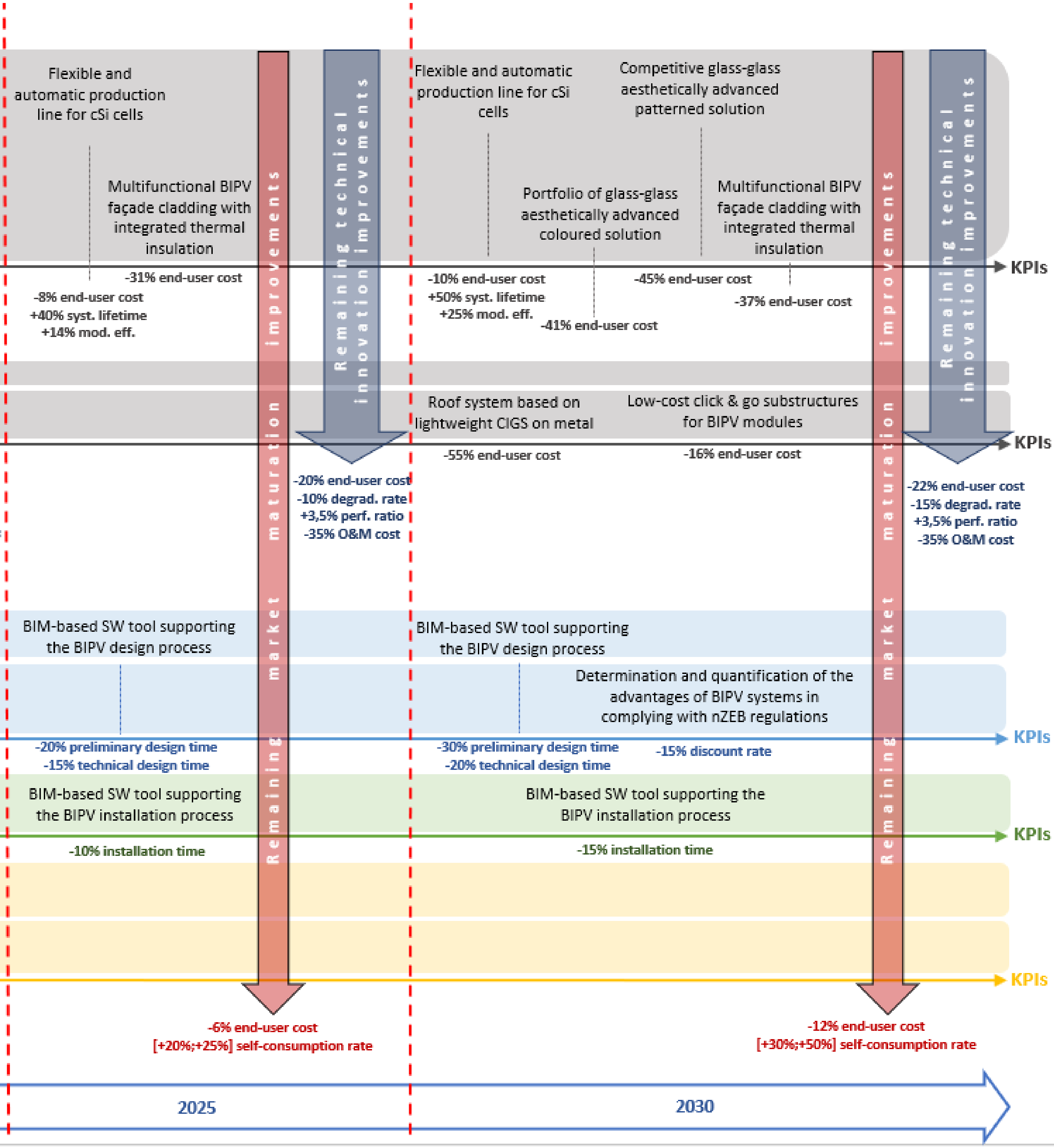
Flexible and automatic production line for cSi cells
Multifunctional BIPV façade cladding with integrated thermal insulation
-31% end-user cost
-8% end-user cost
+40% syst. lifetime
+14% mod. eff.
Remaining market maturation improvements
Remaining technical innovation improvements
Flexible and automatic production line for cSi cells
Competitive glass-glass aesthetically advanced patterned solution
Portfolio of glass-glass aesthetically advanced coloured solution
Multifunctional BIPV façade cladding with integrated thermal insulation
-10% end-user cost
+50% syst. lifetime
+25% mod. eff.
-41% end-user cost
-45% end-user cost
-37% end-user cost
KPIs
Roof system based on lightweight CIGS on metal
Low-cost click & go substructures for BIPV modules
-55% end-user cost
-16% end-user cost
KPIs
-20% end-user cost
-10% degrad. rate
+3,5% perf. ratio
-35% O&M cost
-22% end-user cost
-15% degrad. rate
+3,5% perf. ratio
-35% O&M cost
BIM-based SW tool supporting the BIPV design process
BIM-based SW tool supporting the BIPV design process
Determination and quantification of the advantages of BIPV systems in complying with nZEB regulations
KPIs
-20% preliminary design time
-15% technical design time
-30% preliminary design time
-20% technical design time
-15% discount rate
BIM-based SW tool supporting the BIPV installation process
BIM-based SW tool supporting the BIPV installation process
KPIs
-10% installation time
-15% installation time
KPIs
-6% end-user cost
[+20%;+25%] self-consumption rate
-12% end-user cost
[+30%;+50%] self-consumption rate
2025
2030

6 INFLUENCE ON COMPETITIVENESS

Based on the information gathered in Section 5, the quantitative description, based on the KPIs, of the different improvements can be translated in terms of competitiveness. This allows to compare the impacts of each improvement with a unique indicator. The methodology used to compute the competitiveness values has been already presented in deliverable 1.1. A reminder is presented in Appendix in Section 10.1. As only the relative changes on the competitiveness will be measured, the business model applied in the modelling is of minor relevance. Although, to limit the impact of external factors, a business model without financial incentives of any kind is considered, i.e. solely based on self-consumption and valuation of the non-self-consumed PV production at wholesale market price. Then, what has been defined and used in D1.1 as the "value-based approach" is taken. This might seem contradictory to some of the conclusions of D1.1, where the "extra cost approach" was pointed out as the most appropriate, even if it is partially based on the "value-based" one. This choice has been made to facilitate calculations and limit the amount of assumptions, which are already numerous. Indeed, an "extra cost approach" would have required to also investigate and quantify the evolution, in terms of technology and cost, of conventional building envelope solutions. Such investigation is beyond the scope of the present report. In addition, it raised the risk to significantly complexify the work to be conducted and to create an additional source of uncertainty.

Each improvement planned in the framework of the BIPVBOOST project will be first evaluated alone in order to measure their very own impact. The other improvements introduced in Section 5 will be first gathered based on the meta-category they can be associated with. To do so, and despite the various improvements are scheduled on the short and medium-term, all parameters except for the KPI(s) affected by the improvement are kept constant over time. Indeed, taking into account escalation rates would mean making an assumption on another potential improvement. Finally, the projected end-user cost variations as well as the competitiveness values' variations resulting from it are expressed in nominal values.

6.1 Best-case individual influence on competitiveness

For each considered reference case, the relevant improvements are assessed by computing their impact on the competitiveness metric. In addition to the main KPI, i.e. the competitiveness, the end-user cost has also been chosen, to reflect the impacts of the different improvements. To calculate the cost-reduction allowed by one improvement or one category of improvements at a given time horizon, all (if more than one) end-user cost reductions associated to this improvement and planned before or at the given time horizon are concatenated into one cost-reduction value. BIPVBOOST improvements are assessed individually as they are generally already a combination of different sub-improvements. Other improvements are grouped according to the two defined meta-categories, technical innovations or market maturation. The assumption is made that all improvements of these meta-categories as well as their impacted KPIs are independent. In other words, it is assumed that the occurrence of an improvement does neither hinder nor does help the occurrence of another improvement. The same assumption applies for KPIs, for which it is considered that the impact of the variation of one KPI does not interfere with the impact of the variation of another one. This is supported by the sensitivity analysis conducted in Deliverable 1.1. in which potential dependant parameters were studied and that came to the conclusion that no strong dependency existed.

Finally, the improvements or groups of improvements considered are gathered in Table 6.1

Table 6.1 Summary of improvement meta-categories

Id	Name
TI_1	Technical innovation: Automatic and flexible BIPV production lines for cSi cells
TI_2	Technical innovation: Automatic and flexible BIPV production lines for back-contact cells
TI_3	Technical innovation: Roof system based on lightweight CIGS on metal
TI_4	Technical innovation: Improved logistics by enhanced crating
TI_5	Technical innovation: Glass façades based on upgraded plug-and-play substructure
TI_6	Technical innovation: Portfolio of glass-glass coloured solutions
TI_7	Technical innovation: Façade cladding with integrated thermal insulation
TI_8	Technical innovation: Portfolio of glass-glass patterned solutions
TI_9	Technical innovation: Rest of the improvements
MM_1	Market maturation: BIM based tool for design and installation
MM_2	Market maturation: Predictive energy management system
MM_3	Market maturation: Failure detection and diagnosis tool
MM_4	Market maturation: Rest of the improvements

Regarding the interpretation of the following charts, what should be paid attention to is to what extent the various improvements impact the competitiveness of one given reference case. On the contrary, it cannot, based on the following figures, be determined that one improvement has more impact on the competitiveness of one reference case than on the competitiveness of another reference case. Indeed, this information is not available as the represented changes on the competitiveness are relative and as the competitiveness' base case value of each reference case is different. This explains why, in the case reference case SFH_b, which has a low absolute competitiveness value (around 50 €/m² and thus, a smaller order of magnitude), the impacts are on average ten times more important than in the other reference cases. Furthermore, as it will be further discussed in Section 7, the combined relative impact of all improvements on competitiveness cannot be obtained by simply summing the individual relative impacts.

Finally, concerning the design used, the choice of stacked columns allows to picture the impact on the competitiveness reached at each milestone. For example, to read the impact of all improvements until 2025, both the blue and orange columns must be taken into account. One important thing to note with regards to the different time-horizons is that, in the different sources identified thanks to the literature review, the impacts of various improvements are only known for specific years. In addition, the introduction of a certain improvement on the market can follow different paths (continuous or discontinuous). Therefore, when the impact was only known for year N, it was assumed that before year N no impact would be seen. Thus, the intermediary time-horizons should be indicative only as a small blue column and a large grey column are not necessarily the sign that most of the improvements takes place in 2030 but only that most impacts are known for 2030. Finally, the base values for the end-user cost (respectively the competitiveness) are displayed in bold, in the top right-hand corner of the chart (respectively the top left-hand corner).

6.1.1 Industrial building reference case

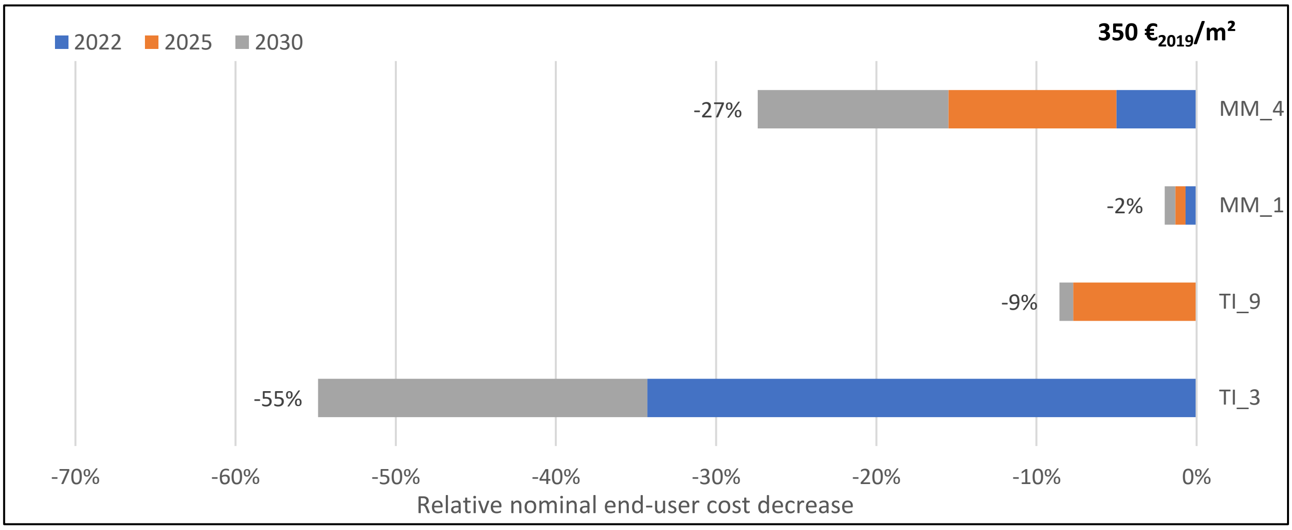

Figure 6.1 Individual improvements' relative impact on end-user cost for the IB reference case

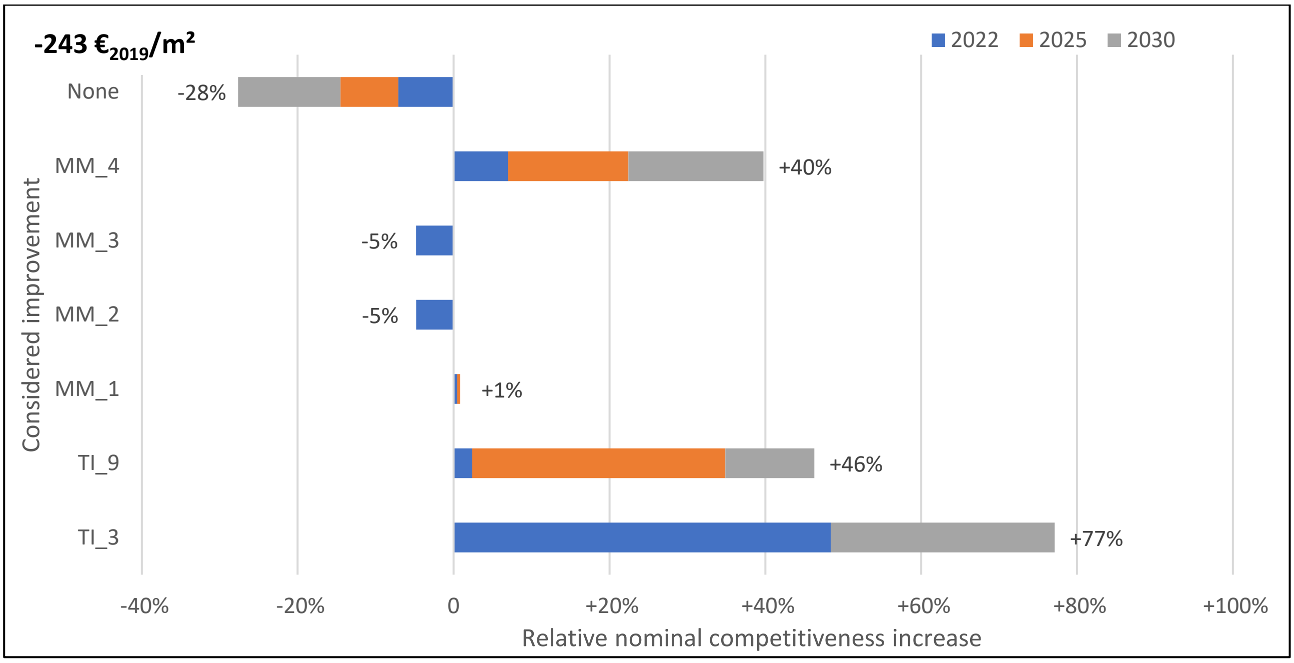

Figure 6.2 Individual improvements 'relative impact on competitiveness for the IB reference case

The BIPVBOOST planned improvement aiming at developing industrial roof systems based on lightweight CIGS on metal (TI_3) is the improvements with the most impact. This improvement alone could allow to reach an end-user cost of approximately 134 $€_{2019}/m^2$ by 2030 in the best case, in comparison with the current 350 $€_{2019}/m^2$. In this reference case, based on CIGS technology, significant benefits could also come from promising potential module efficiency increases, which are blended in the category "technical innovation: rest of the improvements" (TI_9). On the other hand, as self-consumption rates are typically already very high in such configuration, e.g. base case value standing at 90% for this reference case, predictive BEMS has a limited impact.

6.1.2 Single family house reference case

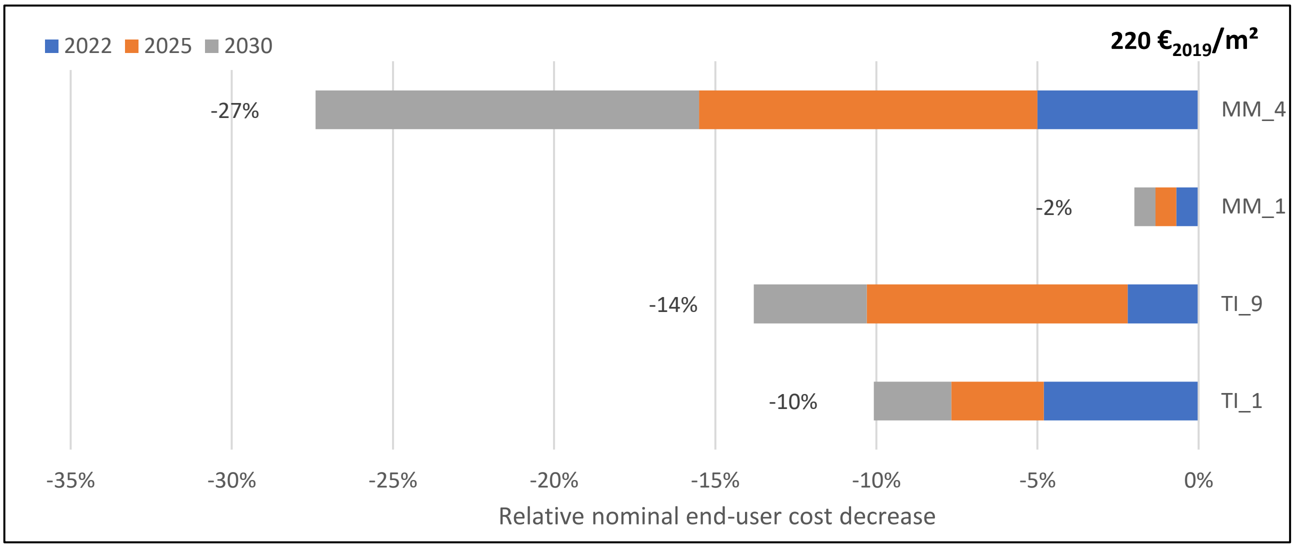

Figure 6.3: Individual improvements' relative impact on end-user cost for the SFH_b reference case

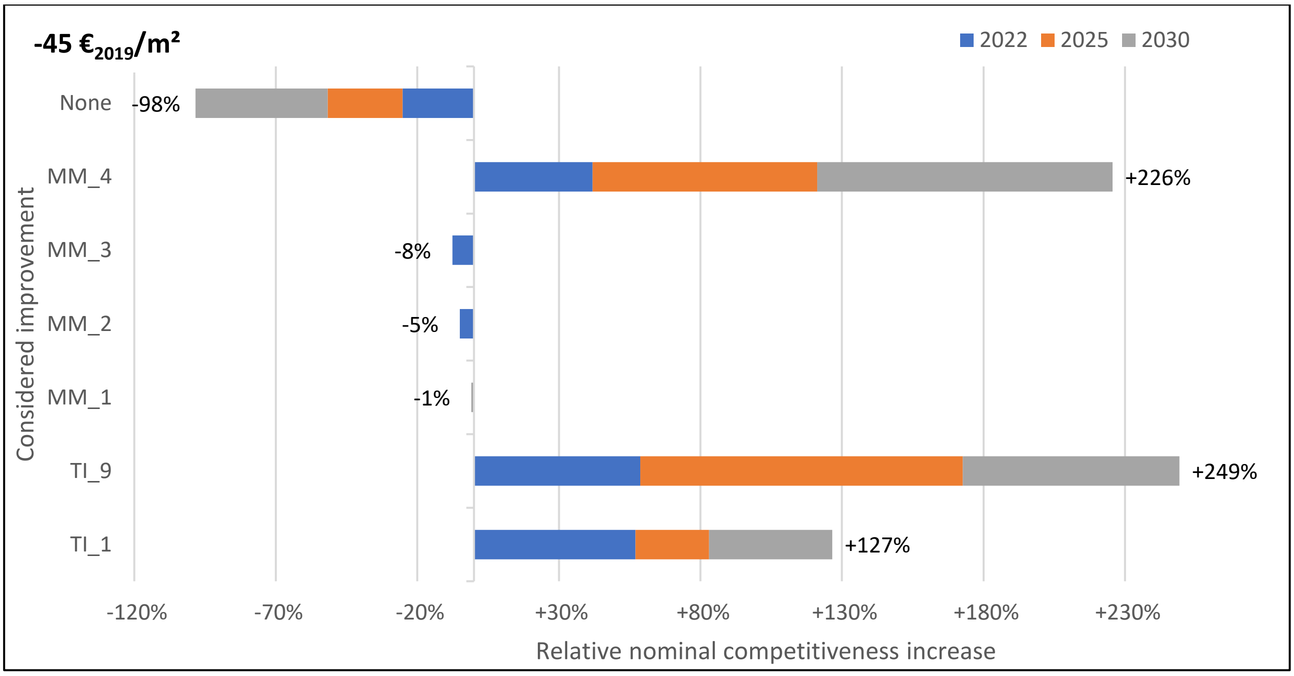

Figure 6.4 Individual improvements 'relative impact on competitiveness for the SFH_b reference case

The single-family house reference case could benefit from important technical innovation-related improvements (TI_9), such as increased system lifetimes and increased module efficiencies thus potentially bringing down the end-user cost to 161 $€_{2019}/m^2$ in 2030 compared to the current 220 $€_{2019}/m^2$ (VAT included). This residential reference case is defined by typically low self-consumption rates of around 30% (base case value). Therefore, the impact of the introduction of a BEMS, which can increase the self-consumption rates, is quite significant. The relative competitiveness increases per improvement are, for most of them, an order of magnitude higher than in the other reference cases. This should not be interpreted as a reference case with more cost-reduction potential but is just a mathematical consequence of the base case competitiveness value.

6.1.3 Educational building reference cases

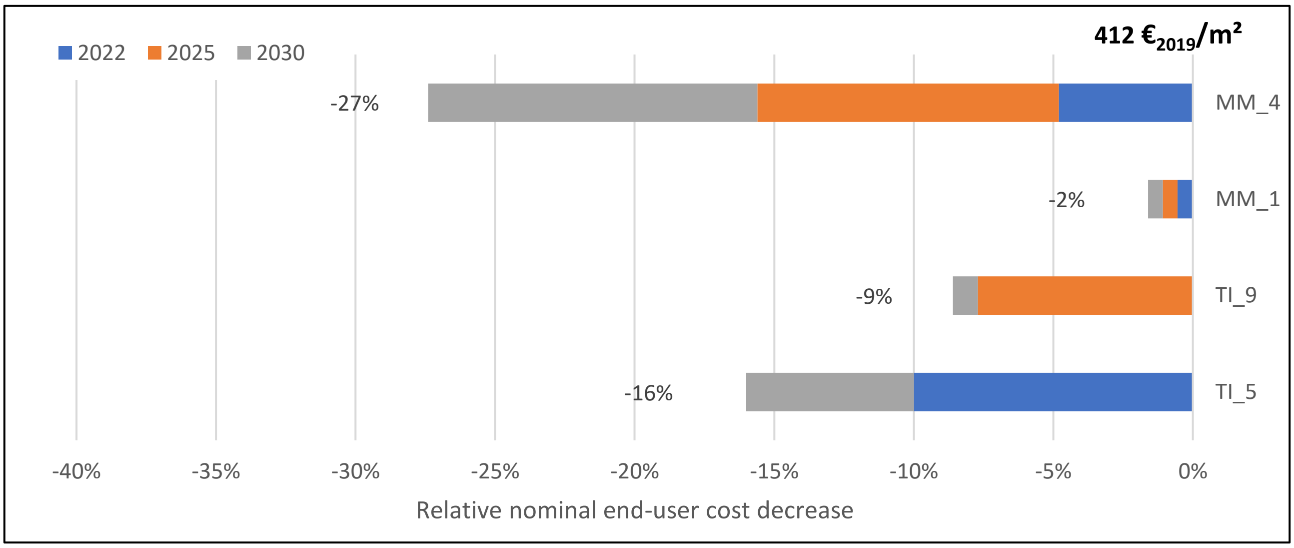

Figure 6.5 Individual improvements' relative impact on end-user cost for the EB_a1 reference case

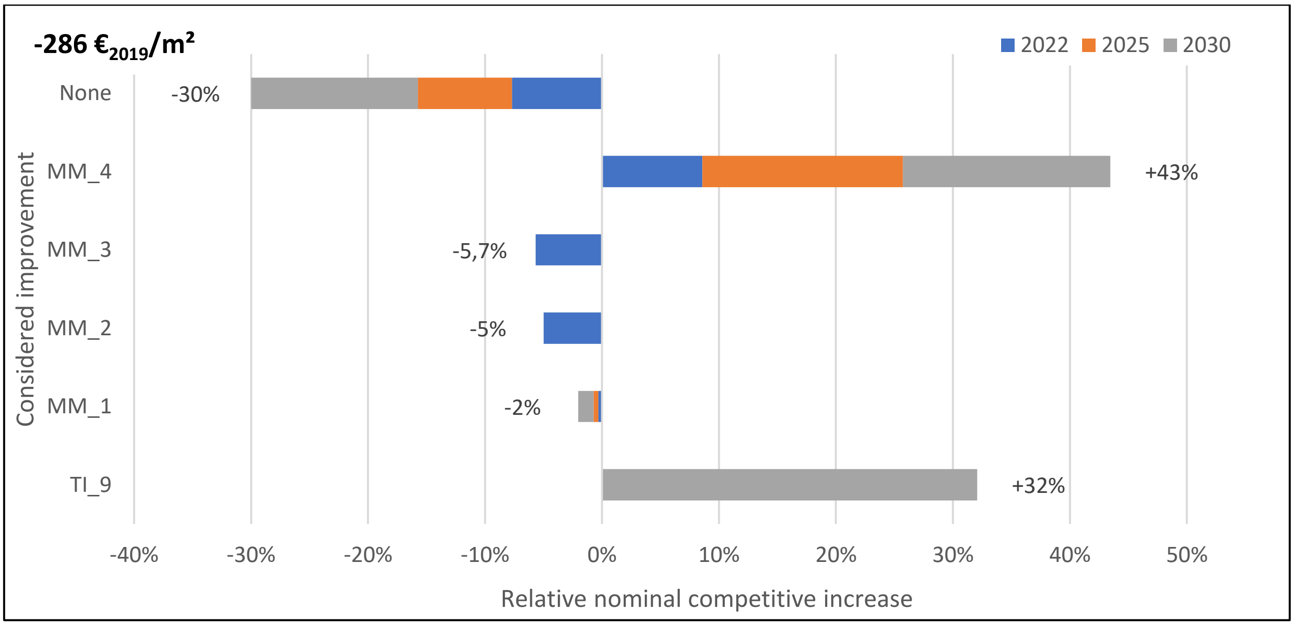

Figure 6.6 Individual improvements ‘relative impact on competitiveness for the EB_a1 reference case

In this reference case, the potential for end-user cost reduction by 2030 is, again, limited. The most impacting single improvement is the innovative substructure developed in the frame of BIPVBOOST (TI_5). Looking at 2030, the major contribution could come from market maturation improvements (MM_4), while the overall technical innovations (TI_9) could also have a significant positive impact, even if of smaller magnitude.

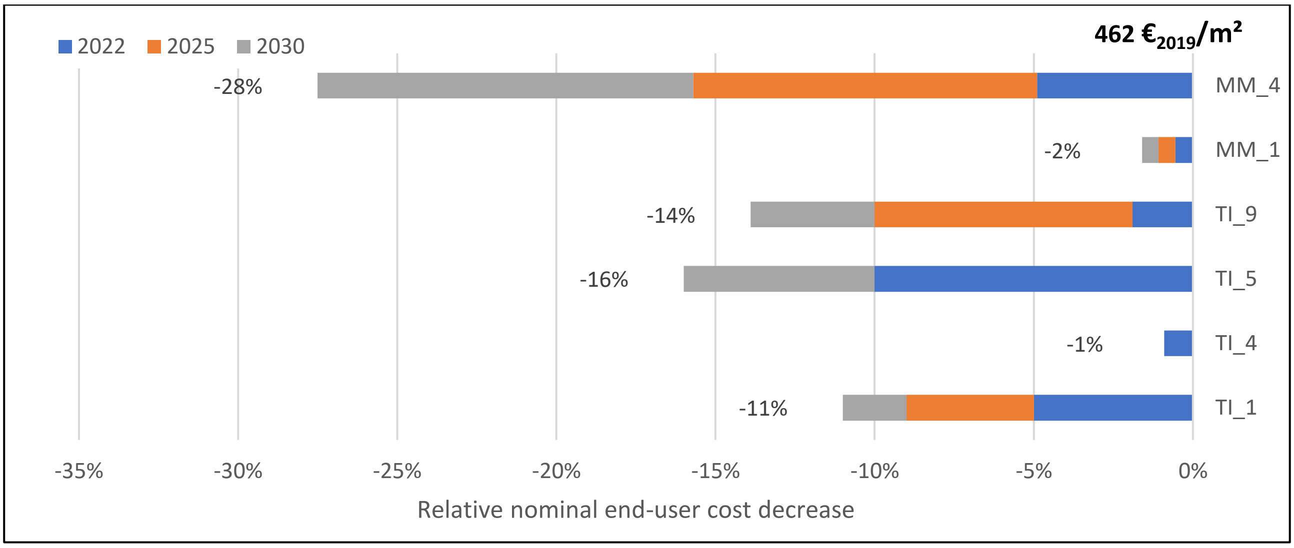

Figure 6.7 Individual improvements' relative impact on end-user cost for the EB_b1 reference case

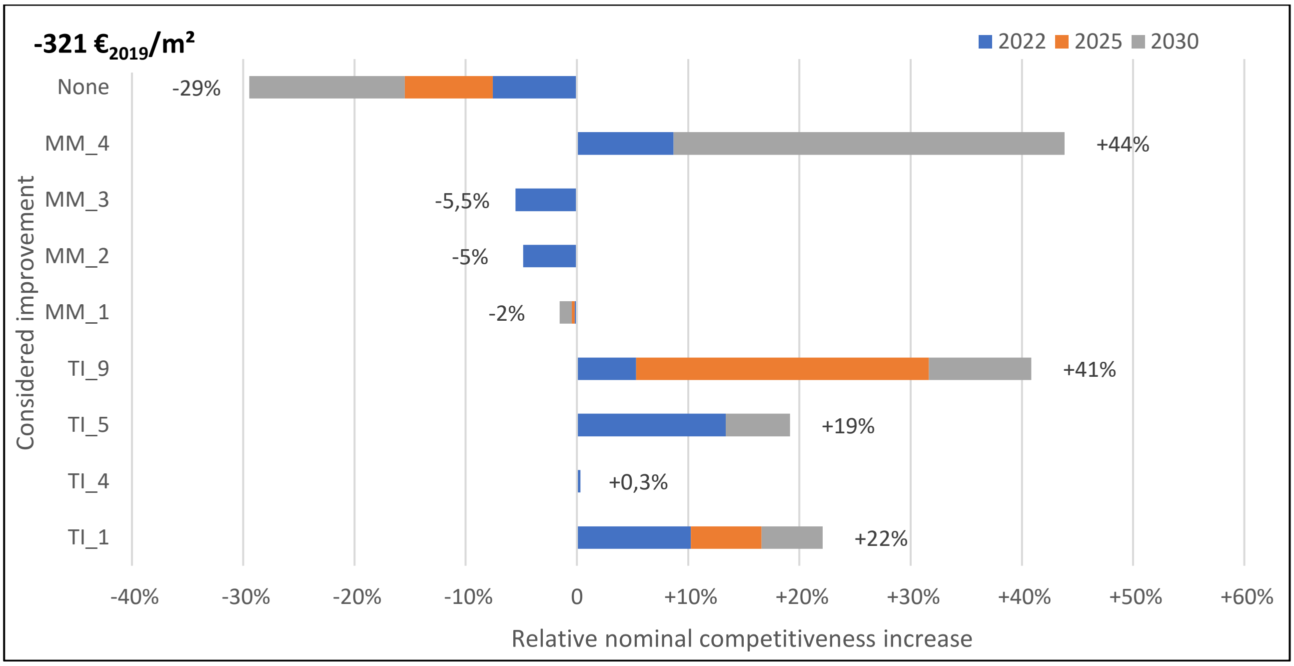

Figure 6.8 Individual improvements' relative impact on competitiveness for the EB_b1 reference case

Regarding reference case EB_b1, equipped with mono crystalline silicon PV cells, the situation is very similar to reference EB_a1, equipped with CIGS PV cells. The main single contributor to end-user cost reduction is TI_5, while market maturation improvements could lead to a reduction of 26% by 2030. When it comes to competitiveness, other technical innovation and market maturation improvements have the highest potential impact. One can also mention the possible impact of the improved manufacturing line (TI_1).

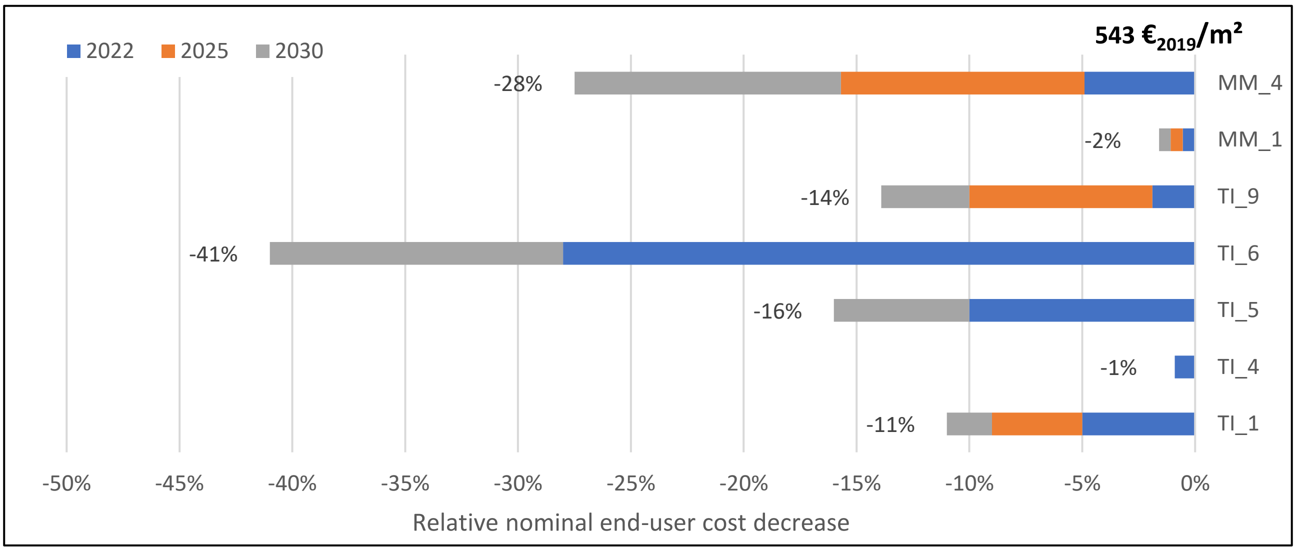

Figure 6.9 Individual improvements' relative impact on end-user cost for the EB_b2 reference case

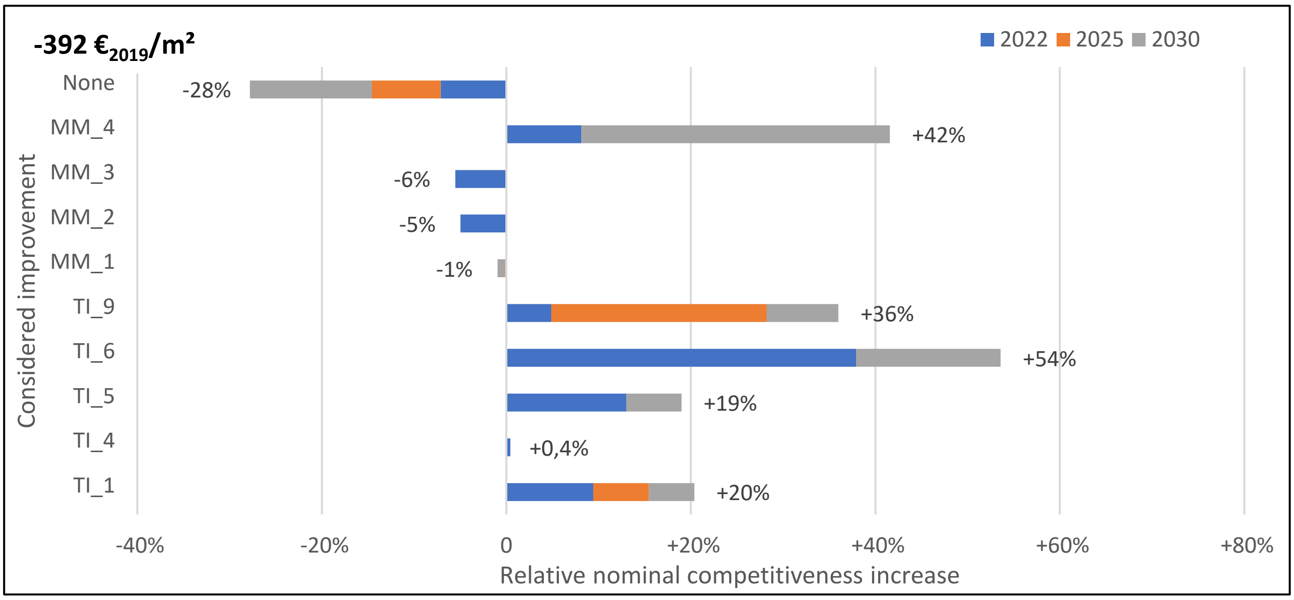

Figure 6.10 Individual improvements ‘relative impact on competitiveness for the EB_b2 reference case

In the EB_b2 reference case, the development of glass-glass coloured solutions (TI_6) allows generous end-user cost reductions compared to current levels, possibly bringing down the end-user cost to 272 $€_{2019}/m^2$ by 2030. Its impact is also visible on competitiveness, with the significant positive variation. Again, main other contributing improvements are TI_9, MM_4 as well as TI_1.

Overall, we see that potential impacts of improvements are more significant than in other EB cases. This can be explained by the fact that such product is less mature, hence base case values are higher and room for improvement is more important.

6.1.4 Multifamily reference case

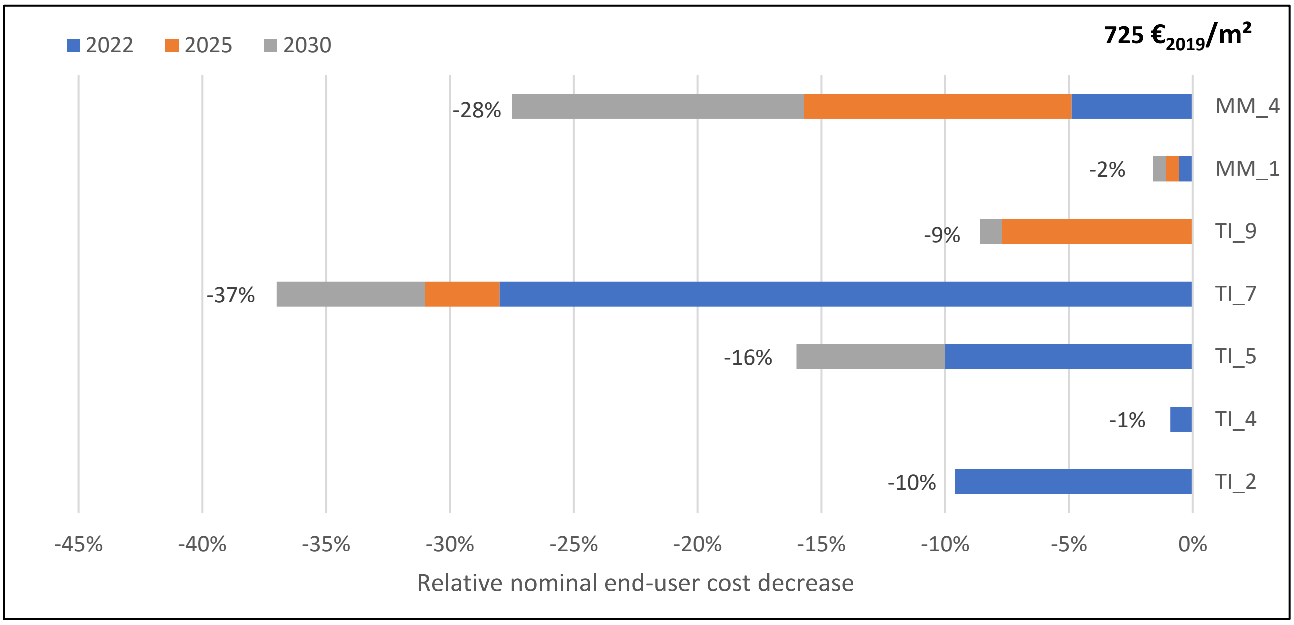

Figure 6.11 Individual improvements' relative impact on end-user cost for the MFH reference case

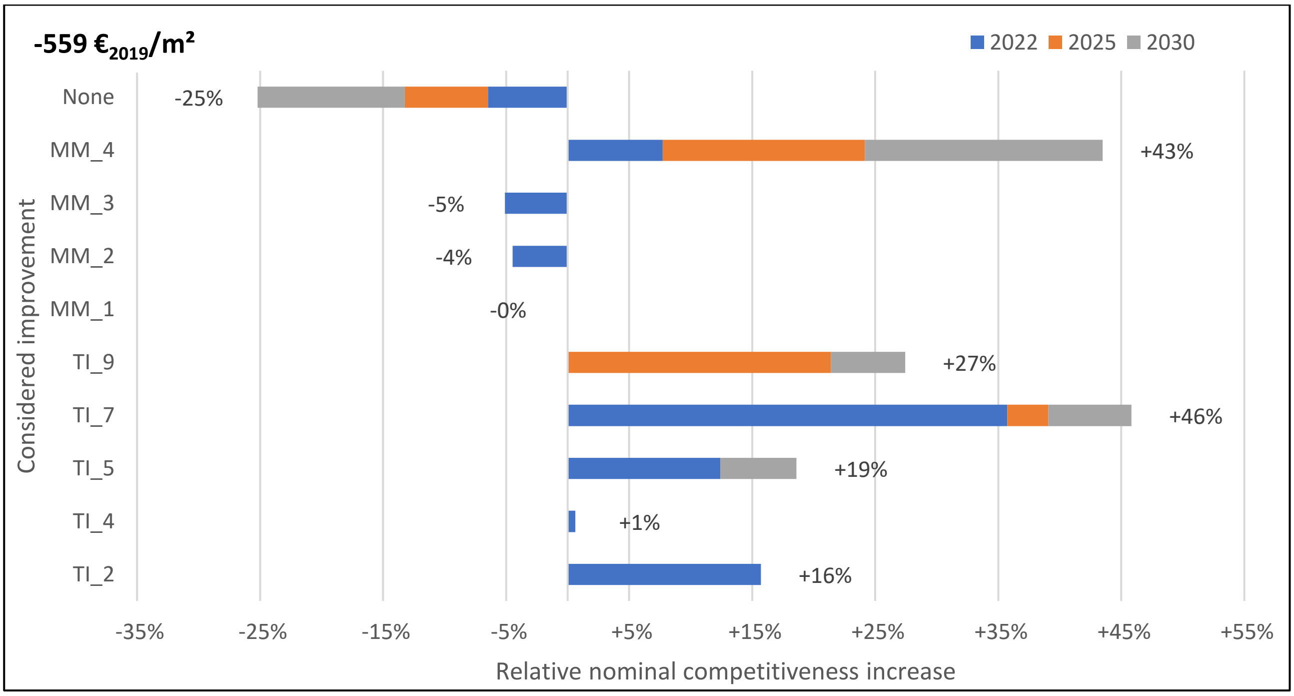

Figure 6.12 Individual improvements 'relative impact on competitiveness for the MFH reference case

The development of a portfolio of façade solutions with integrated insulation (TI_7), in the frame of the BIPVBOOST project, has the potential to enable important end-user cost reductions. The possible influence on competitiveness is also clearly visible. This improvement could allow to reach an end-user cost as low as 388 €$_{2019}$/m² (VAT included). In addition, IBC cell-based modules considered in this reference case also benefit from an important module efficiency increase potential, part of TI_9.

6.1.5 Office building reference cases

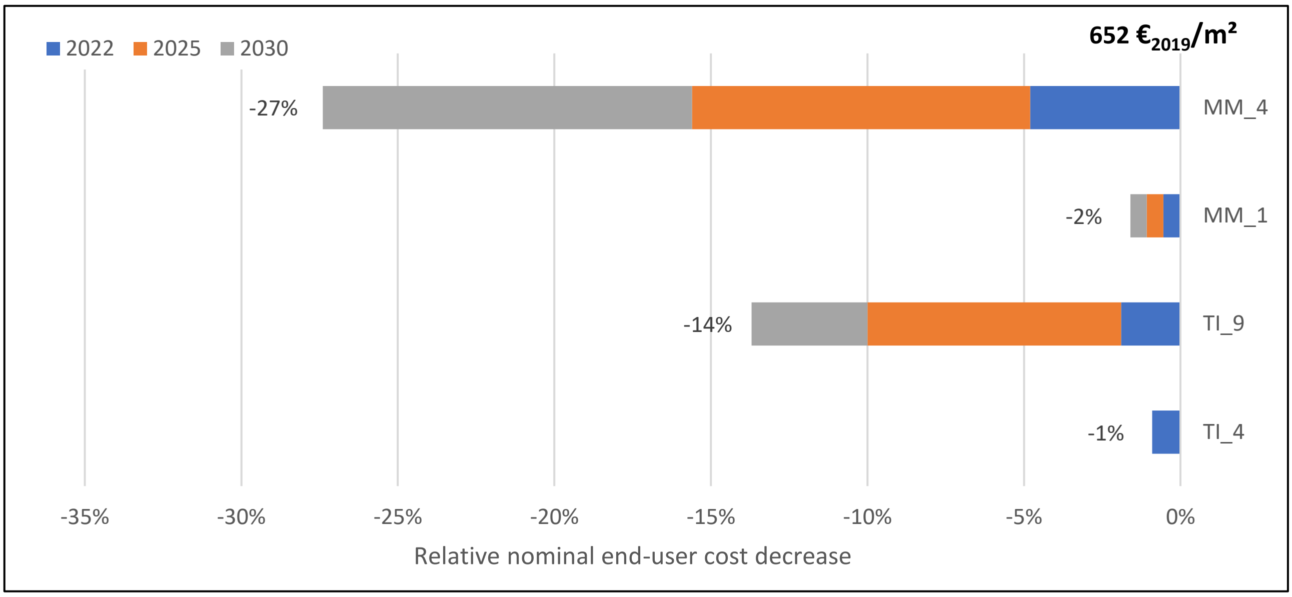

Figure 6.13 Individual improvements' relative impact on end-user cost for the OB_a1 reference case

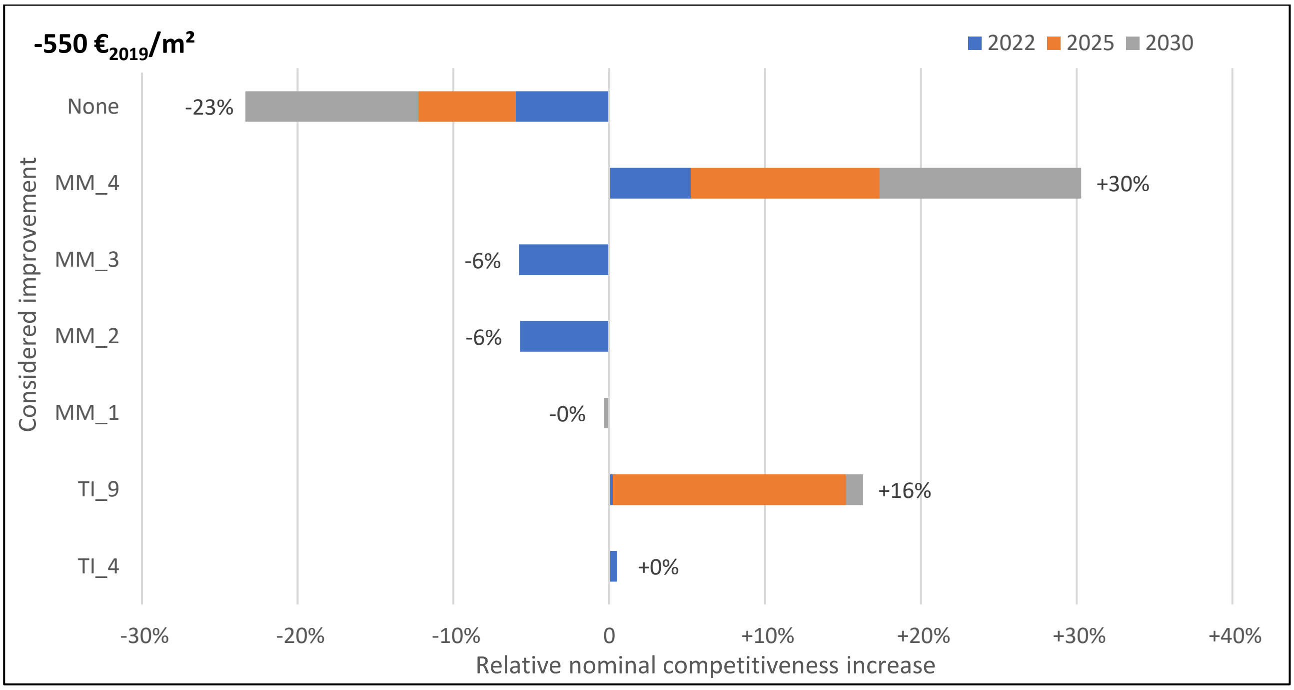

Figure 6.14 Individual improvements 'relative impact on competitiveness for the OB_a1 reference case

The first office building reference case, OB_a1, is equipped with aSi PV cells and concerns a non-ventilated façade solution (curtain wall). Here, market maturation improvements have, potentially, the biggest impact on end-user cost by 2030. This can be explained by the fact that this PV technology is already mature, and potential for improvement is pretty limited. The same situation holds when competitiveness is analysed, which could be improved by 30% by 2030 thanks to MM_4.

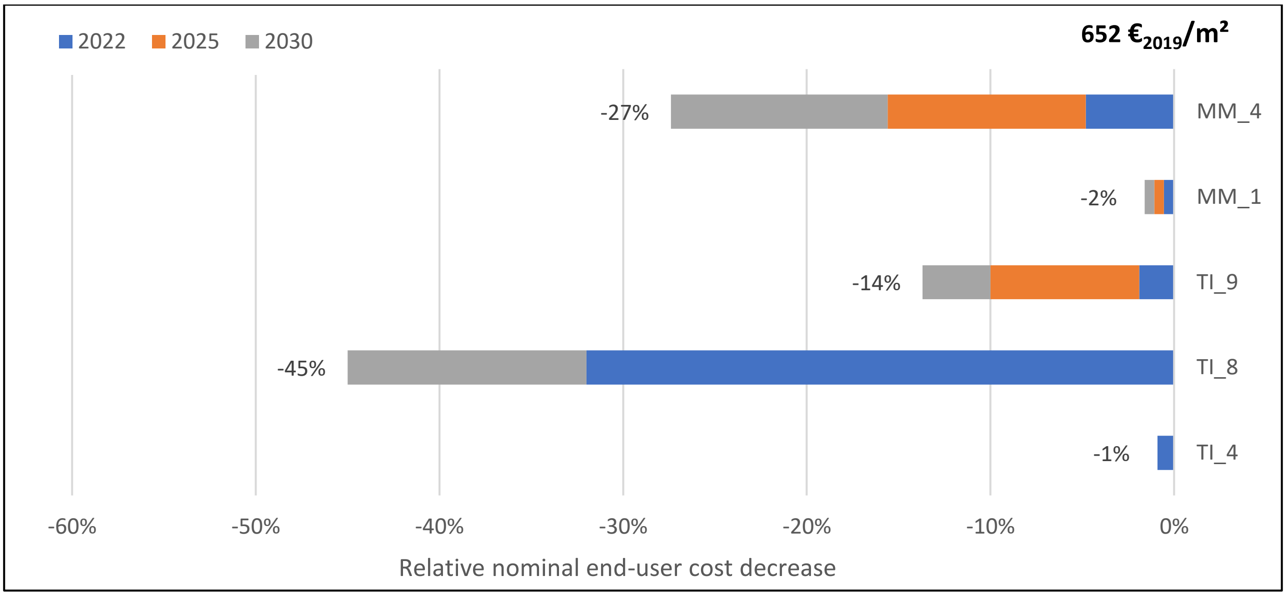

Figure 6.15 Individual improvements' relative impact on end-user cost for the OB_a2 reference case

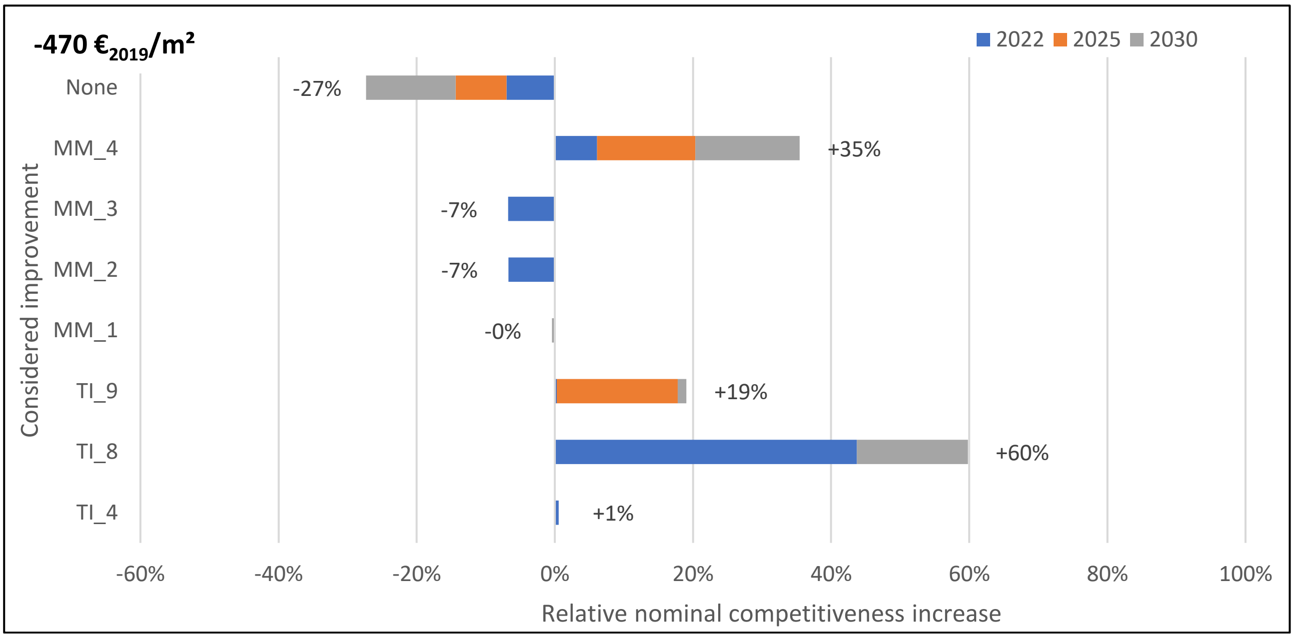

Figure 6.16 Individual improvements 'relative impact on competitiveness for the OB_a2 reference case

As for reference case OB_a1, in this case the amorphous silicon PV technology does not allow to consider increased system lifetime in the technical innovation-related improvements because of the combination of both important annual degradation rates and low efficiency values. Although, the "development of a portfolio of patterned solutions" improvement (TI_8) here could enable important end-user cost reductions, which are also seen with the competitiveness increase. This BIPVBOOST improvement could permit to reach an end-user cost of 305 $€_{2019}/m^2$ by 2030 compared to the current 652 $€_{2019}/m^2$.

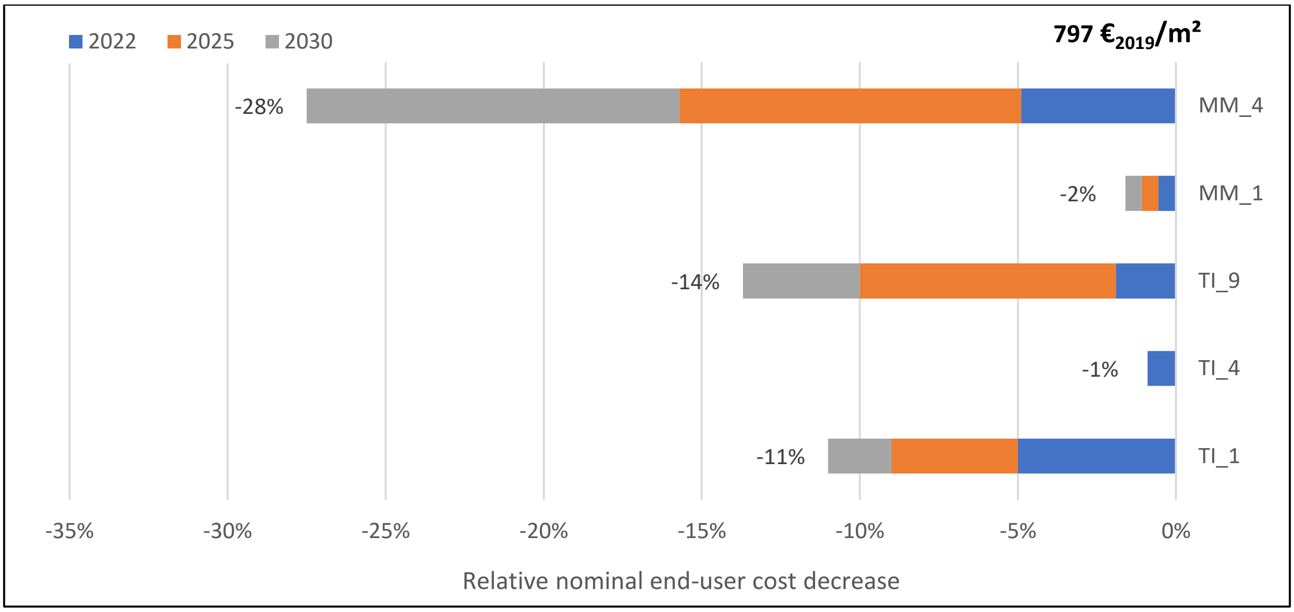

Figure 6.17 Individual improvements' relative impact on end-user cost for the OB_b1 reference case

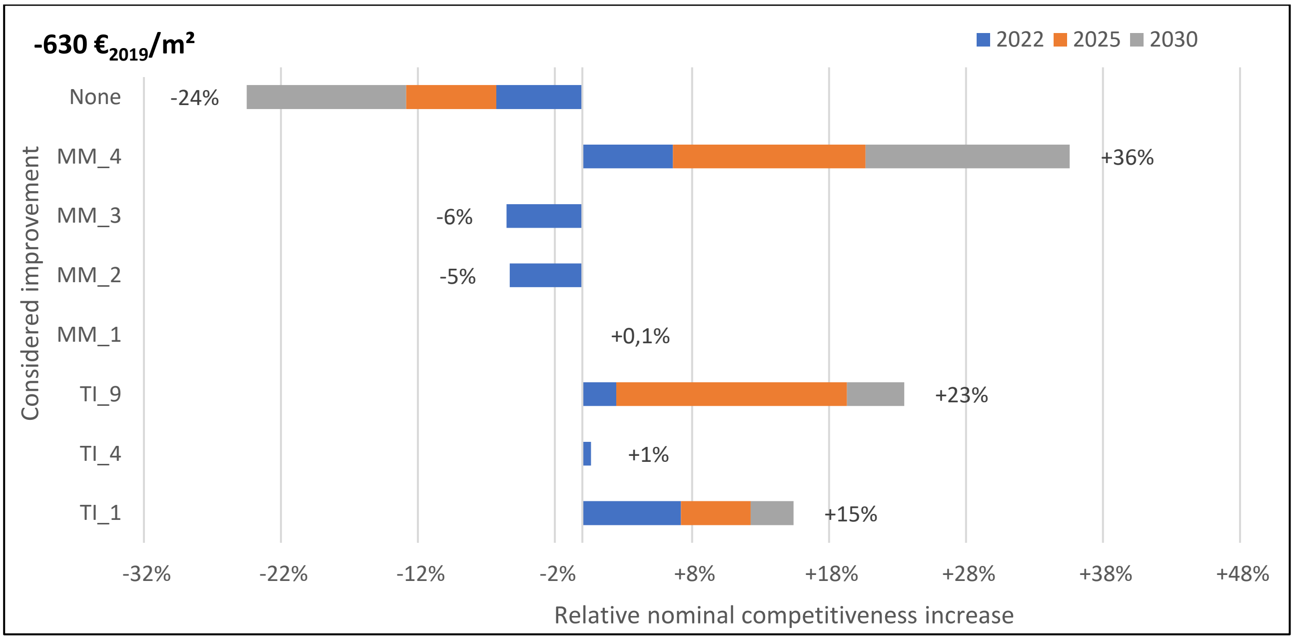

Figure 6.18 Individual improvements 'relative impact on competitiveness for the OB_b1 reference case

In this case, improvement with the highest impact potential, both on end-user cost and on competitiveness is due to market maturation (MM_4). Looking at technical innovations, TI_1 and TI_9 are not so far behind the previously cited market-linked improvement. The situation is quite balanced, but it appears that technical innovation improvements have potentially a higher impact than market maturation ones.

6.2 Highlights

Overall, it can be noticed that technical innovation-related improvements have a higher maximal potential impact than market maturation improvements. This is due to two factors. The first one being that many technical innovations come from the PV sector which, thanks to its size and upward dynamic, fosters the development of improvements whereas market maturation-related improvements are dependent from the BIPV market's development and size. The second factor to take into account is that market maturation improvements are harder to quantify. Therefore, their impact on the competitiveness could be even more important. Nonetheless, it should be pointed out that this statement does not hold for all reference cases. In addition, the difference is not always significant, with a more balanced distribution. This is for example the case for more mature BIPV solutions.

It can be also observed that when improvements are especially tailored for a specific market segment and product, as it is the case for the development of a portfolio of glass-glass coloured solutions, major impacts can be observed. This is also due to the fact that such solution is less mature, from a technical point of view. Hence, the potential for improvement is significant, as already evoked. As far as the temporal distribution is concerned, the impacts are quite balanced and progressive over the years.

Globally, it can be concluded from this first analysis that, in each case, multiple improvements have the potential to substantially impact the end-user cost as well as the competitiveness of BIPV solutions, under different configurations. This, even when considered individually. Such observation is promising, as it demonstrates that even the realization of few of the identified improvements has the potential to have a valuable impact on the attractiveness of BIPV solutions.

Finally, the combination of improvements and mitigation of the above presented results will be analysed discussed in the following section.

7 COMBINED IMPACT OF IMPROVEMENTS

This section aims at providing a collective assessment of the different improvements. A first approach is to deduce the combined impact from the individual impacts presented in Section 5. The corresponding results would depict the impact on competitiveness or the end-user cost in a best-case scenario. This scenario is based on the underlying assumption that any barrier to implementation is entirely overcome and that each targeted improvement will be achieved, leading to an expected impact that will be reached by up to 100%. Therefore, three other approaches/scenarios were defined to give a more realistic overview on the improvements' potential impacts.

7.1 Scenario definition

This section aims at making the impact pathways on the competitiveness and on the end-user cost more realistic, based on different possible evolution patterns for the BIPV sector.

The first scenario considered is a technology-push scenario in which important R&D investments contribute to the development of major technical innovations, eventually benefiting the sector by increasing the economic attractiveness of BIPV systems. In the second scenario, called demand-pull scenario, an increasing demand for BIPV products accelerates the expansion of the market and stimulates learning-by-doing gains. Consequently, the cost-reductions are driven by market maturation improvements, such as economies of scale. Finally, a last scenario considers that neither R&D investments nor demand increase are predominant and will consist in the balanced scenario.

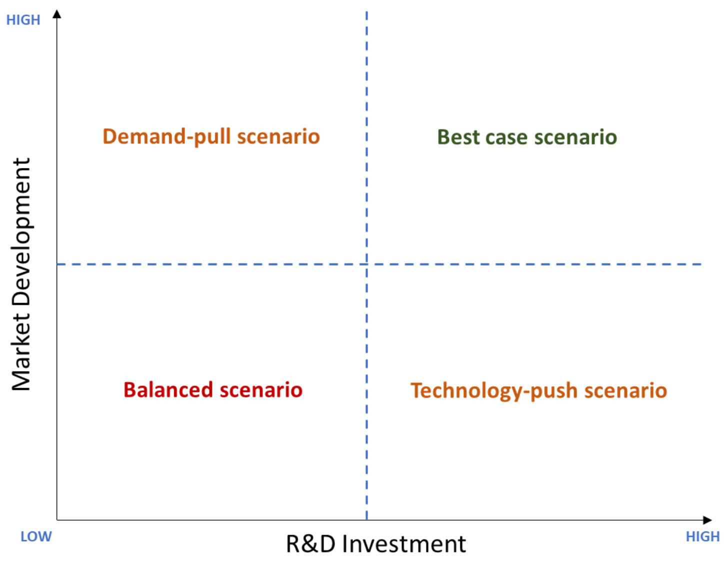

Figure 7.1: Simplified matrix illustrating the logic behind the defined scenarios

A corrective factor has been defined to quantify the deviation from the maximum potential cost-reduction previously illustrated. A corrective factor of 30% indicates that only 70% of the maximal planned impact will be achieved. This factor is composed of a meta-category-specific component as summarised in Table 7.1 and an improvement-specific value which will be presented in more details in Section 7.2. Note that corrective factor relative to the technical innovation specific to PV is identical in all scenarios. Indeed, it is considered that PV and BIPV sectors are, for the aspects presented in Section 5, independent.

Table 7.1 Meta-category-specific corrective factor component for 2022

	Technology-push scenario	*Demand-pull scenario*	*Balanced scenario*
Technical innovation (BIPV)	15%	30%	30%
Technical innovation (PV)	15%	15%	15%
Market maturation	30%	15%	30%

7.2 Barriers to implementation

In Section 5, for some improvements, barriers to implementation belonging to different categories (market barriers, economic & financial barriers, technological barriers, communication & dissemination barriers and political & legal barriers) were described. In the demand-pull scenario (respectively the technology-push scenario), the barriers of market maturation improvements (respectively of technical innovation improvements) are not taken into account.

As the number of barriers increases, or their importance, the meta-category-specific corrective factor component increases proportionally (i.e., the improvements' impact is more or less decreased). The same tendency occurs when the parameter defined as the "time to market" varies. The development of a BIM tool to support the BIPV design and installation processes for example faces numerous barriers and has an important time-to market. On the contrary, the rest of market maturation improvements have only a limited number of barriers and could apply to the complete market rapidly.

7.3 Timing considerations

The final corrective factors have been elaborated based on the defined scenarios and on the assessment of barriers to implementation, as presented in the two previous sections. The outcome of this assessment are corrective factors ranging from 0% in the best-case scenarios to almost 40% for the improvements with the most unfavourable realisation conditions (multiple barriers, important time-to-market lag, applicable to a limited market segment) under the balanced scenario. These values are applicable for the year 2022. As far as the 2025-and 2030 time-horizons are concerned, it is assumed that time will play in favour of reaching the maximal planned impact, thus the corrective factor decreases as time advances.

7.4 Special reference cases

Some BIPVBOOST improvements refer to the development of a BIPV product or system with specific aesthetical or technical characteristics or designed for a specific application. This is the case of various improvements developed within BIPVBOOST project, namely the "development of a portfolio of glass-glass coloured solutions", the "development of a portfolio of glass-glass patterned solutions", the "development a façade cladding with integrated thermal insulation" or the "development of a roof system based on lightweight CIGS on metal". Therefore, the end-user cost reductions associated to these improvements already take into account all improvements impacting the end-user cost and taking place before in the value chain (enhanced crating at manufacturing stage, installation of an automatic and flexible production lines using cSi cells, …). In the end, to evaluate the competitiveness for these specific reference cases, the technical innovation-related improvements add up to the associated BIPVBOOST improvements and, when applicable, with the "development of glass façades based on upgraded plug-and-play substructure". As far as market maturation improvements are concerned, only the rest of the market maturation improvements are taken into account except in the industrial building reference case where the end-user cost reduction already represents the maximal achievable reduction.

7.5 Results

In this section, three charts are presented for each reference case. A first chart shows by how much each improvement contributes to the decrease of the end-user cost in the balanced scenario (the results for the three other scenarios can be consulted in Appendix 2. Two distinct colours allow to quickly differentiate between technical innovations and market maturation improvements and the same abbreviations as those of Table 6.1 were used on the X-axes for readability purposes. The cost decreases are shown in nominal values but the end-user cost at the four milestones as well as the fixed cost are shown in real value, i.e. 2019 €/m². Then, the second chart gives an overview of the different end-user cost trajectories under the four simulated scenarios. For this chart, the evolution is represented in real terms (€$_{2019}$/m²). In these two first charts, the "fixed cost" represented by a black line refers to the notion defined in deliverable 1.1. As a reminder, the fixed costs represent the share of the total end-user cost that is due to the BIPV system as a building envelope solution (including material and installation costs). In this deliverable, the total end-user cost was divided into two components: the extra cost of BIPV representing all the costs that are assignable to the BIPV system as an electricity generation unit and the fixed cost representing all costs that are assignable to BIPV as a construction material system, which would be due in any case, as they are inherent to any building envelope solution, should it be active or not. In the following charts, the fixed costs values are assumed to remain constant over the years. This simplification assumption is supported by the fact that only a limited cost-reduction potential exists for this share of the total end-user cost. Yet, one should bear in mind that minor cost decreases are nevertheless possible. Finally, the last chart provides an overview of the competitiveness decrease until 2030 under the four simulated scenarios. For this last chart, results are also presented in real terms. General observations and commentaries are provided at the end of Section 7.5.

7.5.1 Industrial building reference case

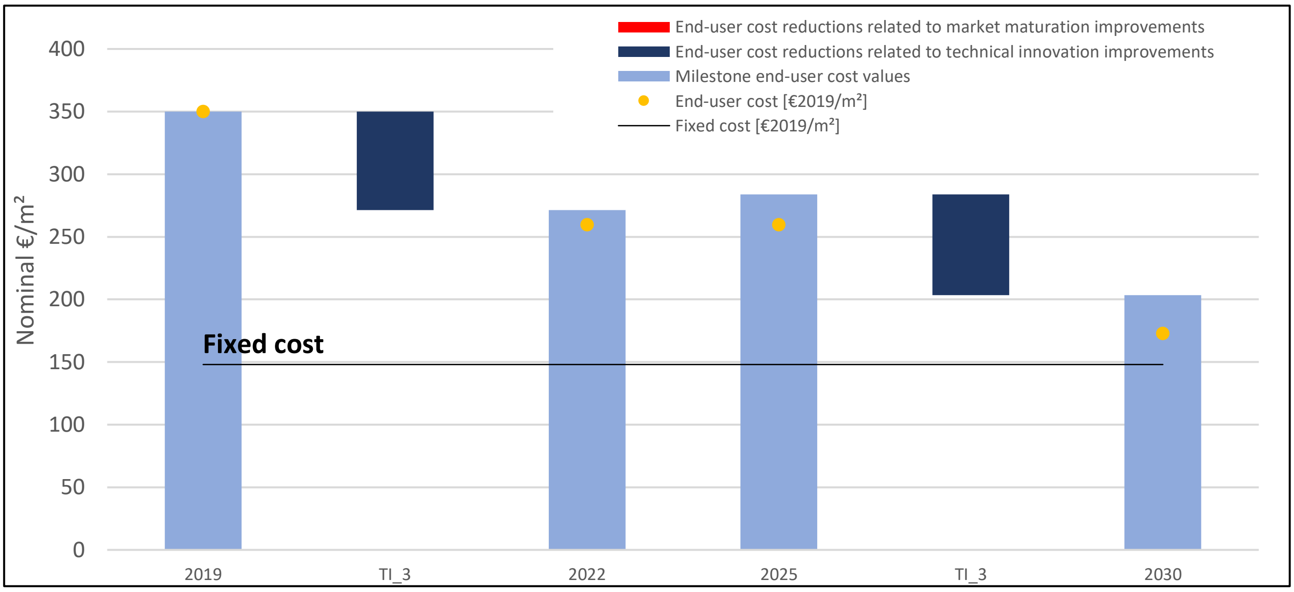

Figure 7.2 Nominal end-user cost decrease under the "balanced" scenario for the reference case IB

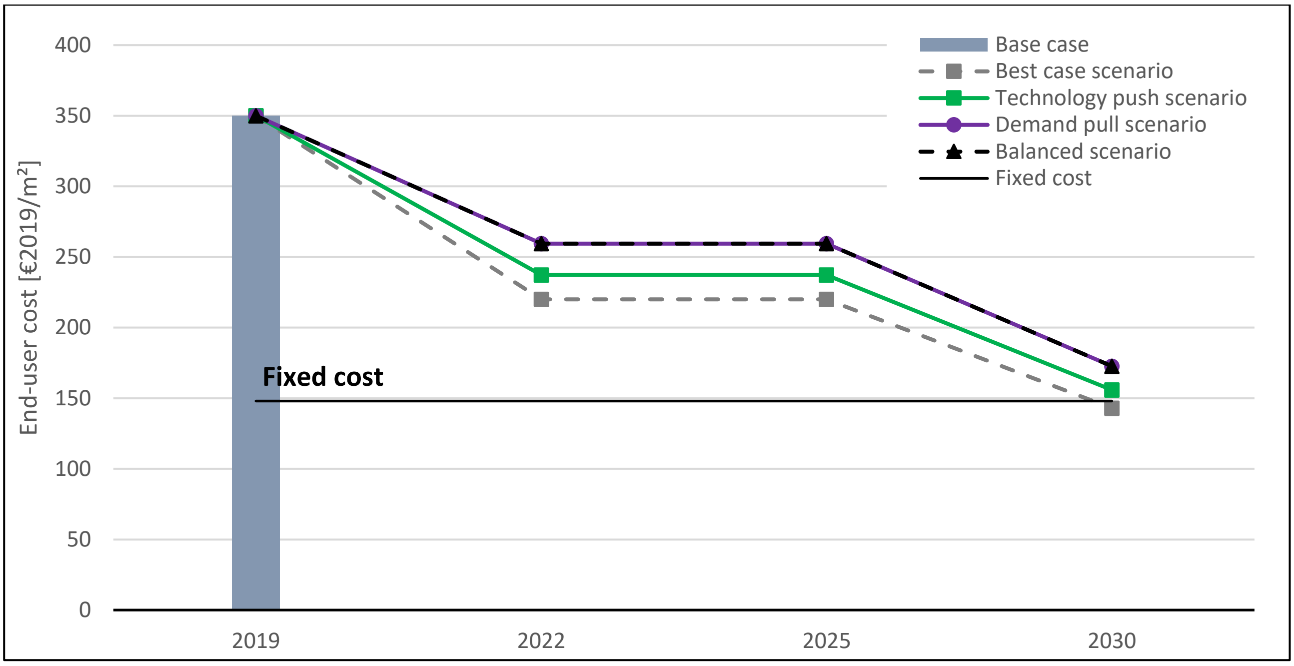

Figure 7.3 End-user cost decrease under different scenarios for the reference case IB

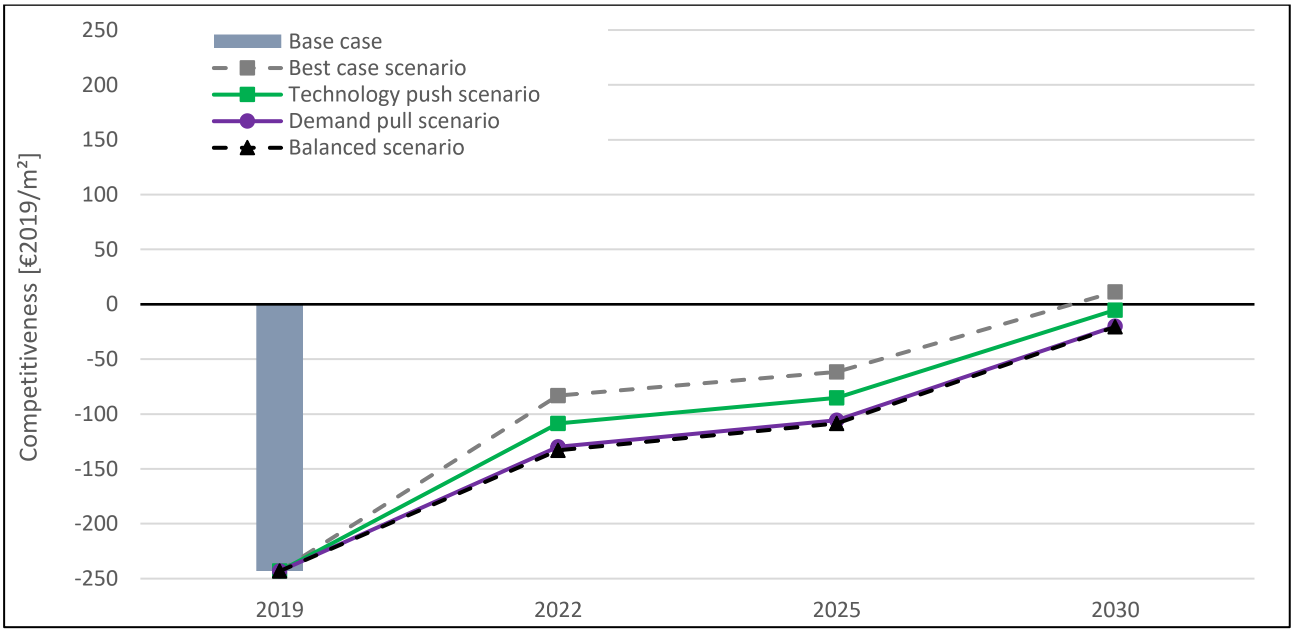

Figure 7.4 Competitiveness increase under different scenarios for the reference case IB

The only improvement assumed to impact the end-user cost in this industrial building reference case is the "development of a roof system based on lightweight CIGS on metal" (TI_3) and will contribute to a 55% end-user cost reduction by 2030. This corresponds to an end-user cost of 173 $€_{2019}$/m² in 2030 under the balanced scenario, thus lying above the fixed cost, in real terms, as shown on Figure 7.2. It can be noticed that both the end-user cost decrease and competitiveness increase are driven by technical innovation related improvements. The potential competitiveness increase pathway is quite homogeneously distributed over the years, reaching the competitiveness threshold in 2025 in the best-case and technology-push scenarios and by 2027 in the other scenarios. Eventually bringing the competitiveness of this industrial building reference case to around -20 $€_{2019}$/m² by 2030, in the balanced scenario.

7.5.2 Single family house reference case

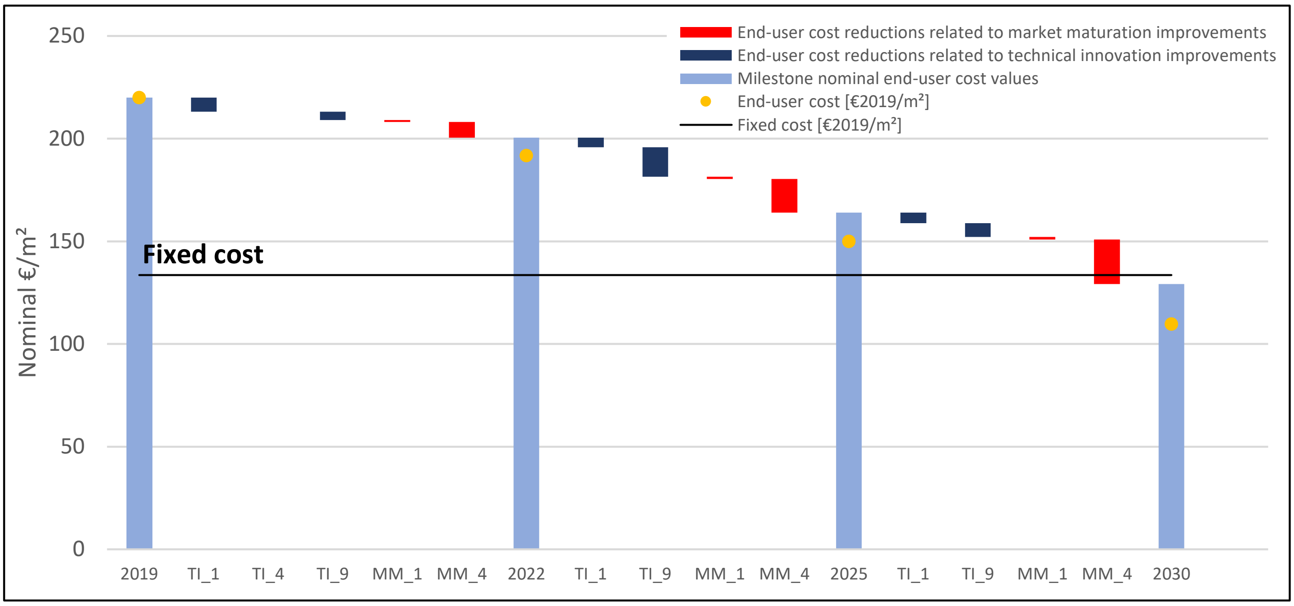

Figure 7.5 Nominal end-user cost decrease under the "balanced" scenario for the reference case SFH_b

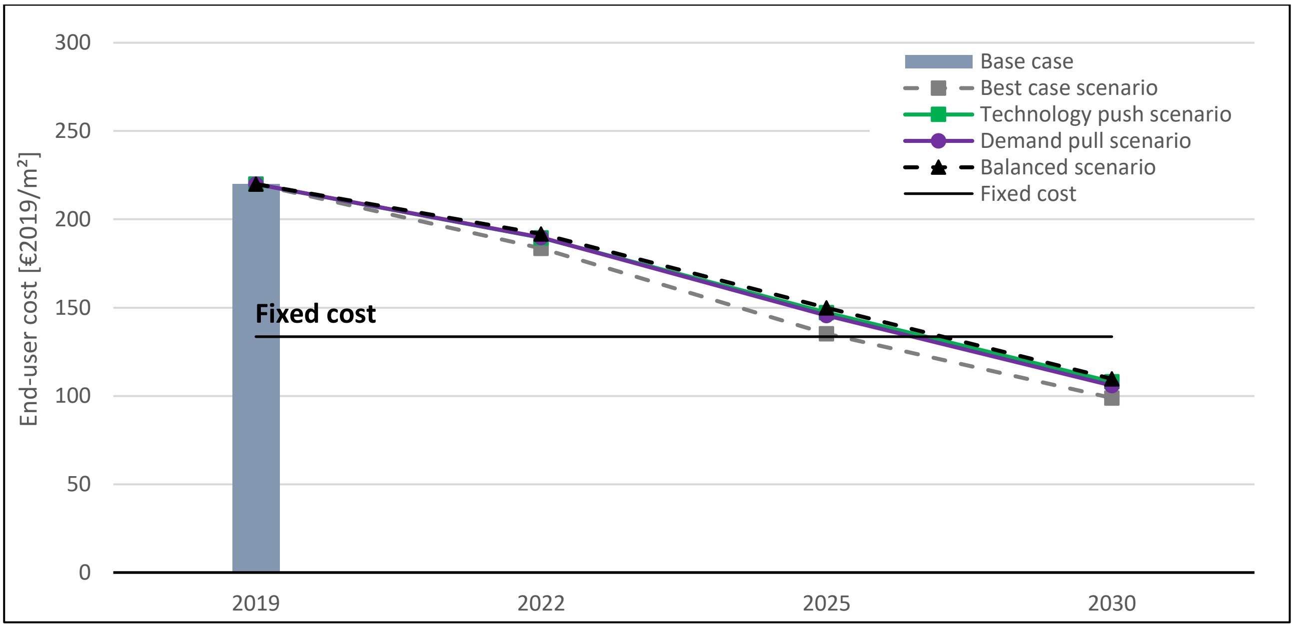

Figure 7.6 End-user cost decrease under different scenarios for the reference case SFH_b

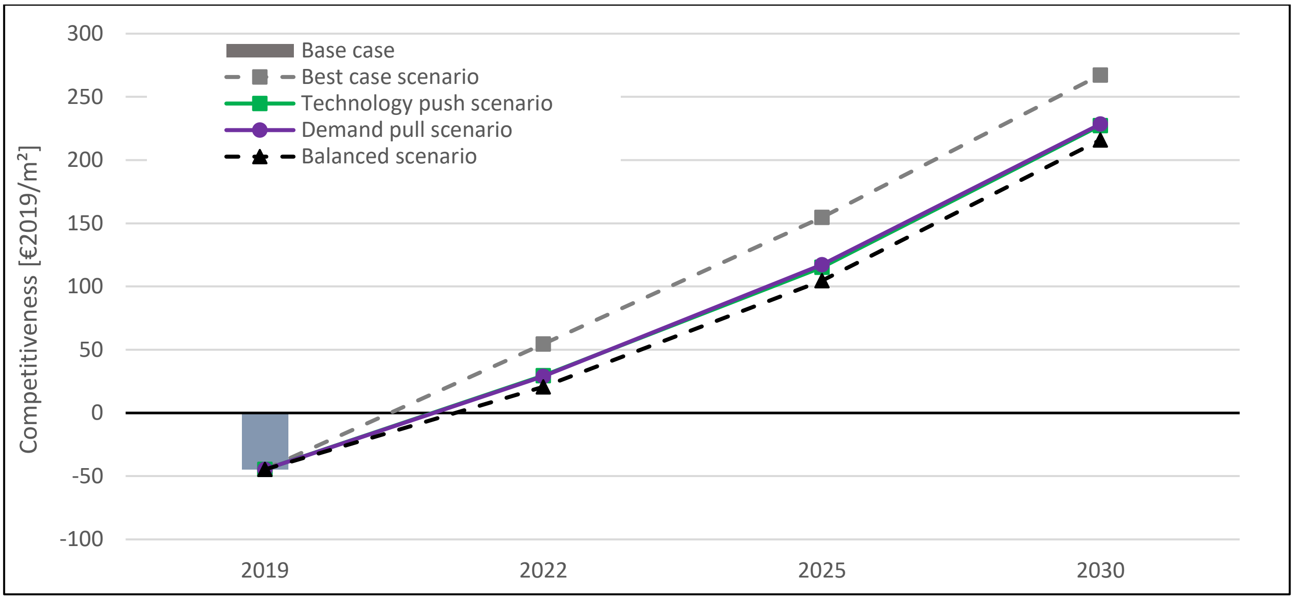

Figure 7.7 Competitiveness increase under different scenarios for the reference case SFH_b

In this single-family house reference case, the end-user cost is projected to decrease by around 41% (nominal decrease) until 2030, thus reaching 109 €$_{2019}$/m² in 2030 under the balanced scenario. Contribution from the different improvements is, as depicted on Figure 7.5, quite uniform. The final figure would lie approximately around the "fixed cost" defined for this reference case in report D1.1, which shows that the potential to be competitive with conventional building envelope solutions, even on a pure cost basis, is real.

The reference case SFH_b is characterised by positive competitiveness values just after 2019, already. Thus, by 2030 very advantageous competitiveness values of around 219 €$_{2019}$/m², even under the balanced scenario, are foreseen. It can also be observed that the competitiveness increase is equally driven by market maturation-related and technical innovation-related improvements.

7.5.3 Educational building reference cases

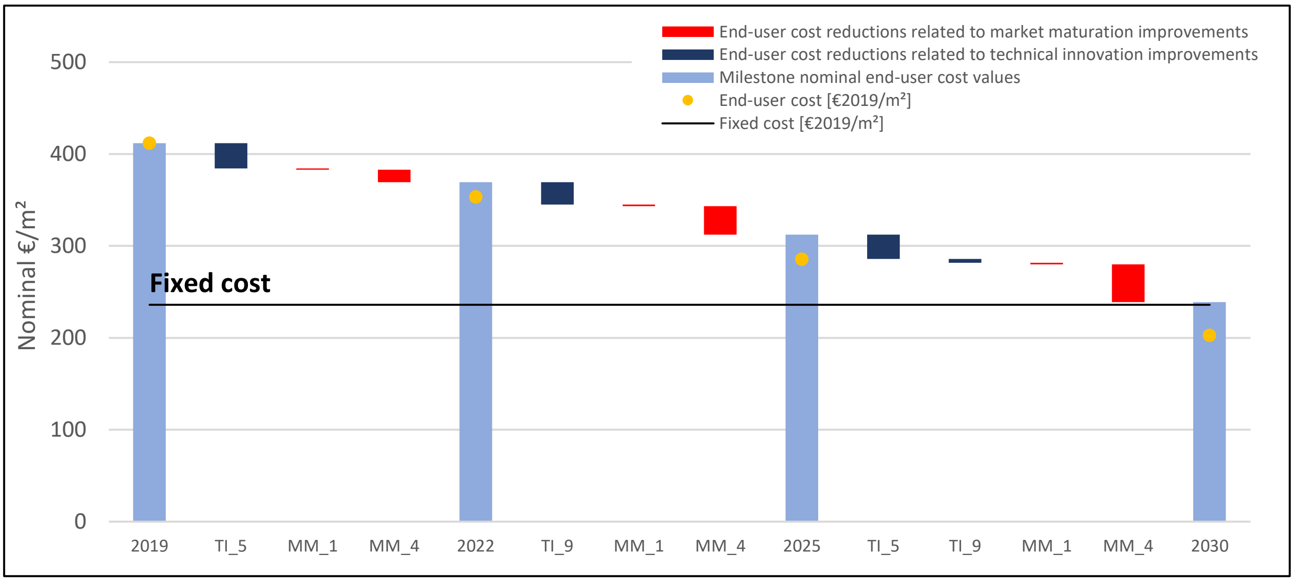

Figure 7.8 Nominal end-user cost decrease under the "balanced" scenario for the reference case EB_a1

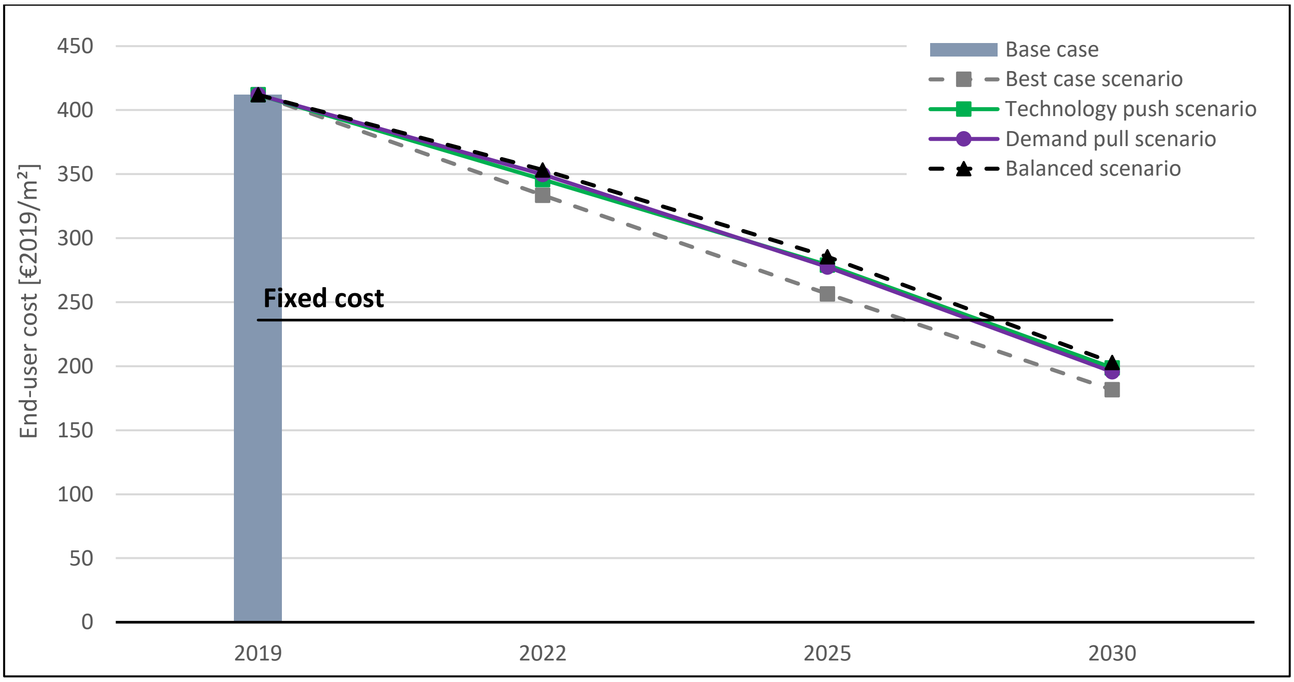

Figure 7.9 End-user cost decrease under different scenarios for the reference case EB_a1

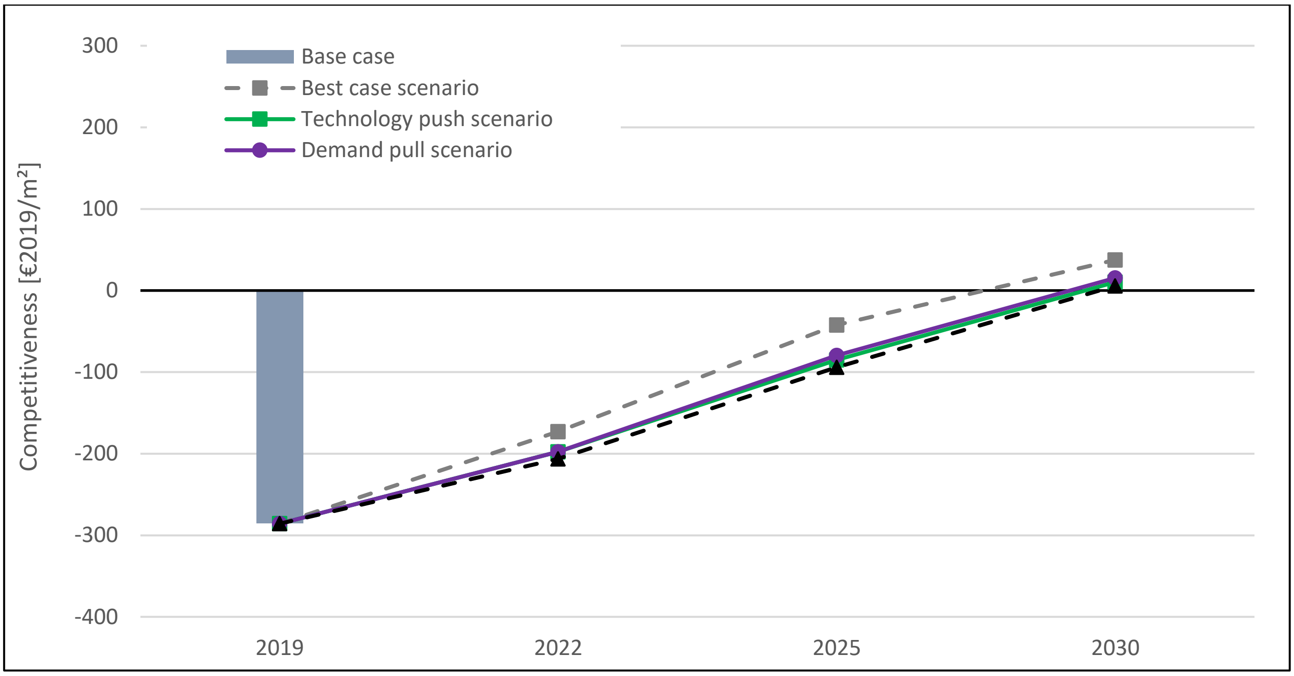

Figure 7.10 Competitiveness increase under different scenarios for the reference case EB_a1

Reference case EB_a1 shows significant potential for end-user cost reduction, when combined effect of improvements is studied. The end-user cost relative nominal decrease amounts to 42%, reaching a value slightly below the associated fixed cost estimated in 2019, under all scenarios. The contribution of the different improvements is relatively uniform. This case, based on CIGS, also has the potential to see a dramatic increase of competitiveness in the short- to medium-term. Depending of the considered scenario, economic attractiveness of such solution could be ensured by 2025 already. By 2030, competitiveness would range between 17 and 44 $€_{2019}$ per m² under the different scenarios.

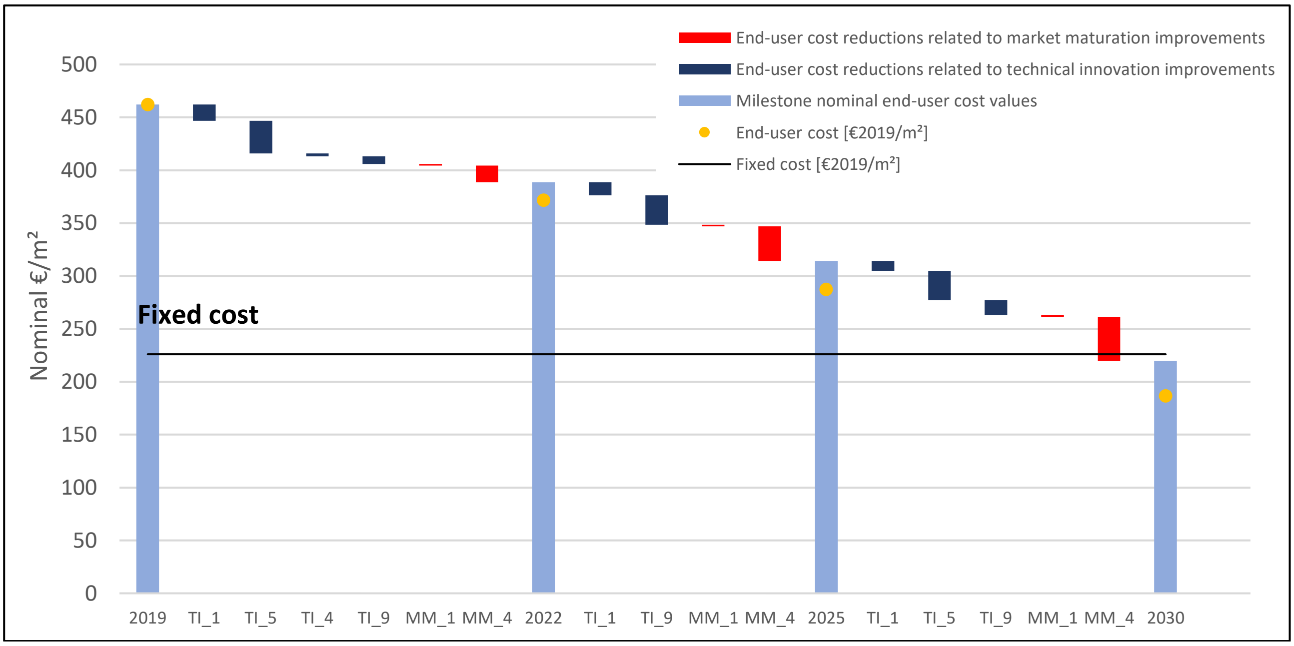

Figure 7.11 Nominal end-user cost decrease under the "balanced" scenario for the reference case EB_b1

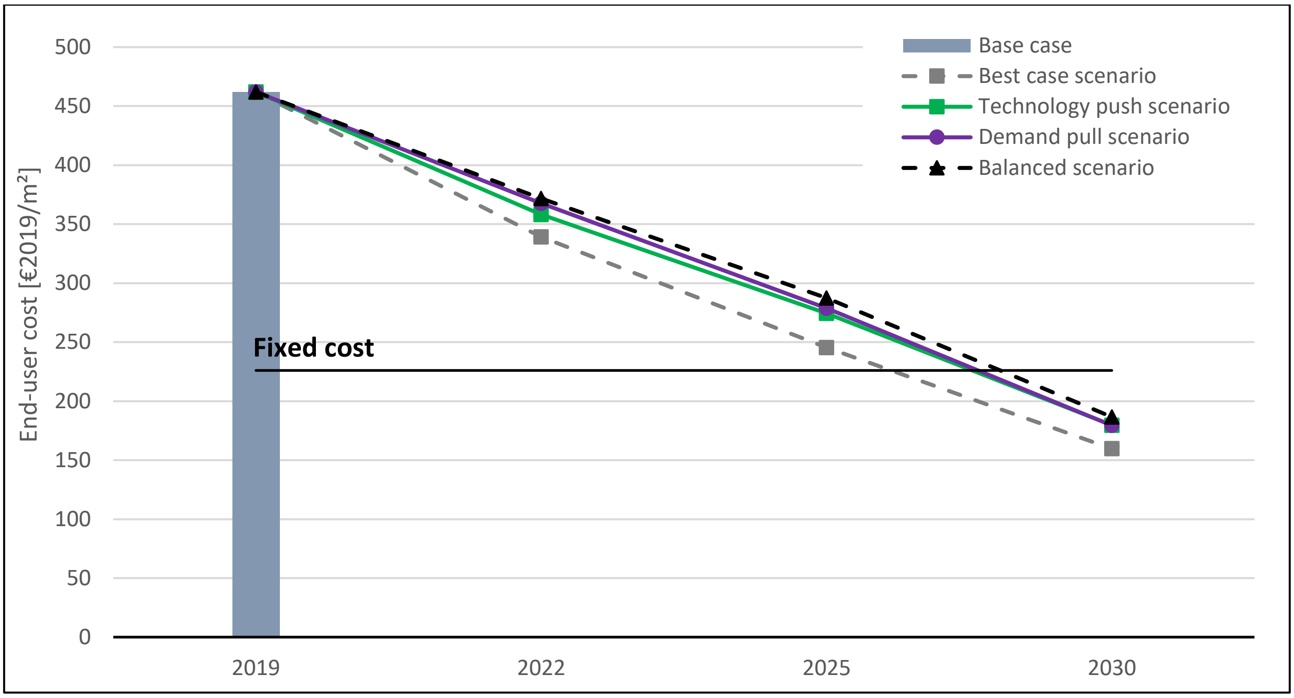

Figure 7.12 End-user cost decrease under different scenarios for the reference case EB_b1

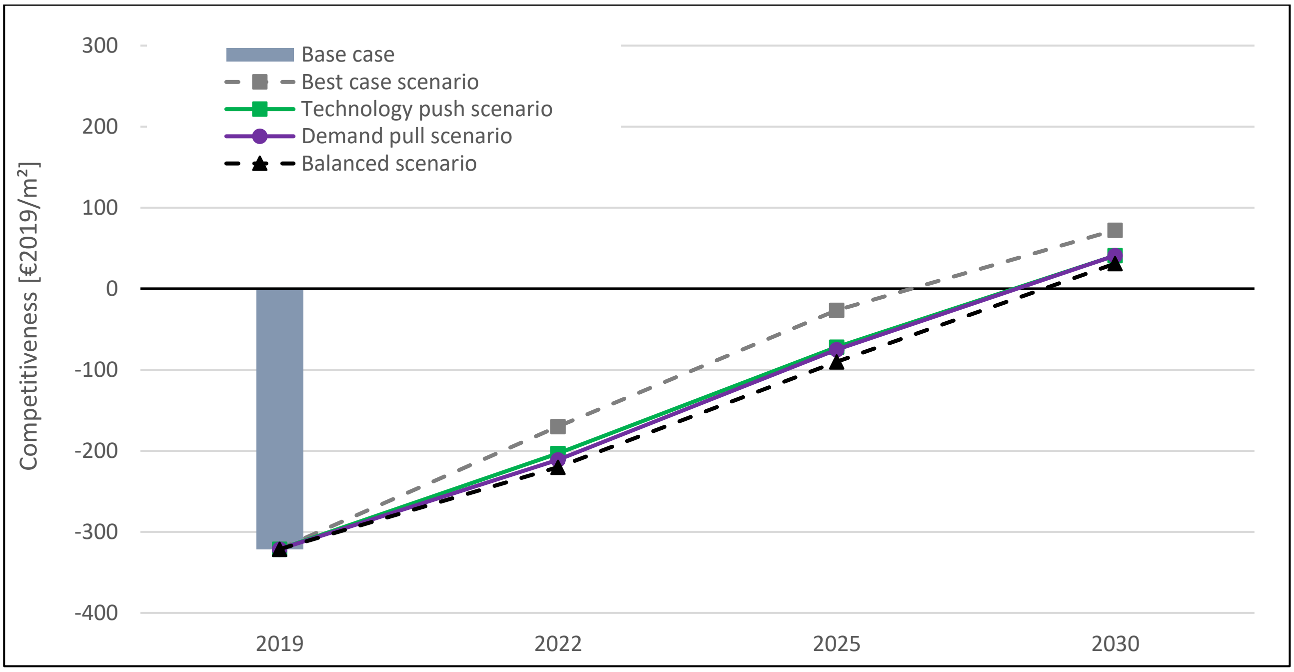

Figure 7.13 Competitiveness increase under different scenarios for the reference case EB_b1

In this reference case, the conclusions to draw is similar to what was said about the EB_a1 case. The situation is even more promising, as end-user cost potential is of higher magnitude, possibly ending below the 200 $€_{2019}/m^2$ mark by 2030, under all scenarios. Similarly, positive competitiveness could be reached by 2027, under all scenarios, and end up around 57 $€_{2019}/m^2$ by 2030.

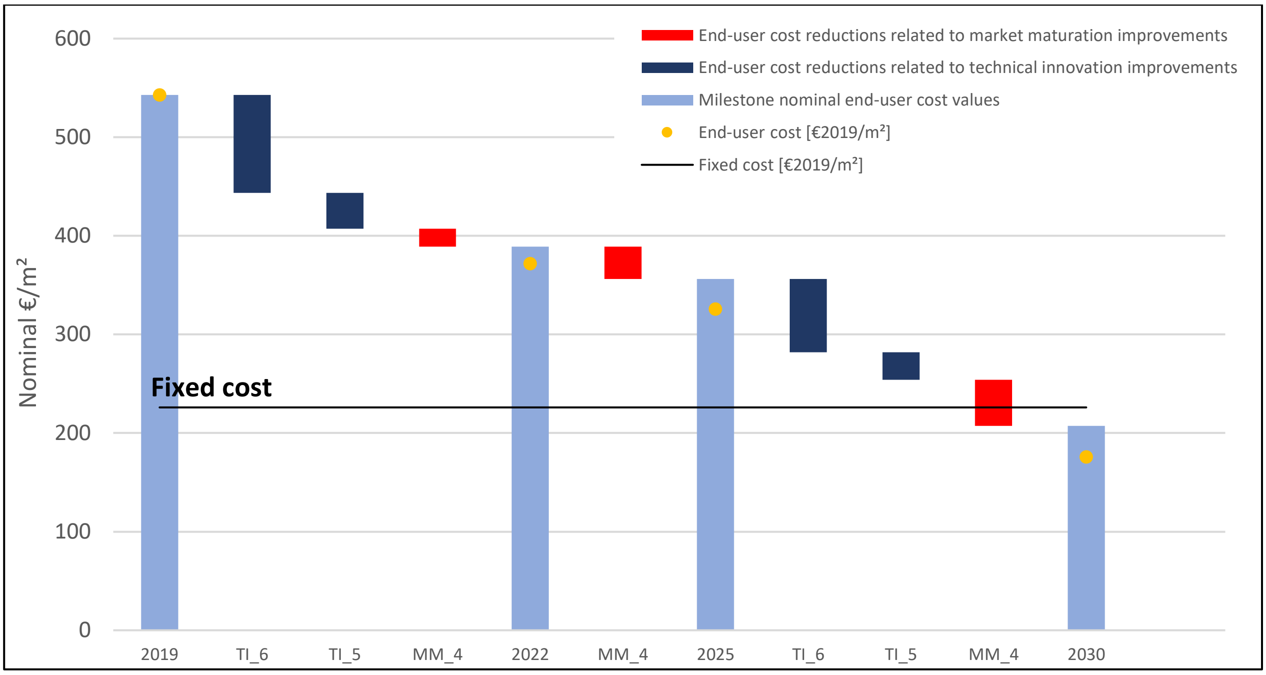

Figure 7.14 Nominal end-user cost decrease under the "balanced" scenario for the reference case EB_b2

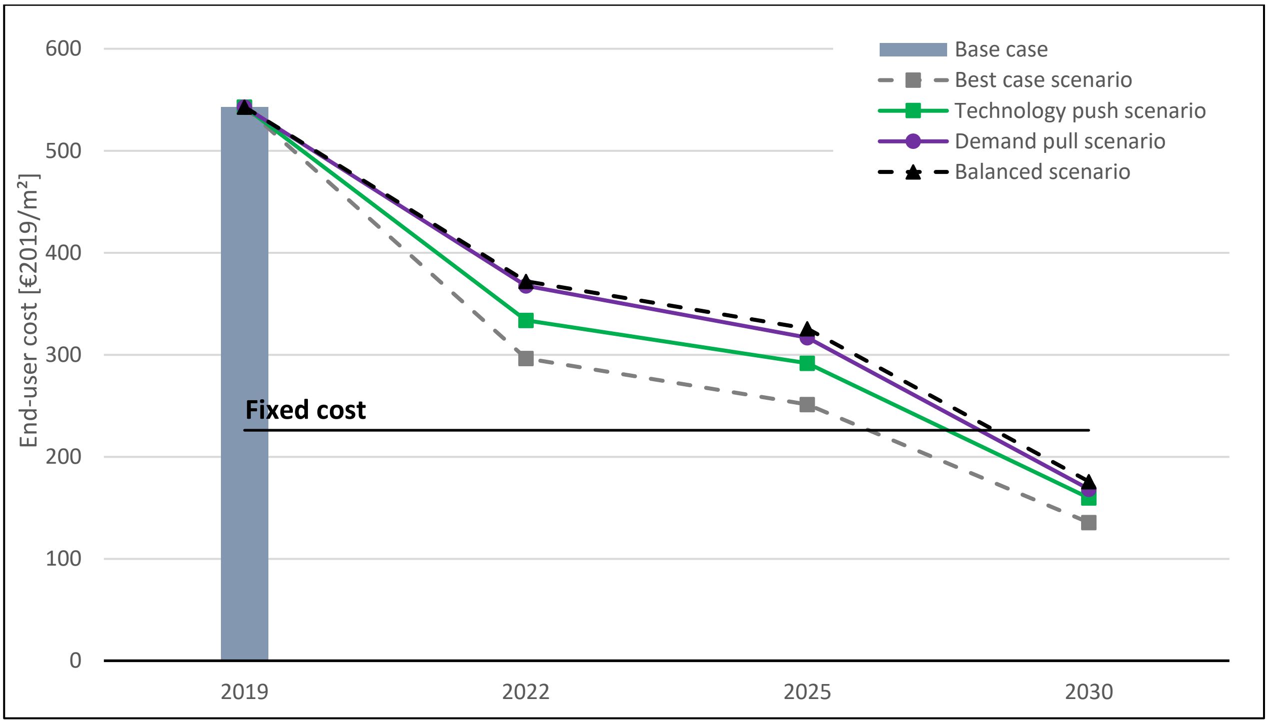

Figure 7.15 End-user cost decrease under different scenarios for the reference case EB_b2

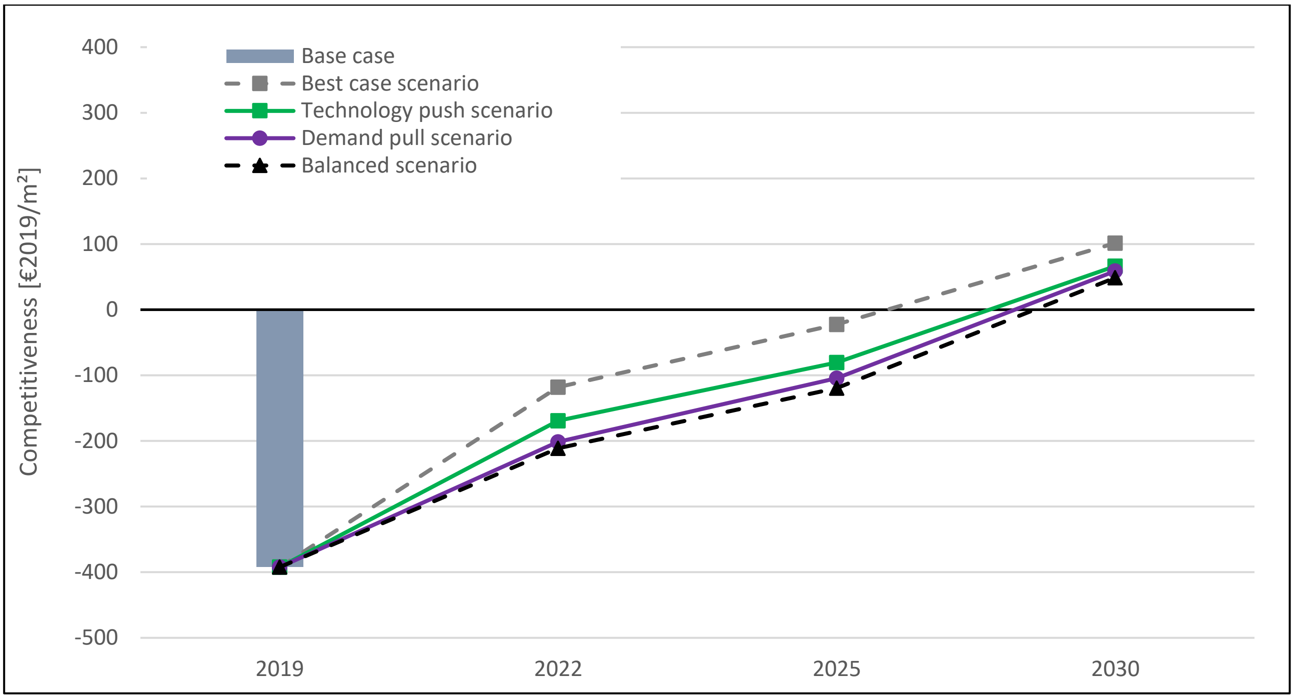

Figure 7.16 Competitiveness increase under different scenarios for the reference case EB_b2

The end-user cost relative decreases for the EB_b2 educational reference equals to 62% (nominal value), reaching again a value below the estimated 2019 fixed cost. Even though the considered reference case is a façade application characterised by lower yield values, the competitiveness threshold is reached by 2027. By 2030, EB_b2 is projected to reach a competitiveness lying just above 60 $€_{2019}/m^2$ in the balanced scenario. Note that in this case, contribution of improvements is less homogenous, and the technical innovation-related improvements should contribute mostly to these results.

7.5.4 Multifamily house reference case

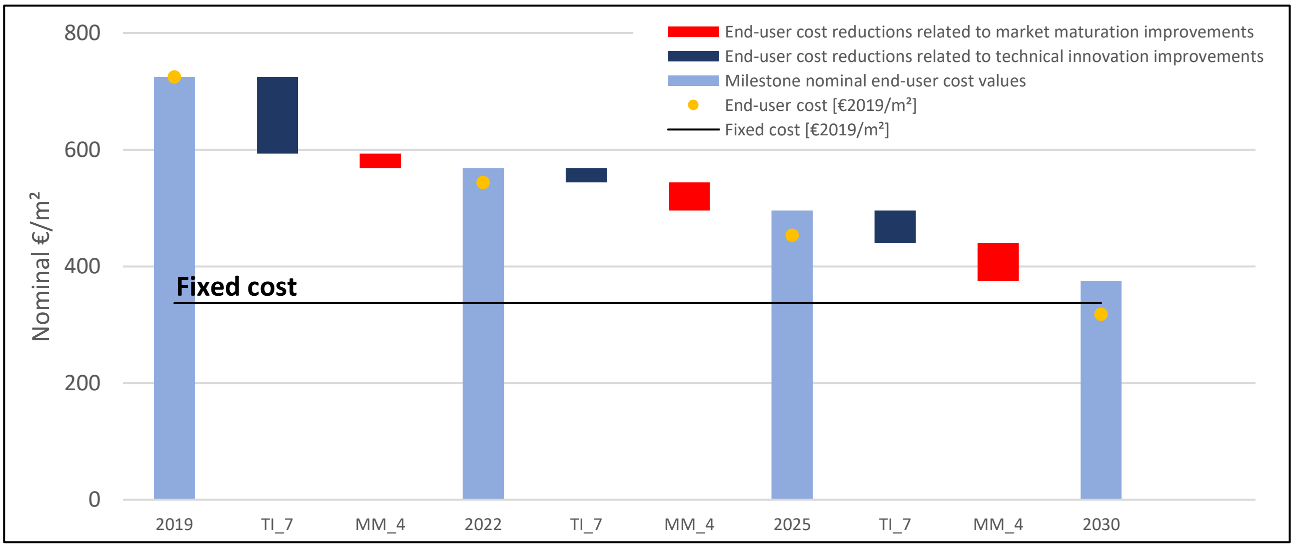

Figure 7.17 Nominal end-user cost decrease under the "balanced" scenario for the reference case MFH

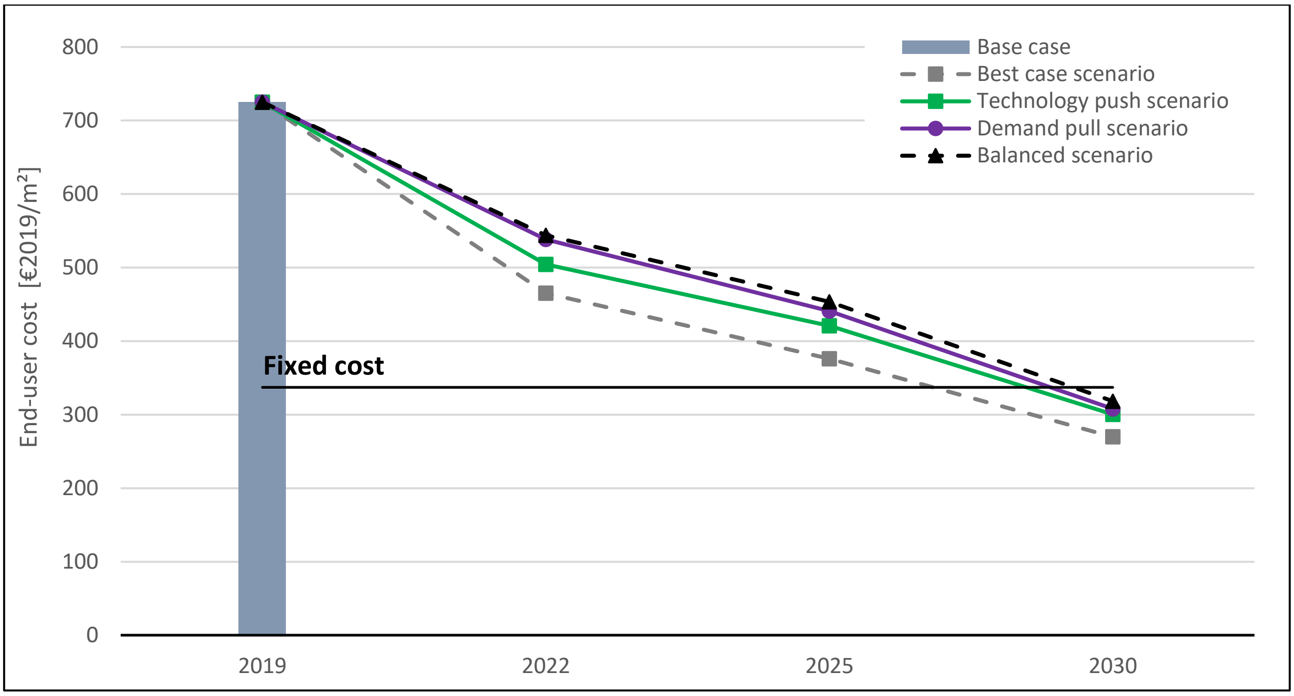

Figure 7.18 End-user cost decrease under different scenarios for the reference case MFH

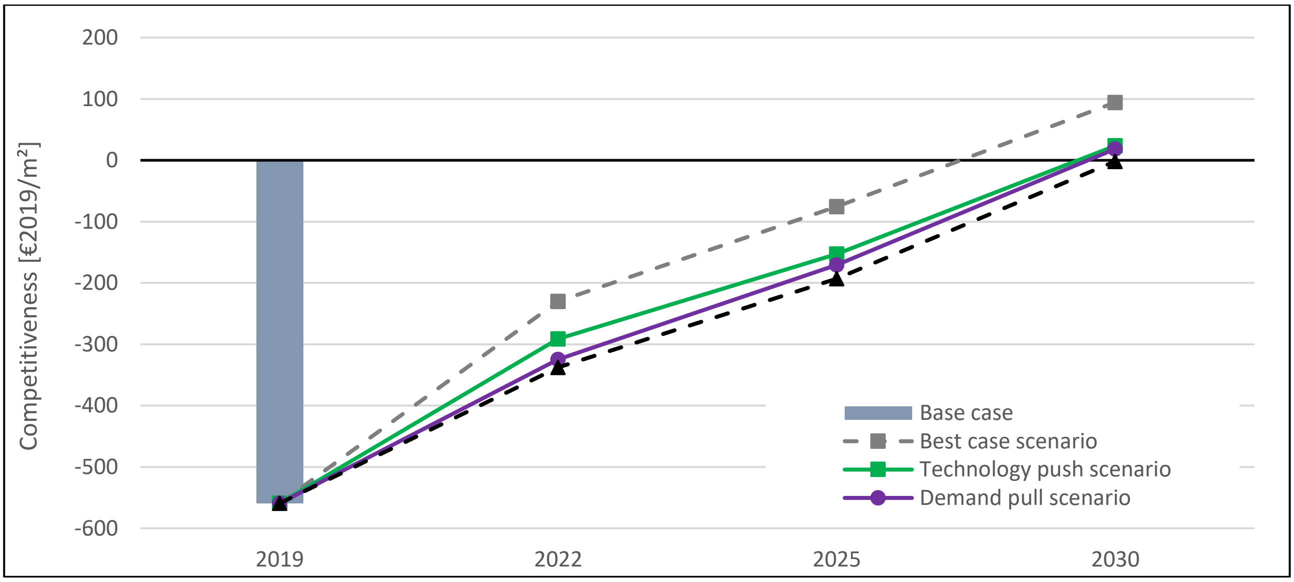

Figure 7.19 Competitiveness increase under different scenarios for the reference case MFH

The improvements for the multifamily house reference case, led by BIPVBOOST projects' "development of a BIPV façade cladding with integrated insulation", are projected to contribute to a 48% end-user cost decrease until 2030. Thus, an end-user cost of 318 $€_{2019}/m^2$ should be reached by 2030 in the balanced scenario, which corresponds to the fixed cost. The competitiveness threshold should be reached by 2028. By 2030, positive competitiveness could be achieved.

It can also be observed that the cost-reduction are mainly driven by technical innovation-related improvements and that the competitiveness increases follow a quite regular pattern over the 11-year time horizon.

7.5.5 Office building reference cases

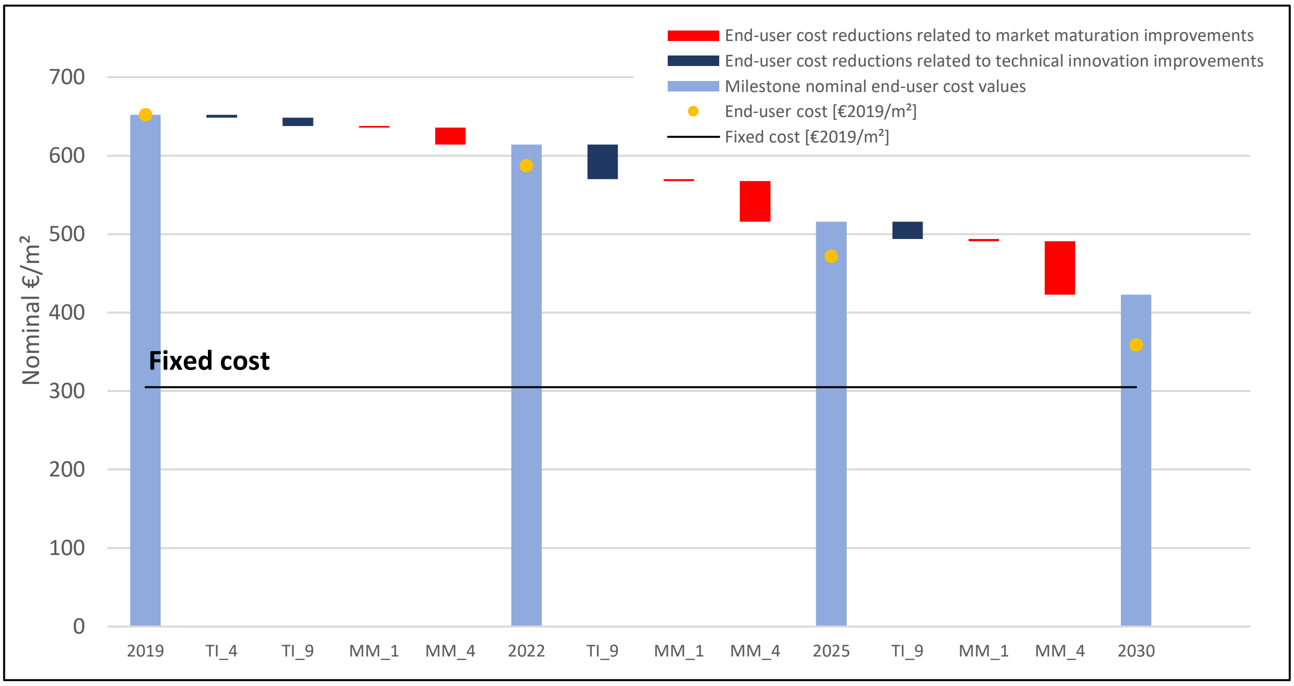

Figure 7.20 Nominal end-user cost decrease under the "balanced" scenario for the reference case OB_a1

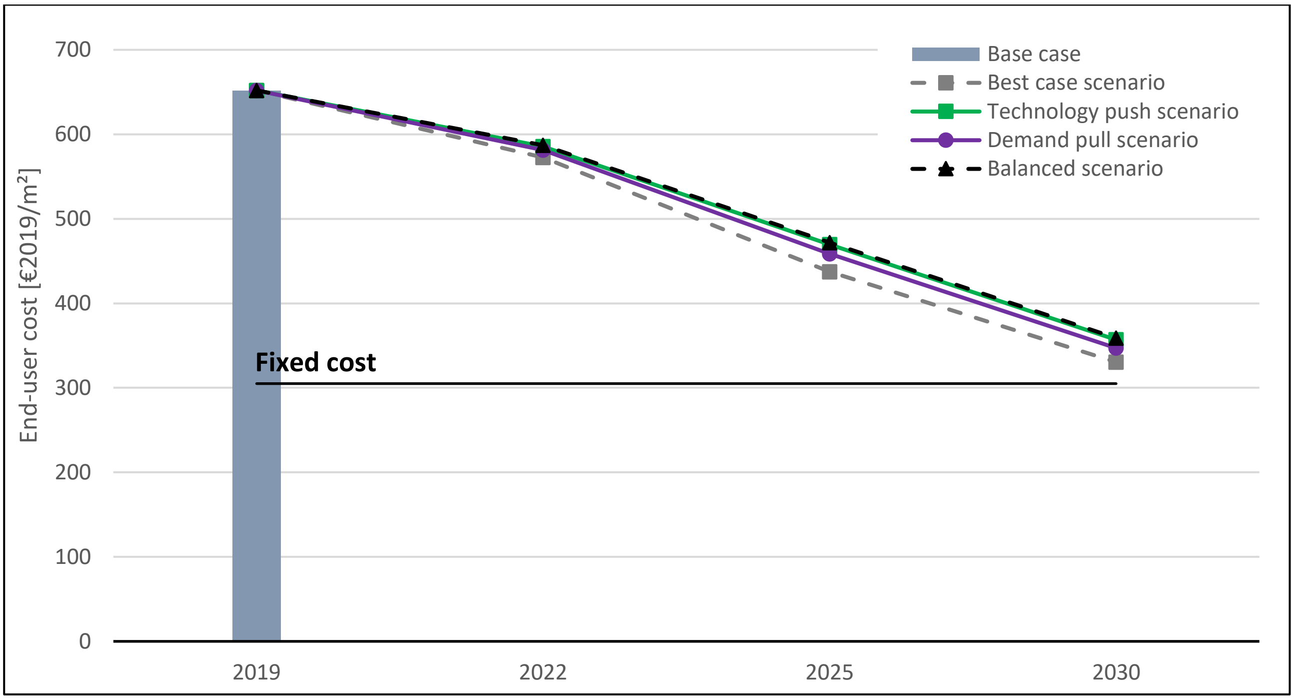

Figure 7.21 End-user cost decrease under different scenarios for the reference case OB_a1

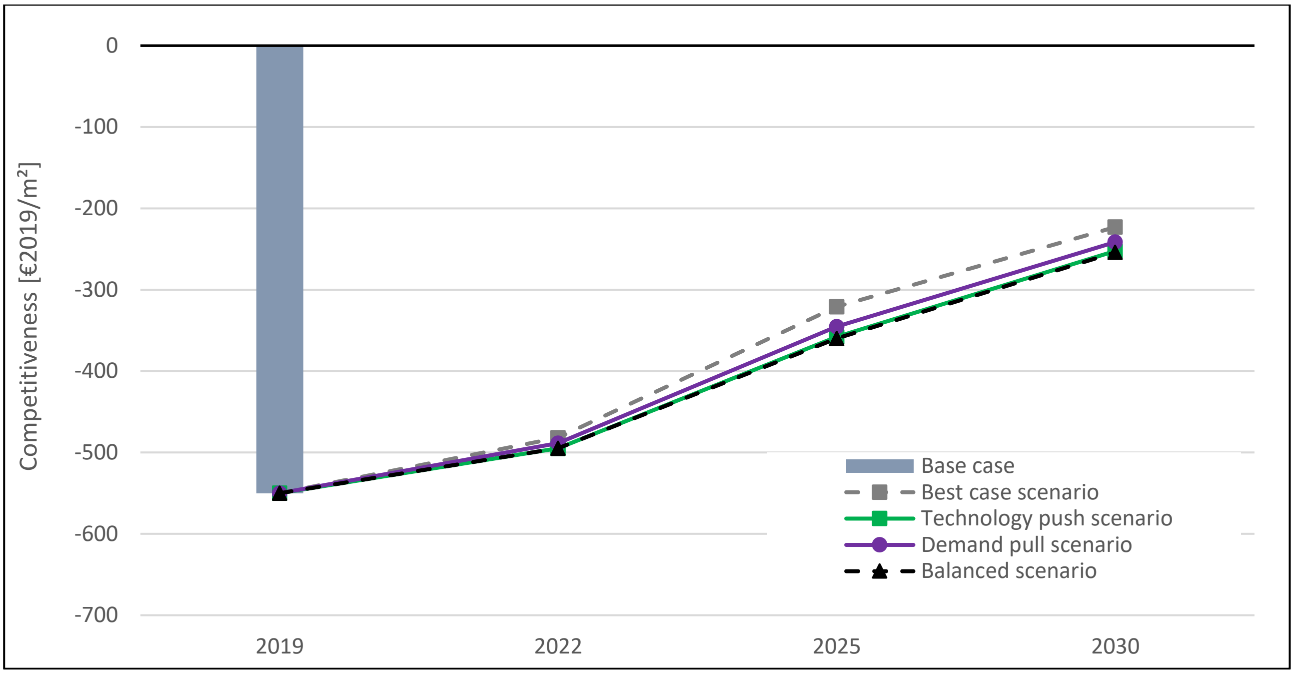

Figure 7.22 Competitiveness increase under different scenarios for the reference case OB_a1

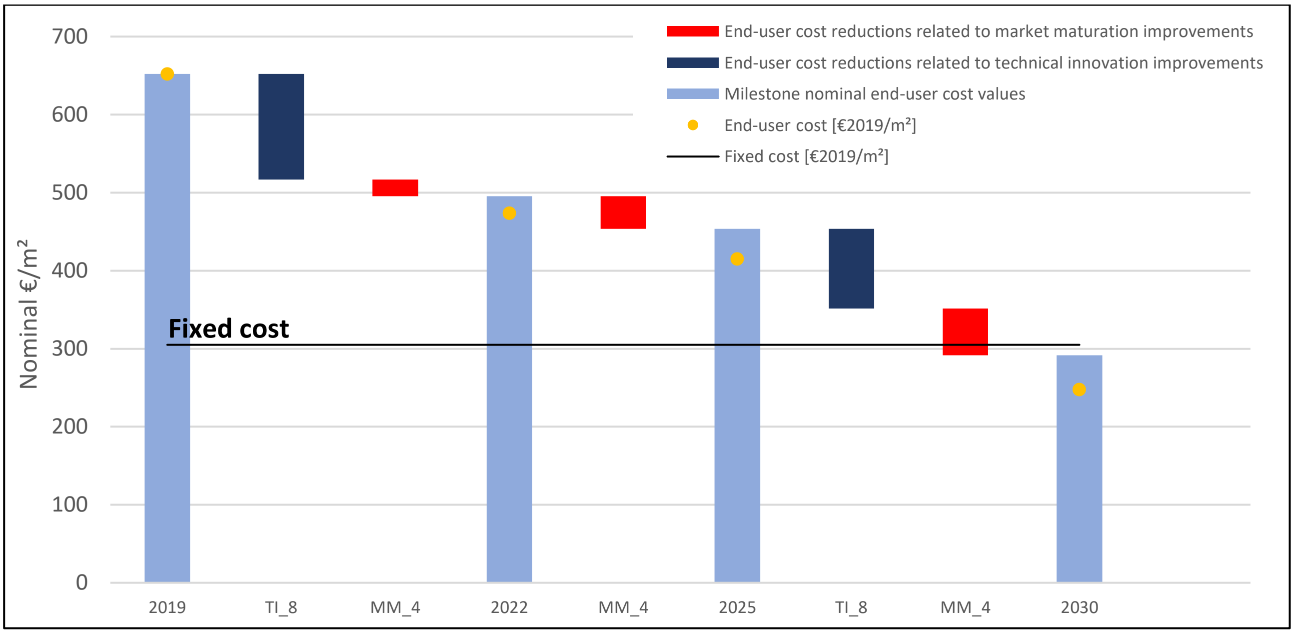

Figure 7.23 Nominal end-user cost decrease under the "balanced" scenario for the reference case OB_a2

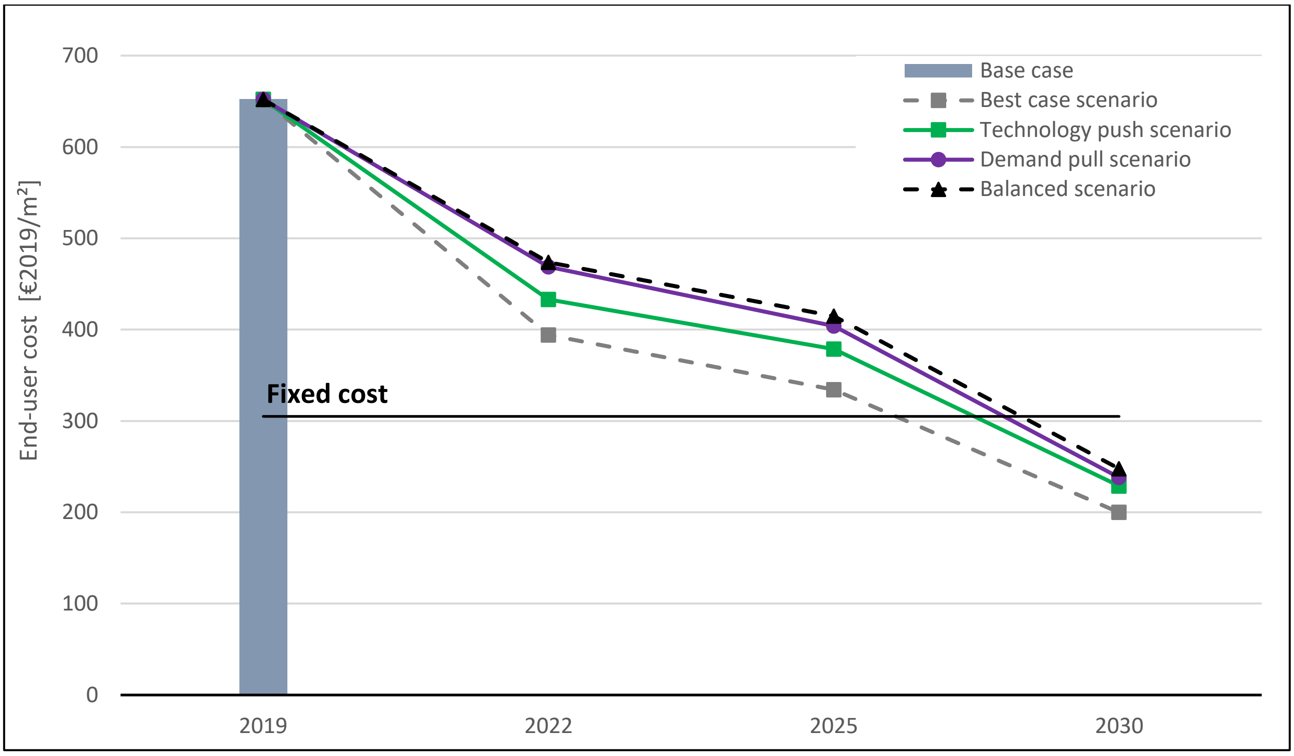

Figure 7.24 End-user cost decrease under different scenarios for the reference case OB_a2

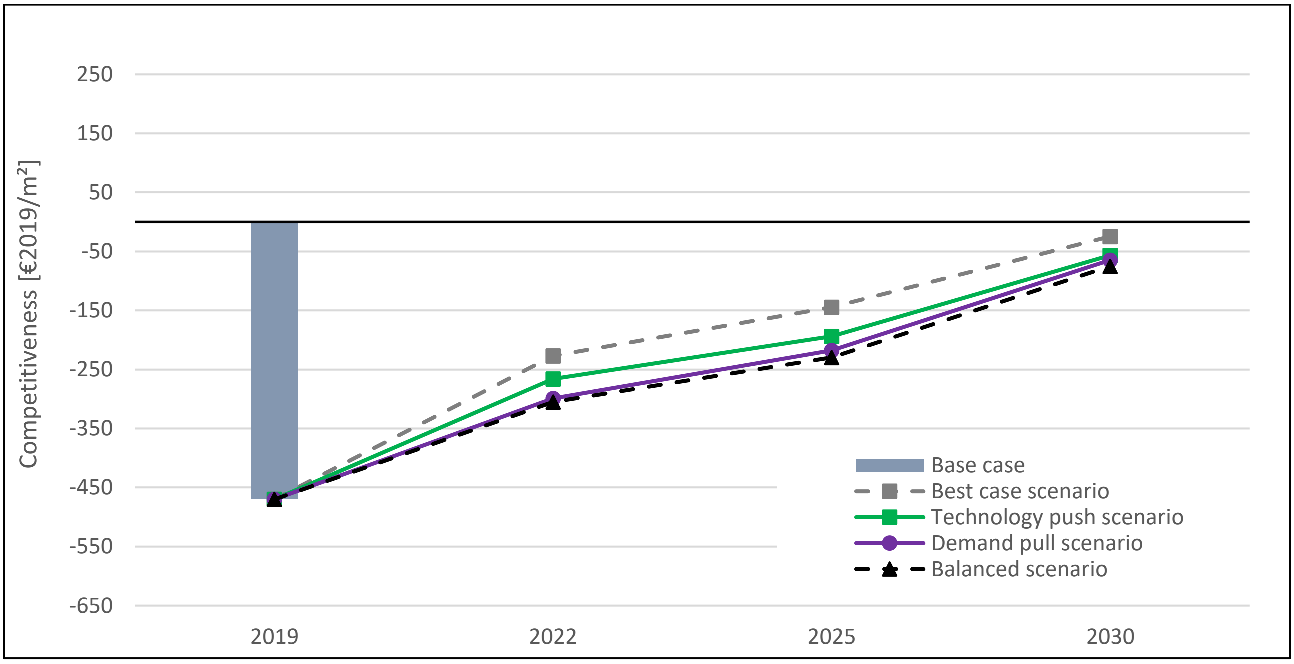

Figure 7.25 Competitiveness increase under different scenarios for the reference case OB_a2

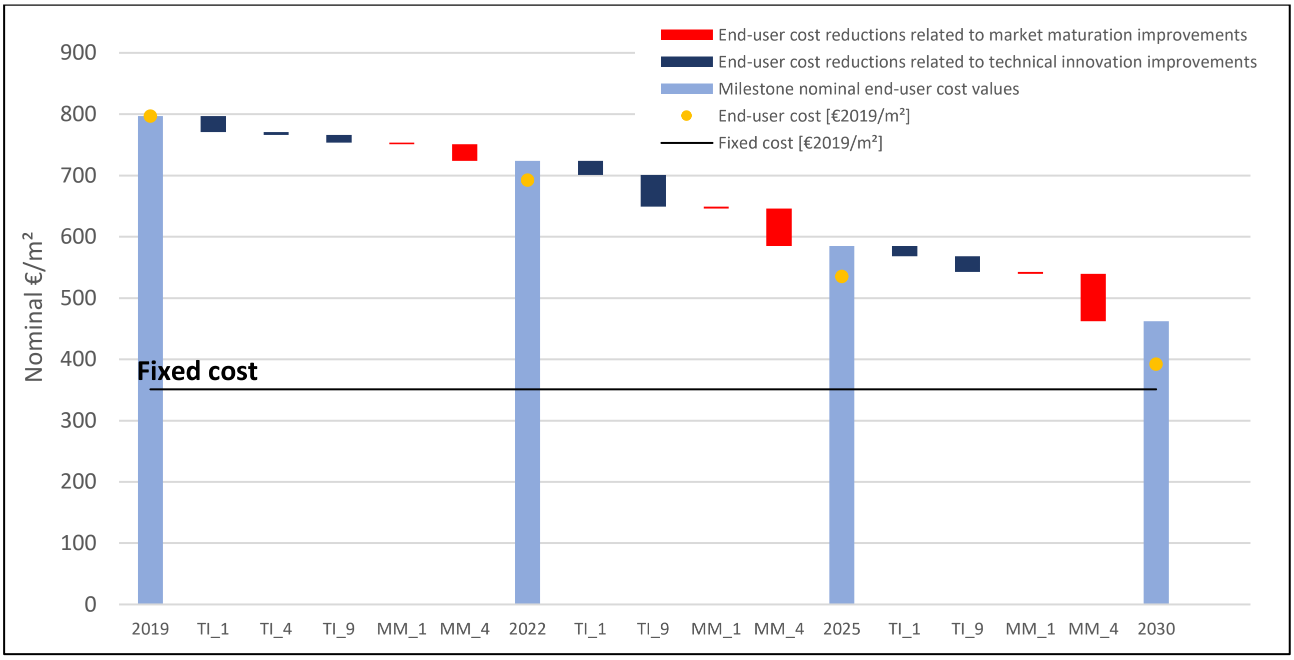

Figure 7.26 Nominal end-user cost decrease under the "balanced" scenario for the reference case OB_b1

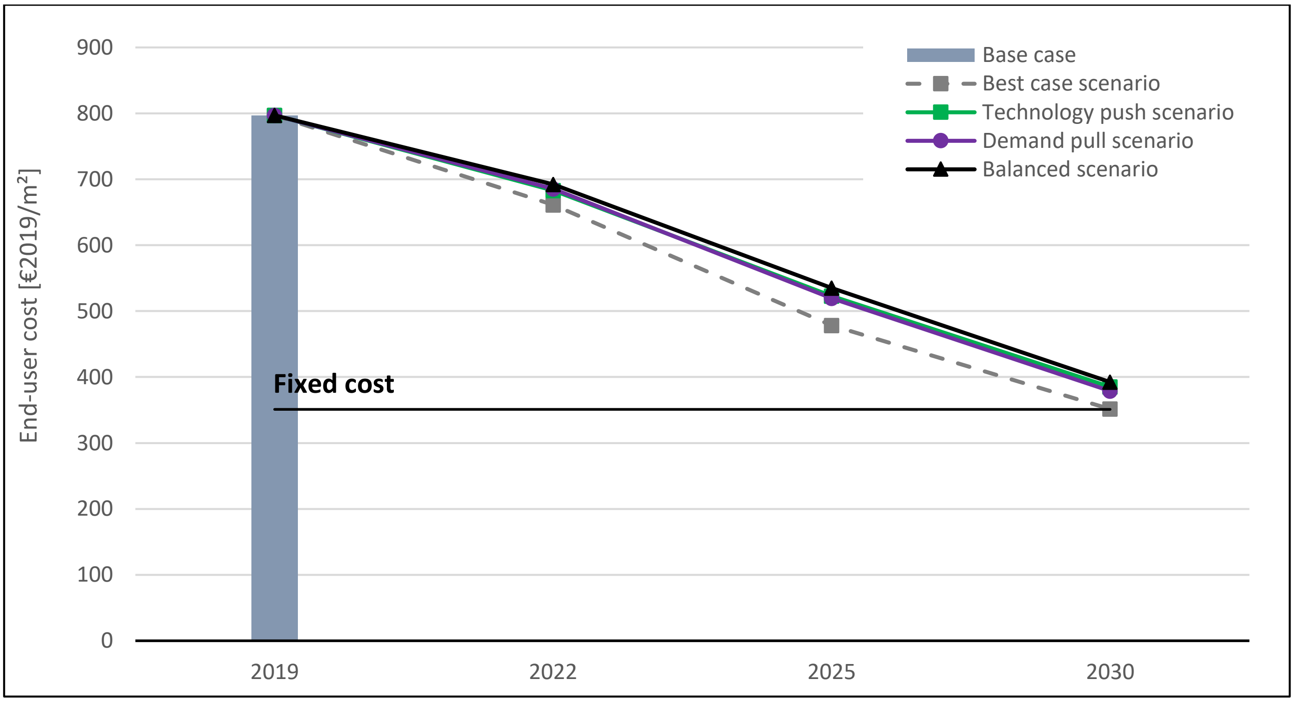

Figure 7.27 End-user cost decrease under different scenarios for the reference case OB_b1

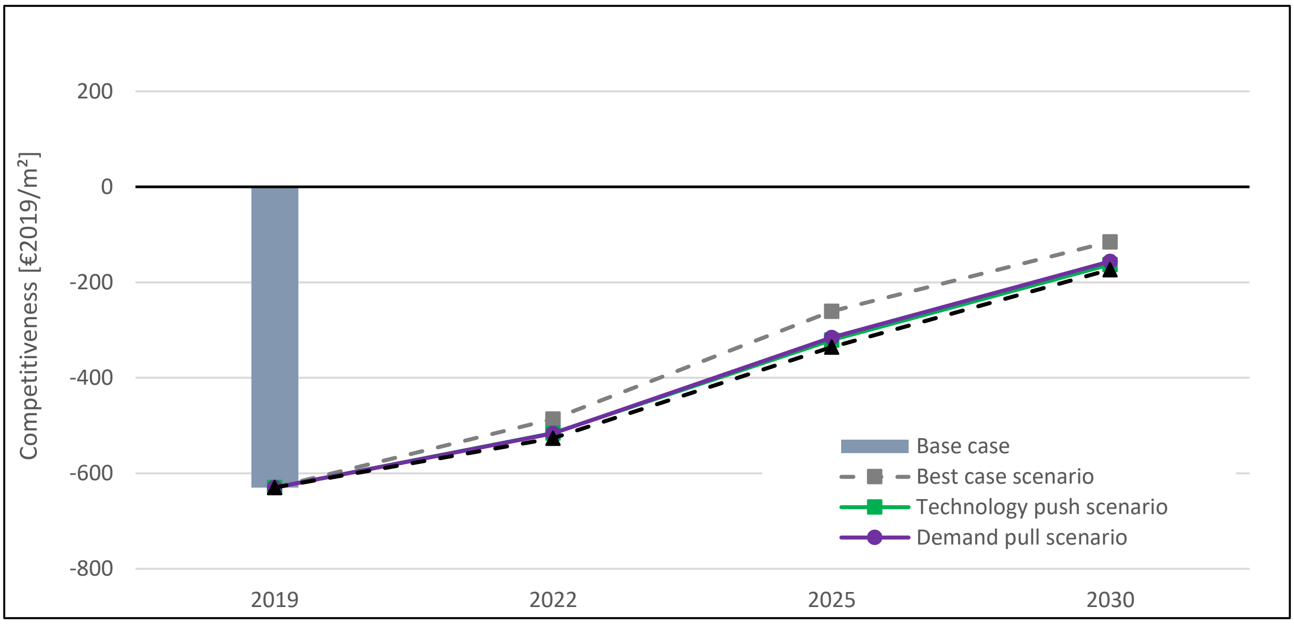

Figure 7.28 Competitiveness increase under different scenarios for the reference case OB_b1

The office building reference cases are the only studied cases in which the competitiveness threshold could possibly not be reached by 2030, under the tested scenarios and parameters. This can be explained by a combination of multiple unfavourable conditions. Indeed, those reference cases consider a semi-transparent curtain wall implying lower efficiency values. In the OB_a1 and OB_a2 reference cases, these low module efficiency values along with important annual degradation rates (due to the use of aSi PV technology) hinder this technology from benefiting from increased system lifetimes.

As far as the OB_b1 case is considered, which is based on crystalline silicon, the technical characteristics are better even though module efficiency lies around 10,45% (in 2019 base case). Nevertheless, the competitiveness threshold is in sight by 2030. In addition, it is worth highlighting that it could be completely reached with the extra cost approach, which for previously explained reasons was not the chosen methodology in this deliverable. No predominance can be observed between technical innovation-related improvements and market maturation-related improvements.

7.6 Highlights

In most of the reference cases analysed, the competitiveness threshold is planned to be reached just after 2025 under the three “realistic scenarios” (“technology-push scenario”, “demand-pull scenario” and “balanced scenario”) and values are promising for the 2030 horizon.

Exceptions are the SFH_b reference case, for which competitiveness is already achieved just after 2019, and the office building reference cases for which the competitiveness is not foreseen to increase sufficiently to become positive, especially in the case of aSi-based BIPV solutions. Indeed, the residential roof illustrated in the SFH_b reference case, through lower end-user costs, advantageous tilt for sun exposure and high module efficiency values reaches very attractive competitiveness values by 2030, approaching 220 $€_{2019}/m^2$ in the balanced scenario. On the contrary, the reference cases set on office buildings are severely handicapped by high end-user cost and low efficiency values due to the semi-transparency, thus staying between 70 and 250 $€_{2019}/m^2$ away from becoming competitive in the balanced scenario.

It is also worth noting that even if promising, uncertainty linked to these results exists, especially when it comes to 2030 figures. In addition, in multiple cases, the predicted end-user cost could end up below the fixed cost defined in 2019, especially at the horizon 2030. This is another factor entailing cautiousness. Indeed, it demonstrates that the impact of the identified improvements could plateau after 2025, and the end-user cost in 2030 could stand higher than predicted here. Nonetheless, considering competitiveness values, this should not prevent the reference cases from being economically attractive.

Finally, one should bear in mind that the competitiveness estimations have been conducted using the “value-based approach”, as explained in the introduction of this section. Should the “extra cost approach” be applied, it is likely that the competitiveness results would show even better trends, and office building reference would likely be competitive as well by 2030[5].

[5] For more information about the different approach, see Appendix and BIPVBOOST report D1.1

8 CONCLUSION

Following the trend initiated in the last decade, cost-reductions in the BIPV sector will be further driven by technical innovations targeting KPIs such as system lifetime, module efficiencies and system end-user cost. Improvements projected to be developed in the frame of the BIPVBOOST project should contribute generously to those reductions, as demonstrated. Moreover, market maturation improvements will further increase the competitiveness of BIPV solutions by impacting other highly influential parameters (as it was drawn from the sensitivity analysis conducted in D1.1) such as self-consumption rates, indirect costs or yearly system yields. Since the impacts of this meta-category of improvements is hard to quantify, various non-defined impacts in this deliverable could further contribute to cost reductions and more broadly to competitiveness increase.

As pointed out in BIPVBOOST report D9.1, “forecasting BIPV markets is difficult exercise” [3], thus it is difficult to determine whether the cost-reductions will be driven mostly by technical innovations or thanks to market maturation factors, such as economies of scales, or by both equally. Therefore, in addition to the best-case scenario, three additional realistic scenarios were defined to reflect different plausible market development patterns. If some significant differences can be observed between the results found with these scenarios, variations are, overall, limited.

The improvements identified and listed in this report, thanks to their impact on end-user costs and other key performance indicators of BIPV solutions, have the potential to significantly enhance BIPV economic attractiveness. On average, the end-user costs values are decreased by up to 47% (nominal value) in the balanced scenario, by 2030. The most significant relative decreases can be observed for educational building reference cases based on cSi with a 62% relative decrease. In comparison, reference cases such as SFH_b or OB_a1 are characterised by a more moderate, yet, still important, end-user cost relative decrease of around 37%. The competitiveness values reached under the “balanced scenario” amount to 54 $€_{2019}/m^2$ on average for all reference cases by 2030 (except for office building reference cases), with most of the positive competitiveness threshold being reached just after 2025. The upper end of the simulated 2030 competitiveness values is constituted by the SFH_b reference case, for which positive competitiveness is already achieved in 2020 and could approach 270 $€_{2019}/m^2$ by 2030 (in the best-case scenario). On the contrary, the office building reference cases compose the lower end of the competitiveness range. Indeed, the semi-transparent curtain wall reference cases remain uncompetitive, under the “value-based approach” applied in this report. Nonetheless, the competitiveness relative increase is significant with a 54% increase for the OB_a1 reference case and 73% in the OB_b1 reference case. In addition, under an “extra cost approach”, the office building reference cases could reach the positive competitiveness threshold by 2030. It is also worth highlighting that such approach seems to be prioritized by the European Commission as it is explicitly used as a KPI in the Declaration of Intent for PV, as evoked already. It can also be mentioned that in the case of curtain walls, the impact of passive properties can be relevant in terms of cooling load reduction, thus providing an added value to the product which is not quantified in this deliverable. Then, it should be reminded that, “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”. [1]

Eventually, these results show that the operational objectives mentioned in the introduction, based on the SET-Plan, are achievable and likely to be met, either by 2025 or 2030. All key performances indicators’ targets, i.e. extra cost of BIPV, end-user cost, module efficiency or system lifetime, are well in sight, for every reference case. Although, it is crucial to point out that the improvements leading to the achievement of these objectives will not naturally develop and implement. It requires pro-active behaviour from all stakeholders across (BI)PV and construction industries, from manufacturers to architects, with a particularly important role to be played by policymakers.

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10 APPENDIX

10.1 Appendix 1

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

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

Where

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

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

Where A is the total available surface for the system.

For more details, please refer to BIPVBOOST report **D1.1 "Competitiveness status of BIPV solutions in Europe".**

10.2 Appendix 2

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)					

10.3 **Appendix 3**

This section shows the detailed results of end-user cost decreases for the best-case, technology-push and demand-pull scenarios.

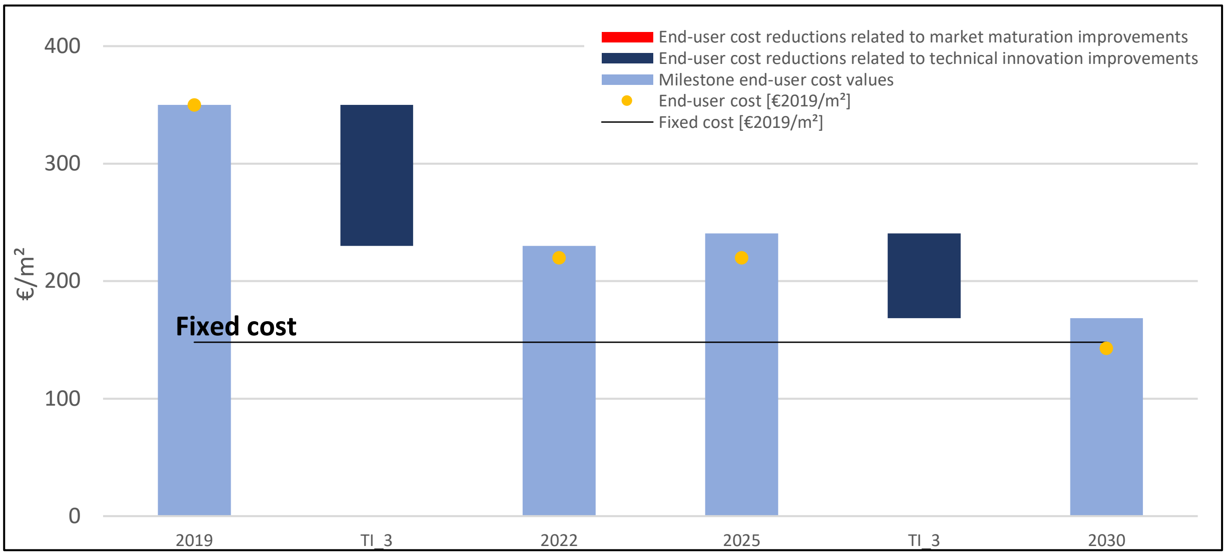

Figure 10.1 Nominal end-user cost decrease under the "best-case" scenario for the reference case IB

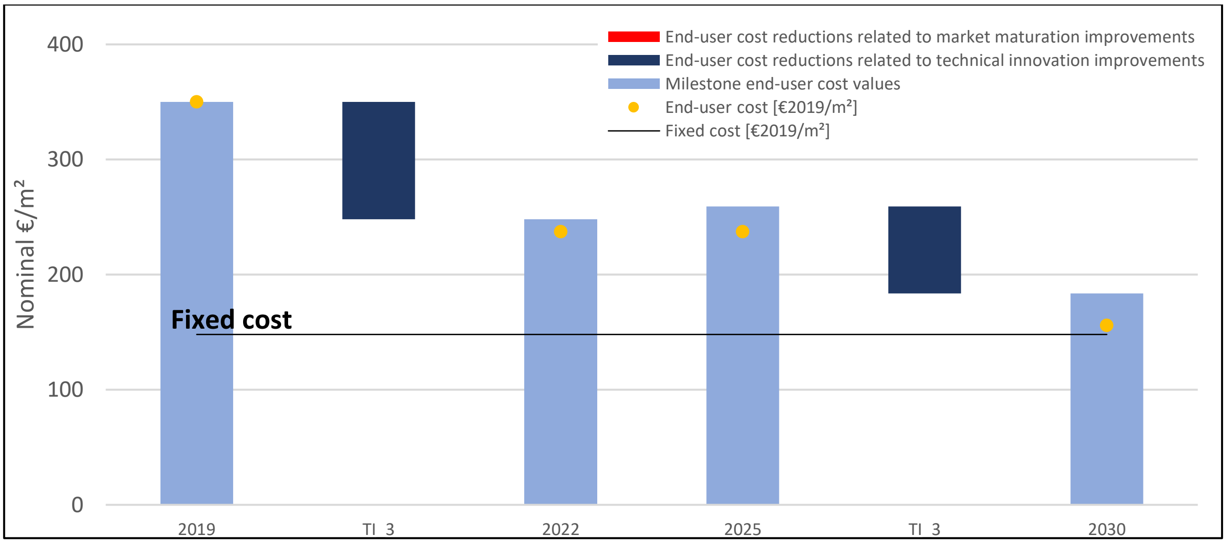

Figure 10.2 Nominal end-user cost decrease under the "technology push" scenario for the reference case IB

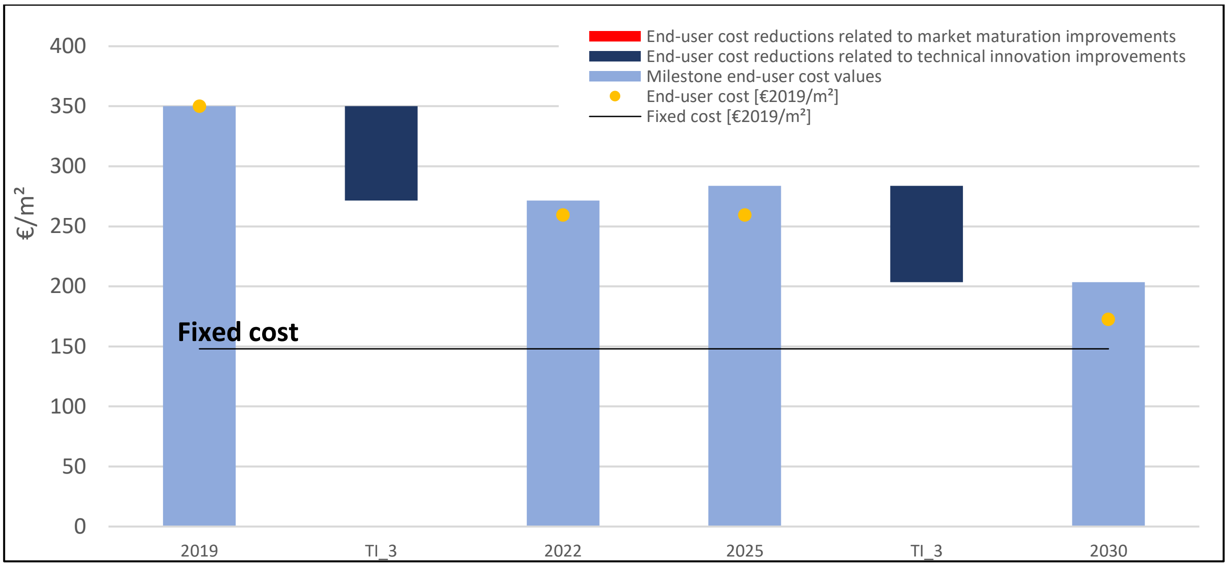

Figure 10.3 Nominal end-user cost decrease under the "demand pull" scenario for the reference case IB

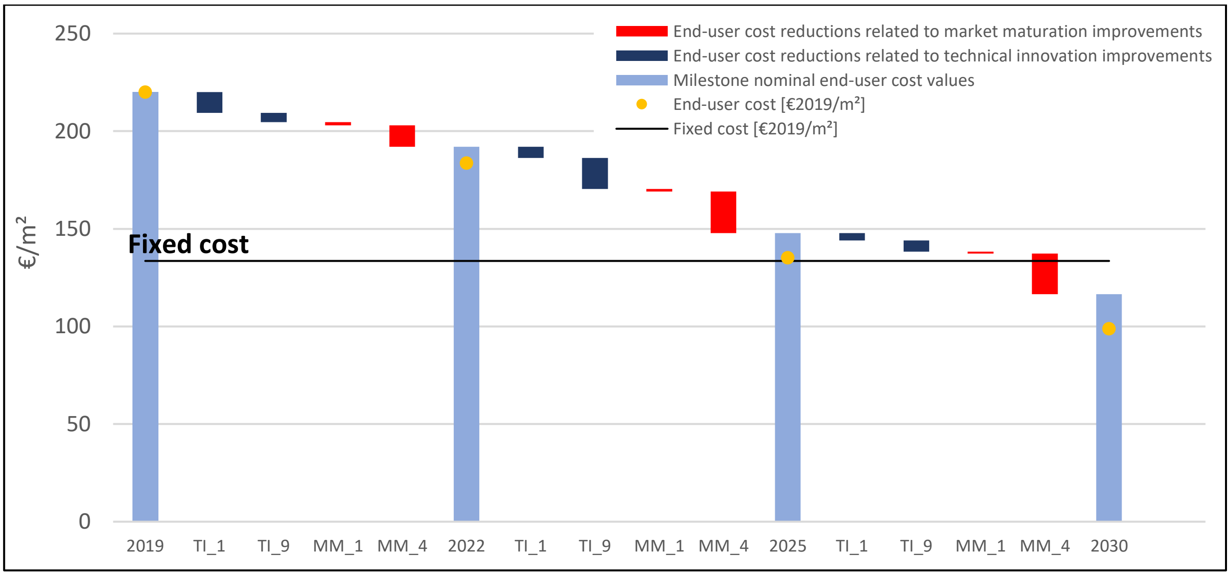

Figure 10.4 Nominal end-user cost decrease under the "best-case" scenario for the reference case SFH_b

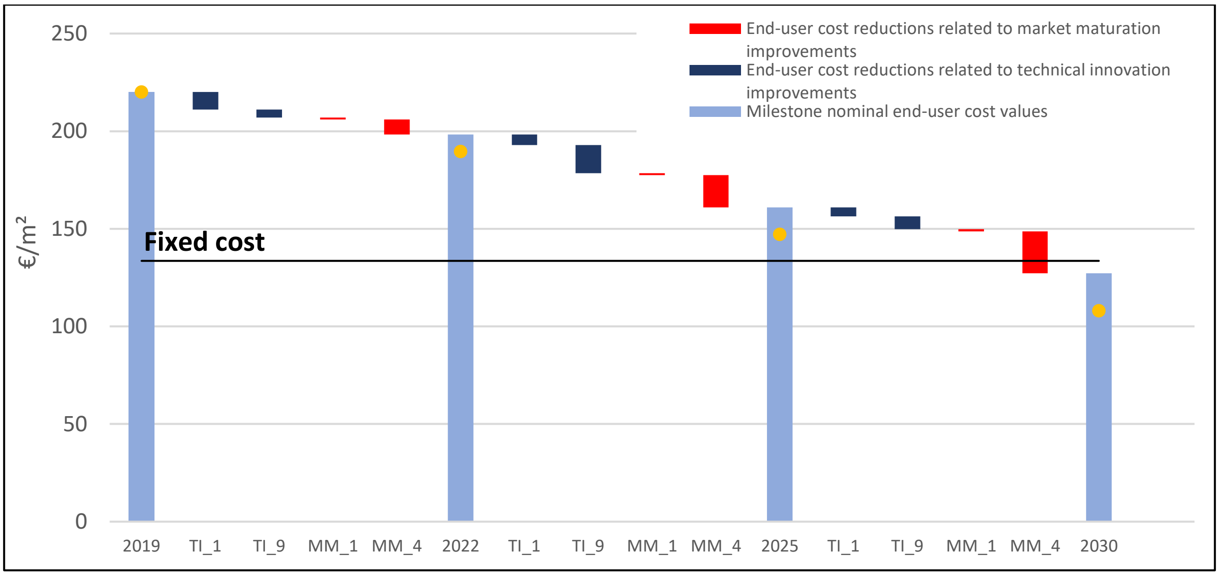

Figure 10.5 Nominal end-user cost decrease under the "technology push" scenario for the reference case SFH_b

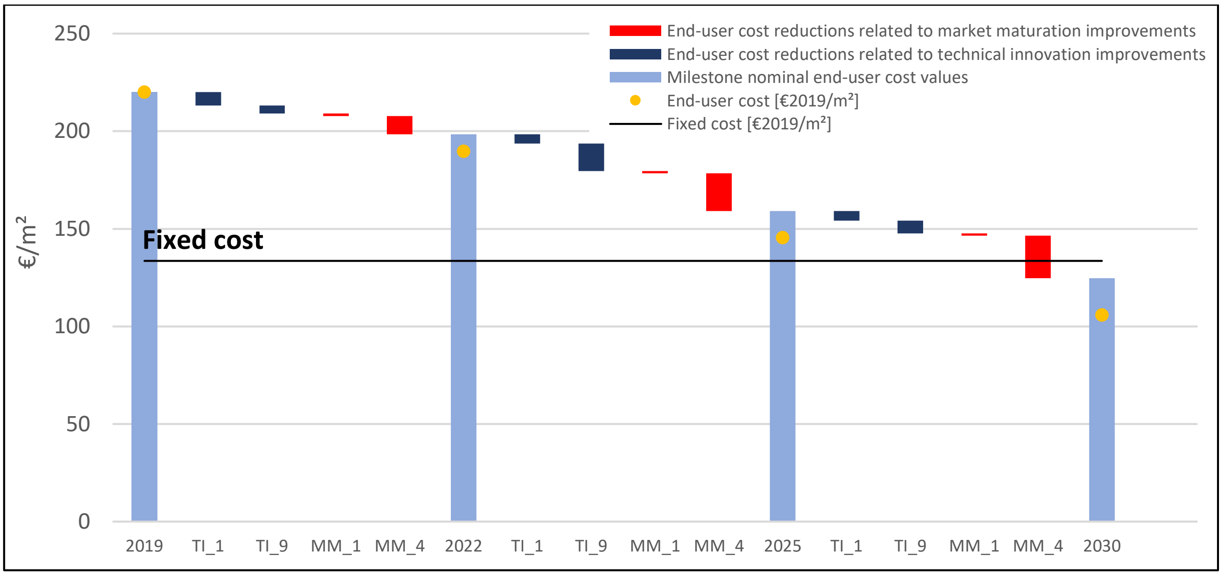

Figure 10.6 Nominal end-user cost decrease under the "demand pull" scenario for the reference case SFH_b

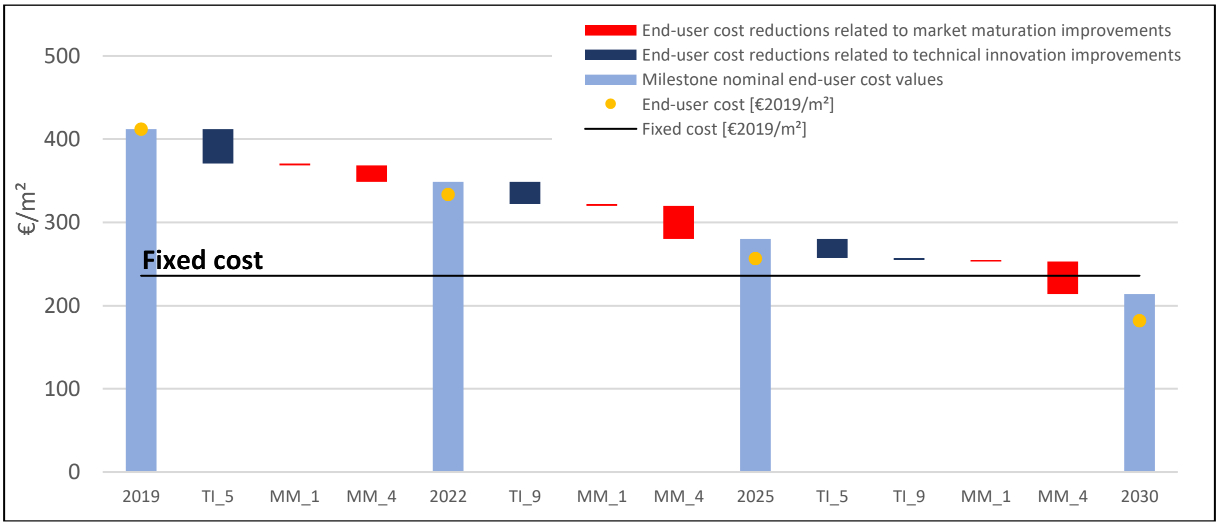

Figure 10.7 Nominal end-user cost decrease under the "best-case" scenario for the reference case EB_a1

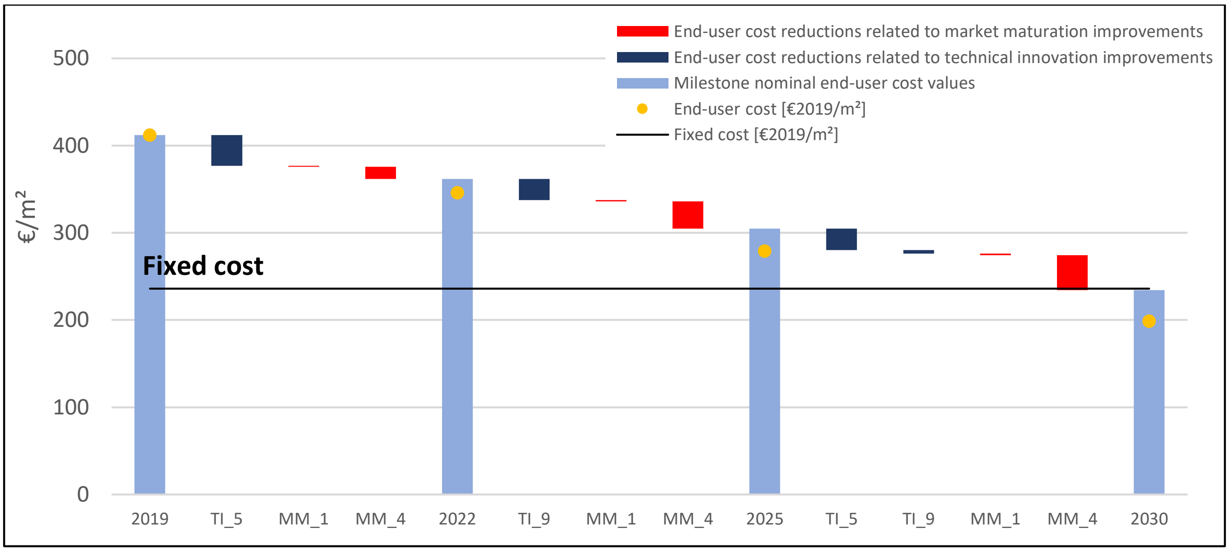

Figure 10.8 Nominal end-user cost decrease under the "technology push" scenario for the reference case EB_a1

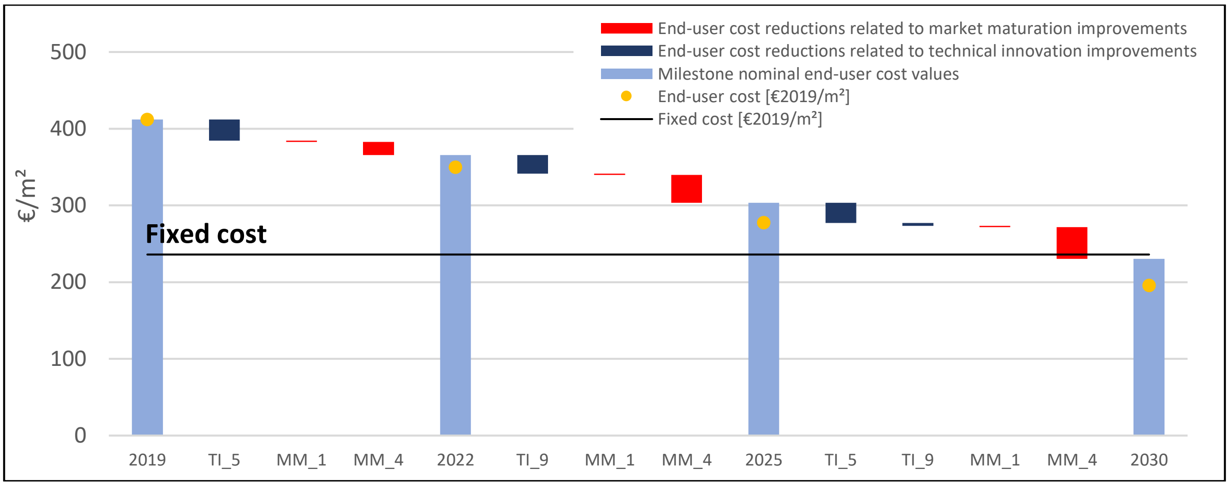

Figure 10.9 Nominal end-user cost decrease under the "demand pull" scenario for the reference case EB_a1

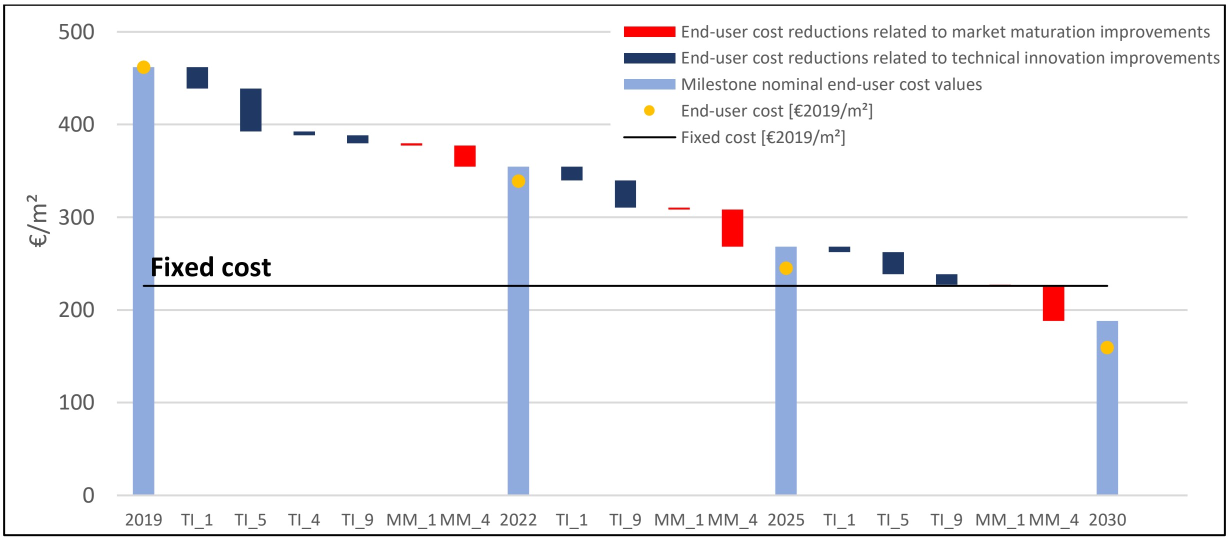

Figure 10.10 Nominal end-user cost decrease under the "best-case" scenario for the reference case EB_b1

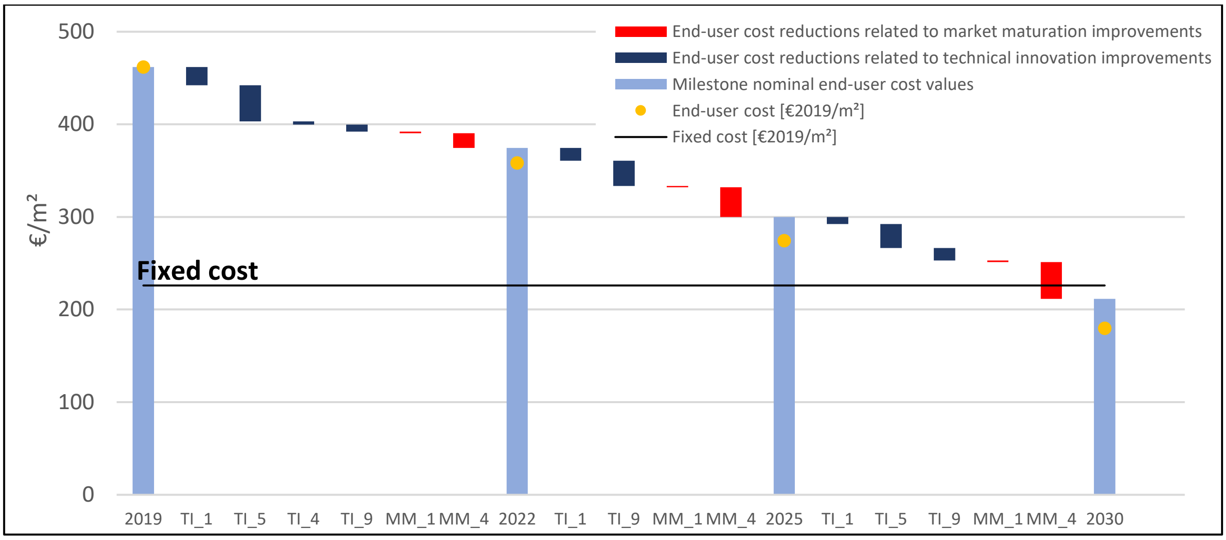

Figure 10.11 Nominal end-user cost decrease under the "technology push" scenario for the reference case EB_b1

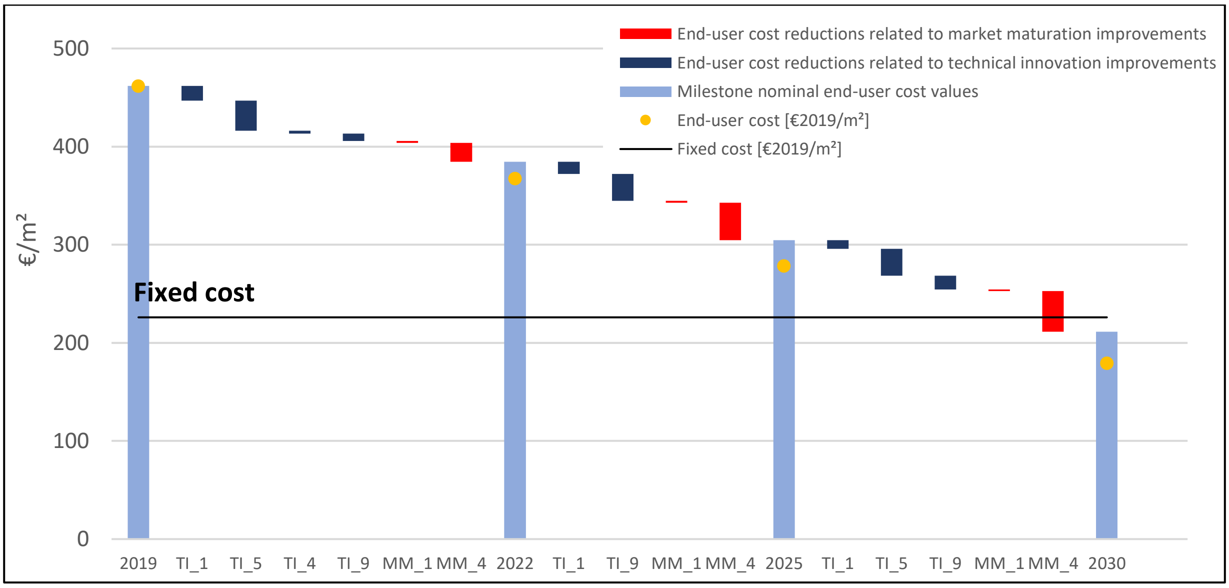

Figure 10.12 Nominal end-user cost decrease under the "demand pull" scenario for the reference case EB_b1

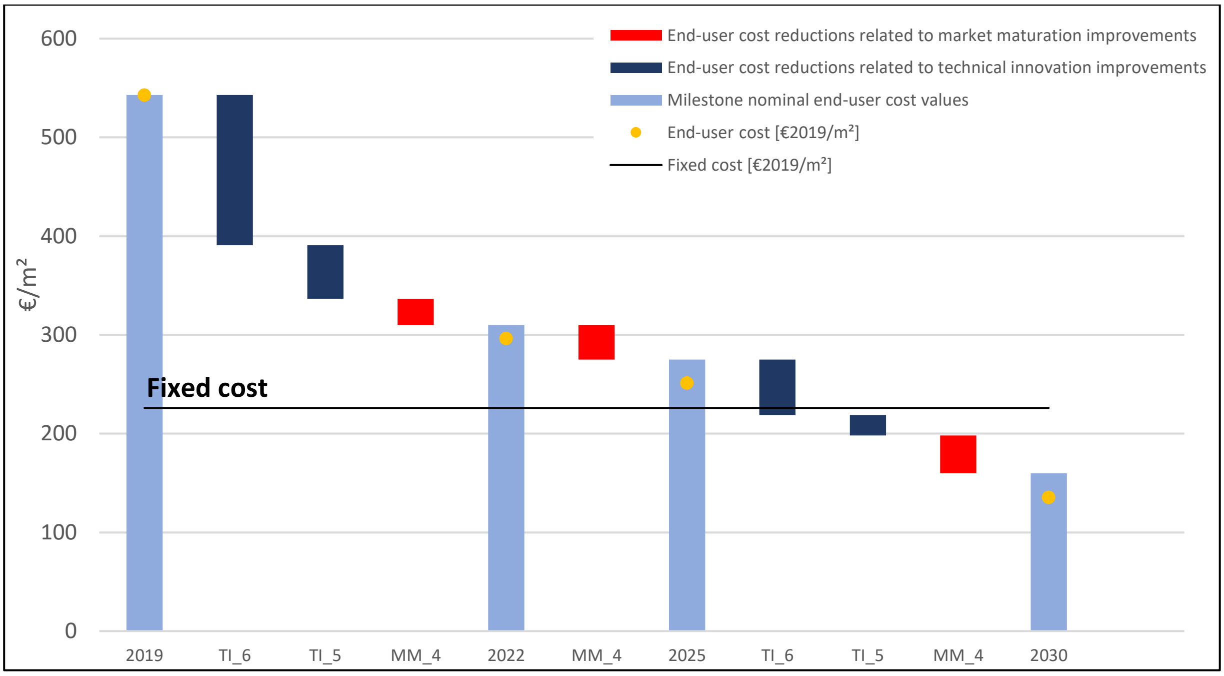

Figure 10.13 Nominal end-user cost decrease under the "best-case" scenario for the reference case EB_b2

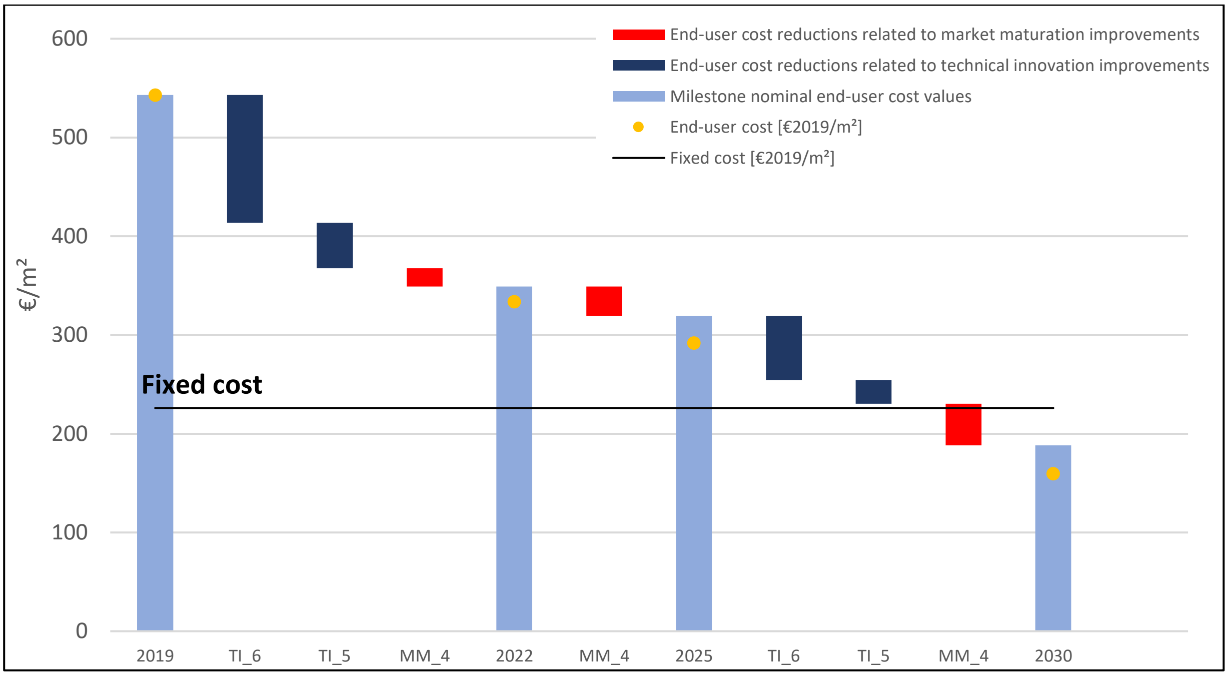

Figure 10.14 Nominal end-user cost decrease under the "technology-push" scenario for the reference case EB_b2

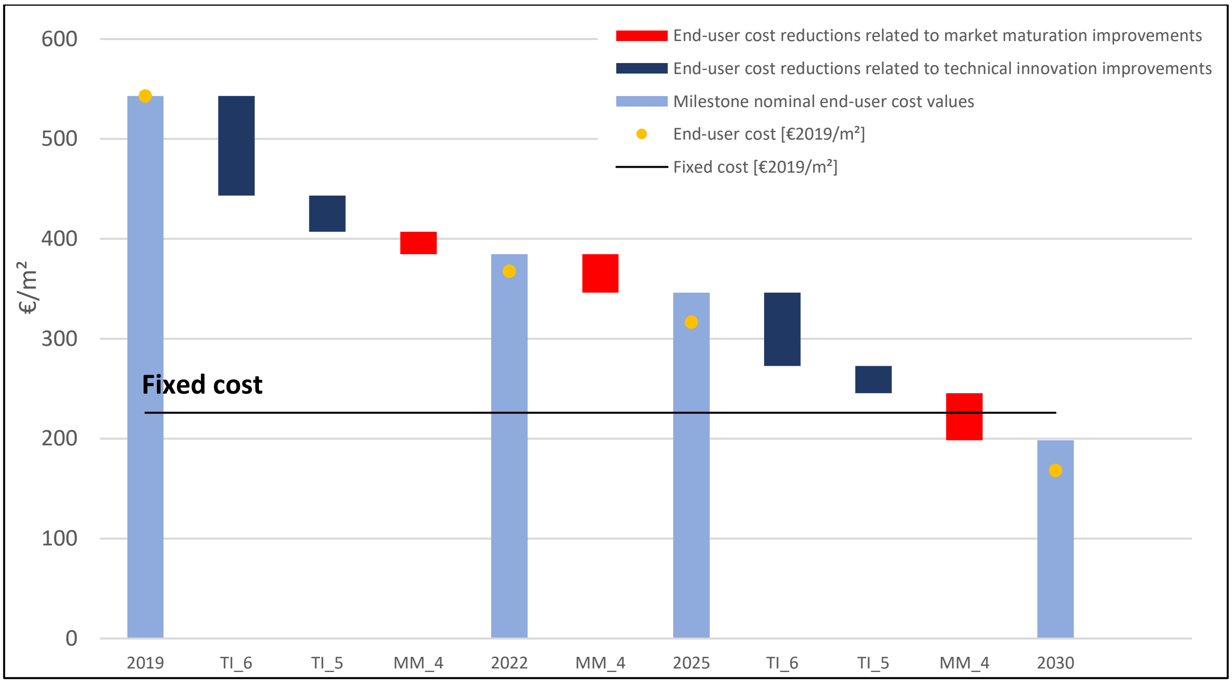

Figure 10.15 Nominal end-user cost decrease under the "demand-pull" scenario for the reference case EB_b2

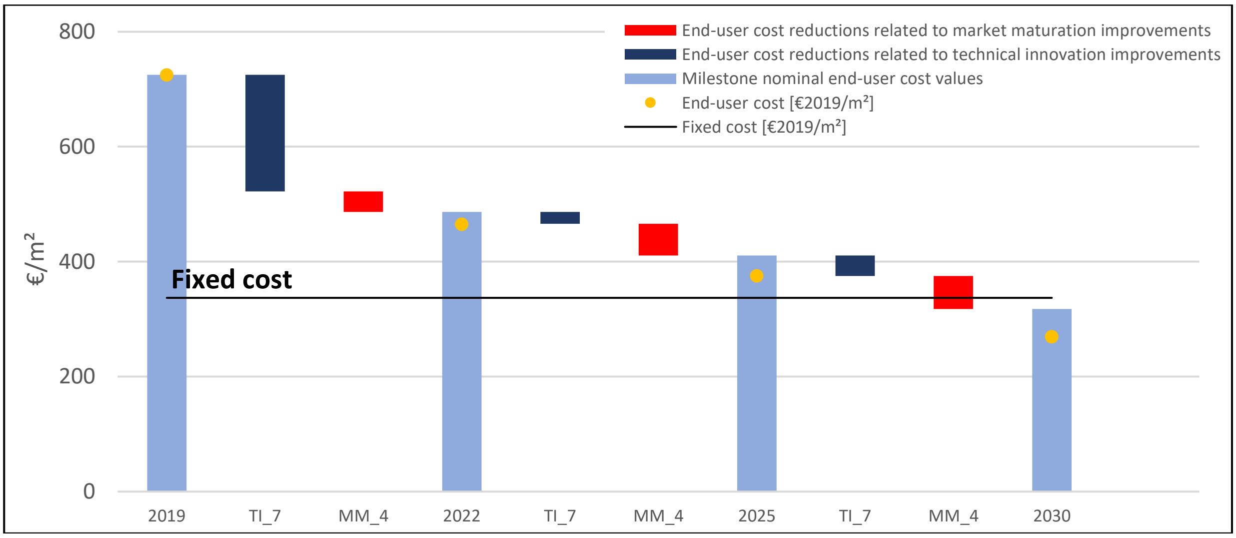

Figure 10.16 Nominal end-user cost decrease under the "best-case" scenario for the reference case MFH

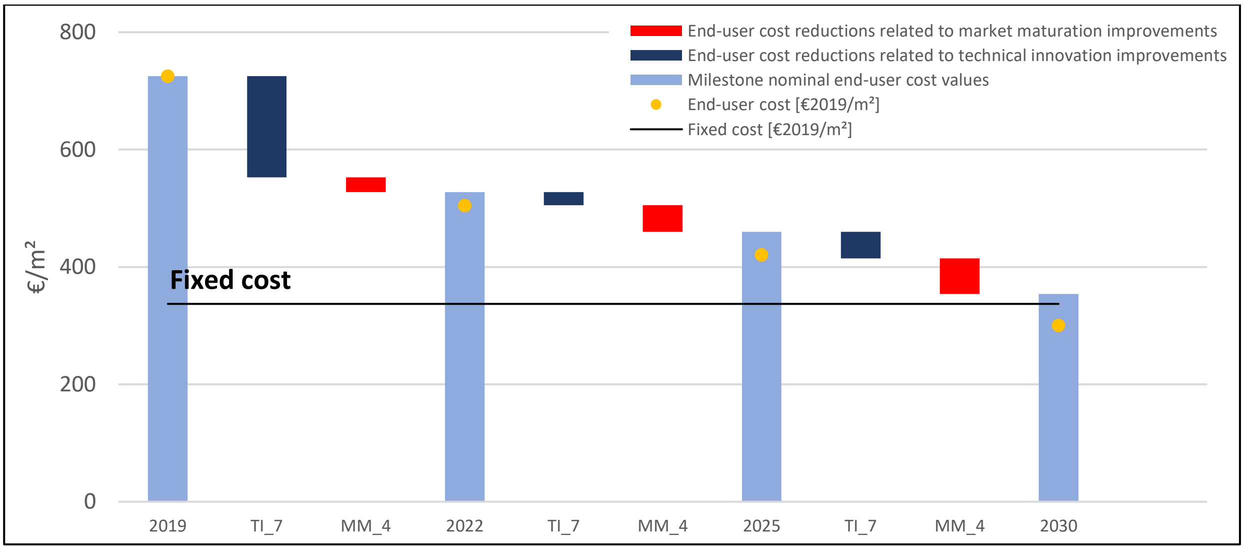

Figure 10.17 Nominal end-user cost decrease under the "technology-push" scenario for the reference case MFH

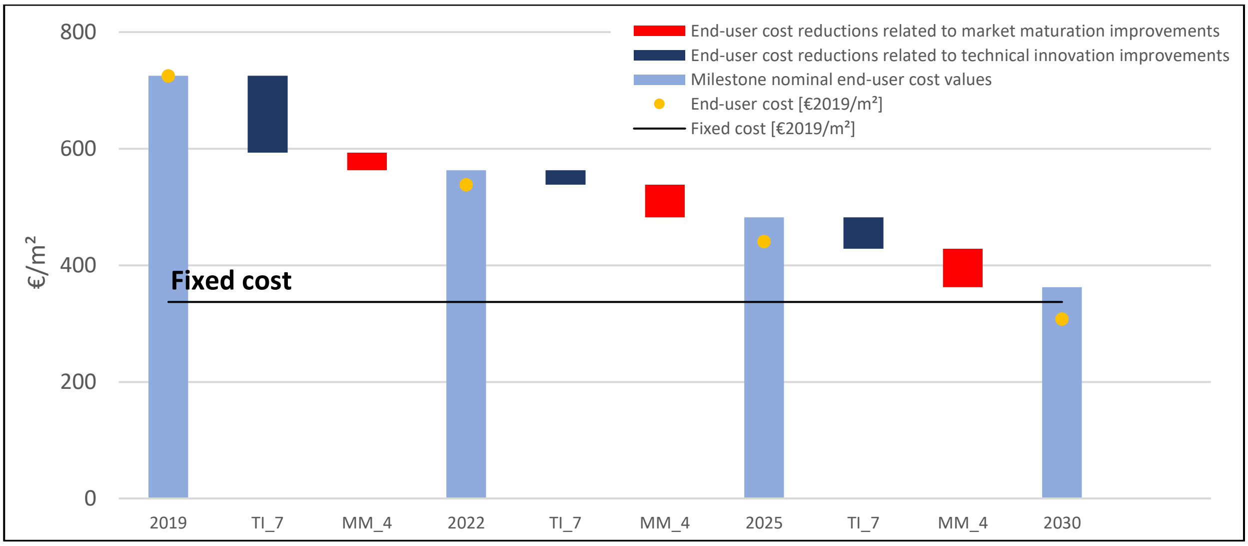

Figure 10.18 Nominal end-user cost decrease under the "demand-pull" scenario for the reference case MFH

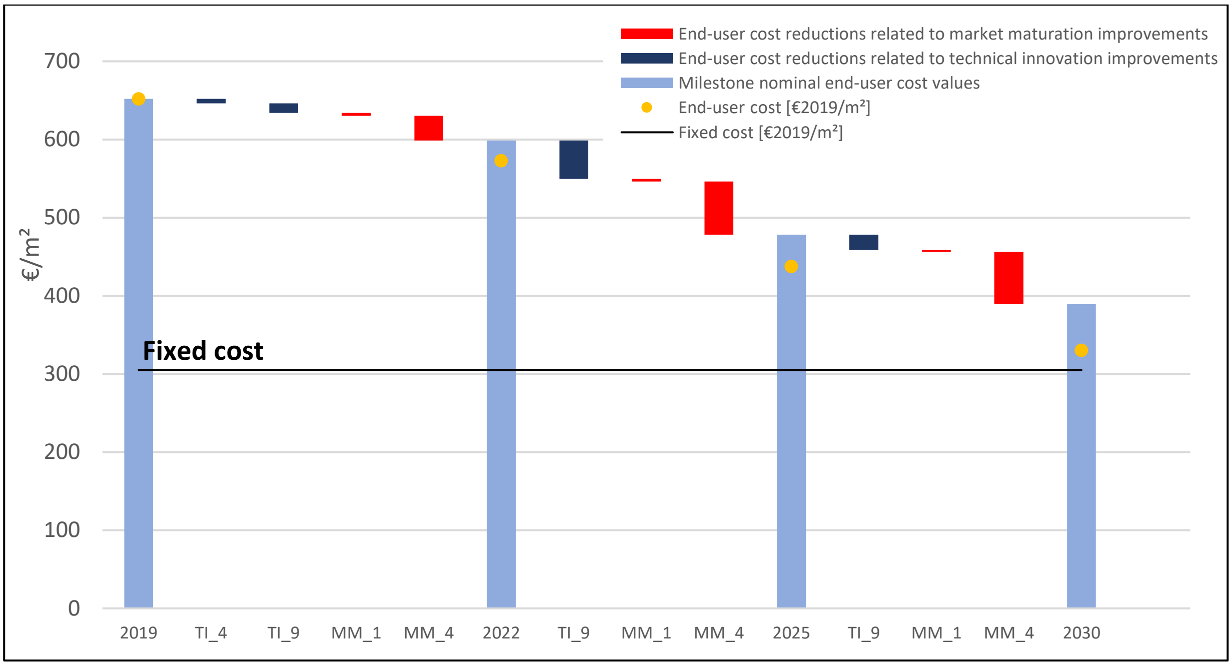

Figure 10.19 Nominal end-user cost decrease under the "best-case" scenario for the reference case OB_a1

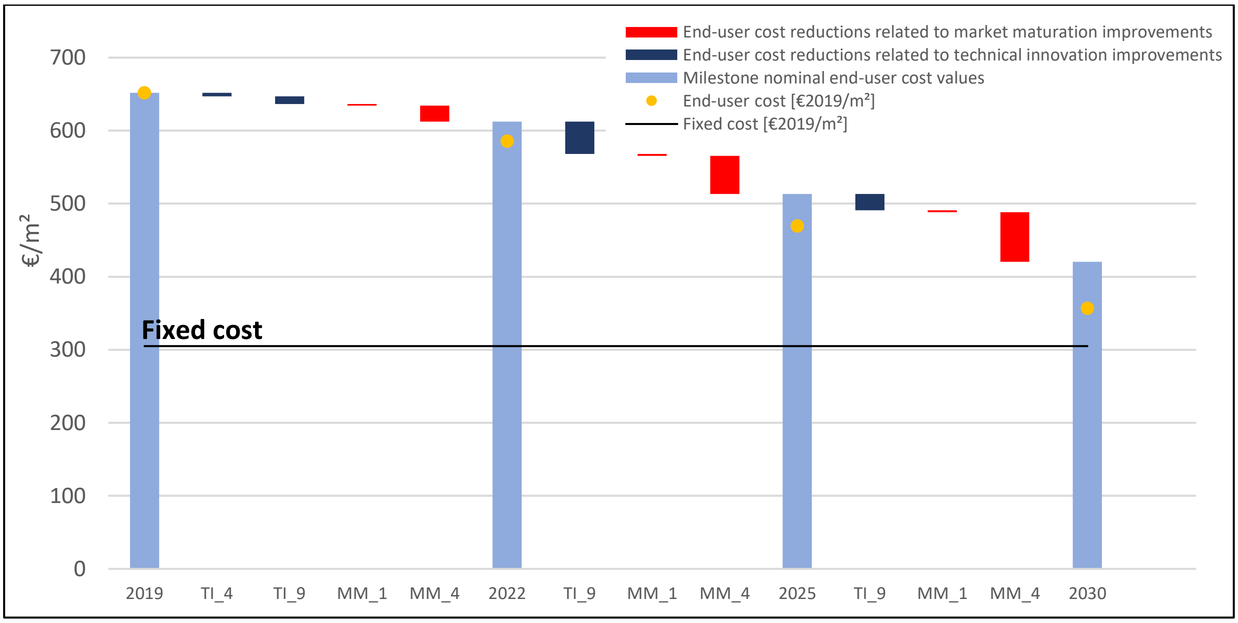

Figure 10.20 Nominal end-user cost decrease under the "technology-push" scenario for the reference case OB_a1

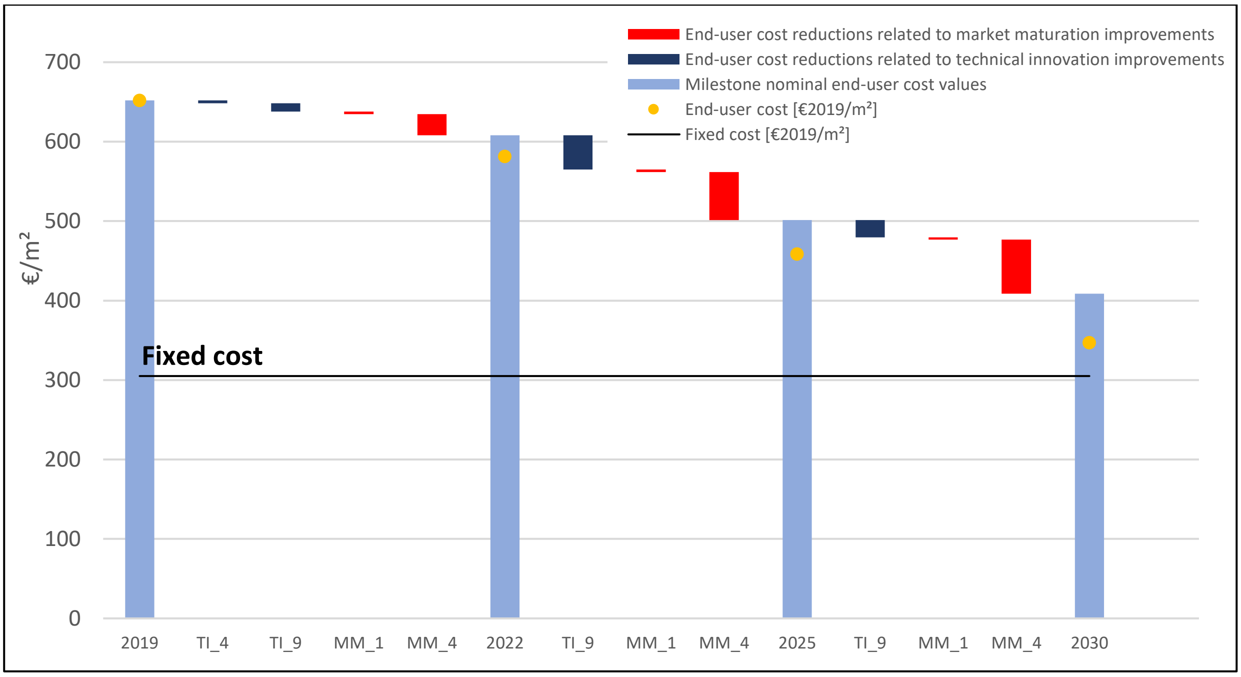

Figure 10.21 Nominal end-user cost decrease under the "demand-pull" scenario for the reference case OB_a1

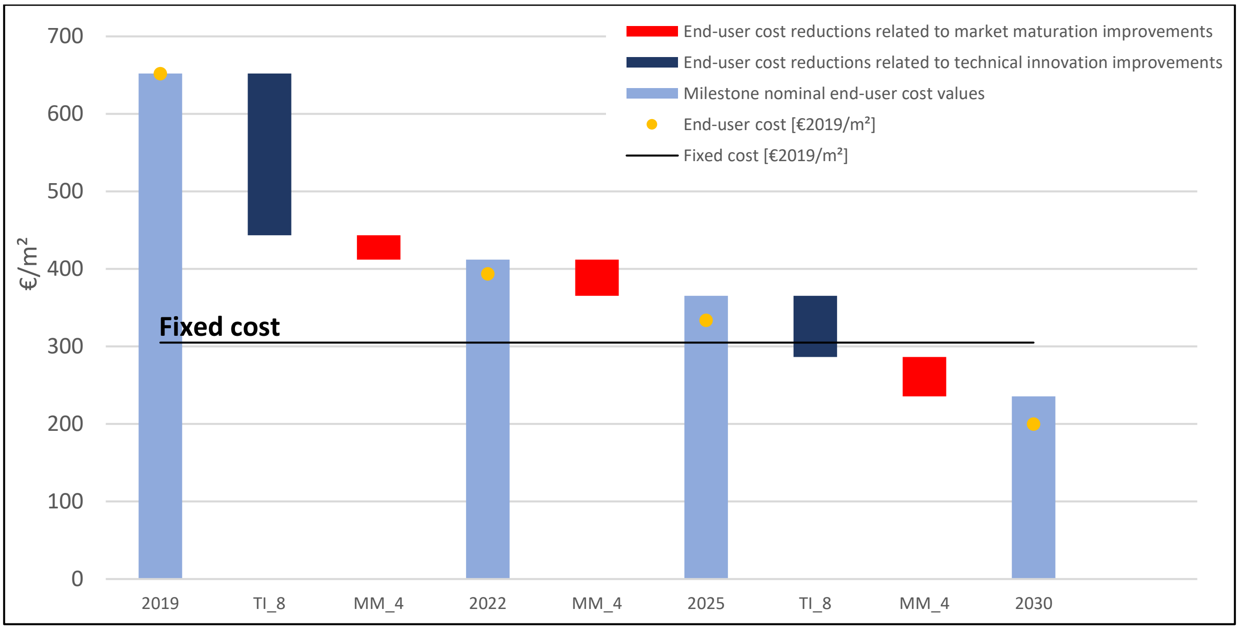

Figure 10.22 Nominal end-user cost decrease under the "best-case" scenario for the reference case OB_a2

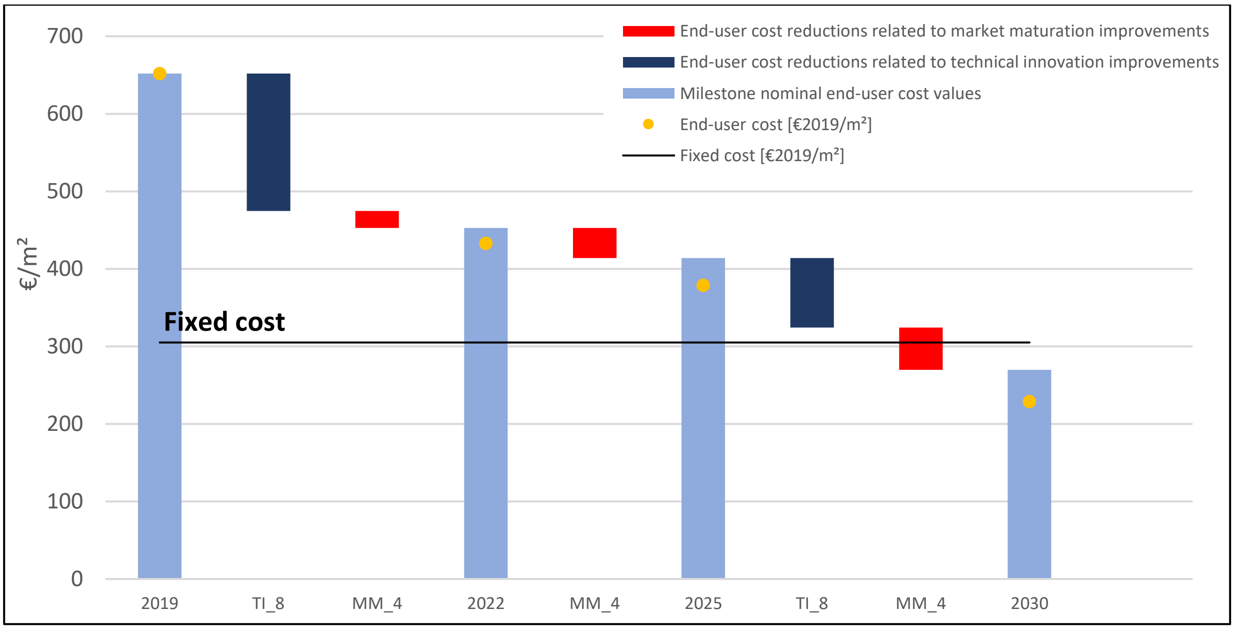

Figure 10.23 Nominal end-user cost decrease under the "technology-push" scenario for the reference case OB_a2

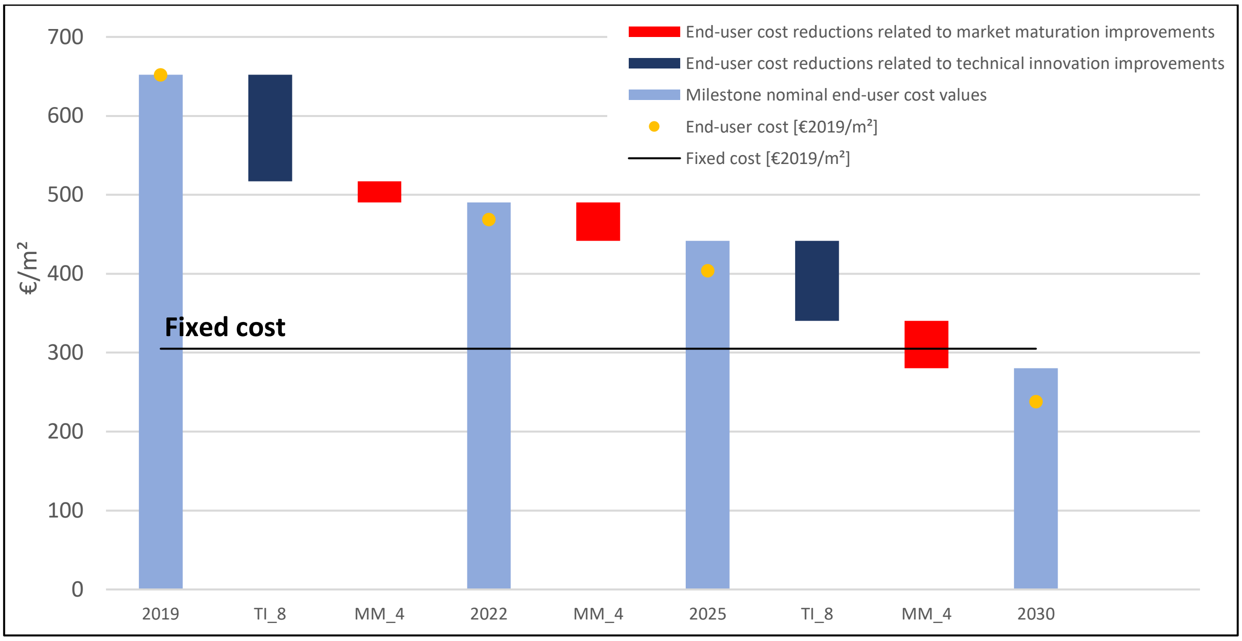

Figure 10.24 Nominal end-user cost decrease under the "demand-pull" scenario for the reference case OB_a2

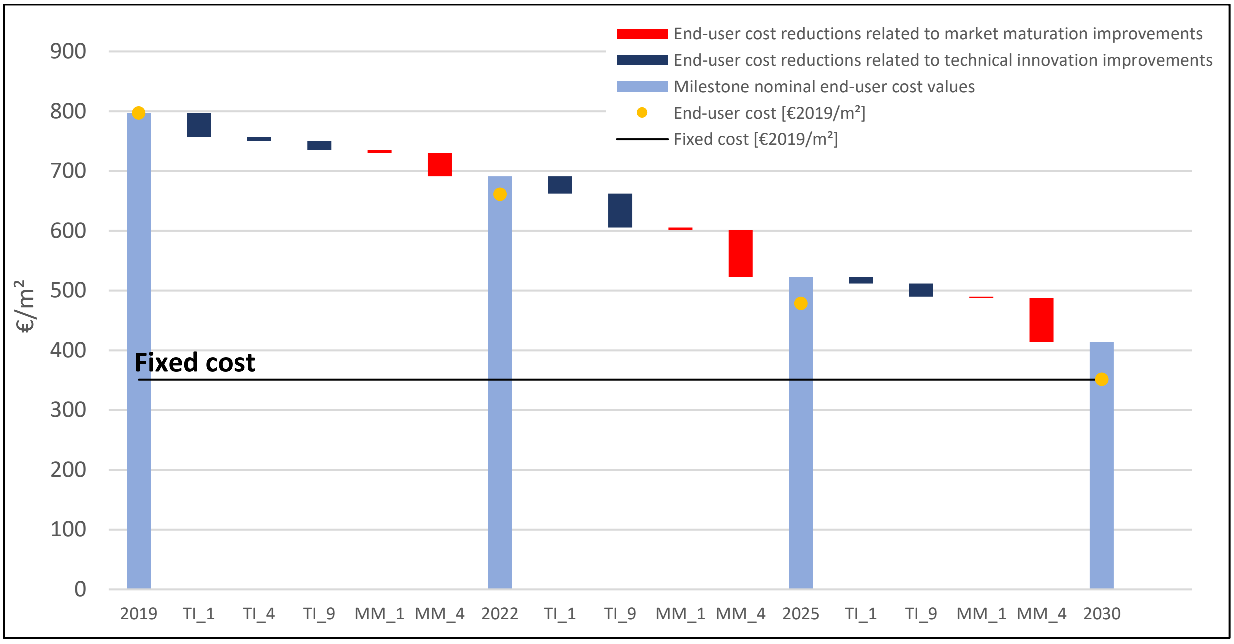

Figure 10.25 Nominal end-user cost decrease under the "best-case" scenario for the reference case OB_b1

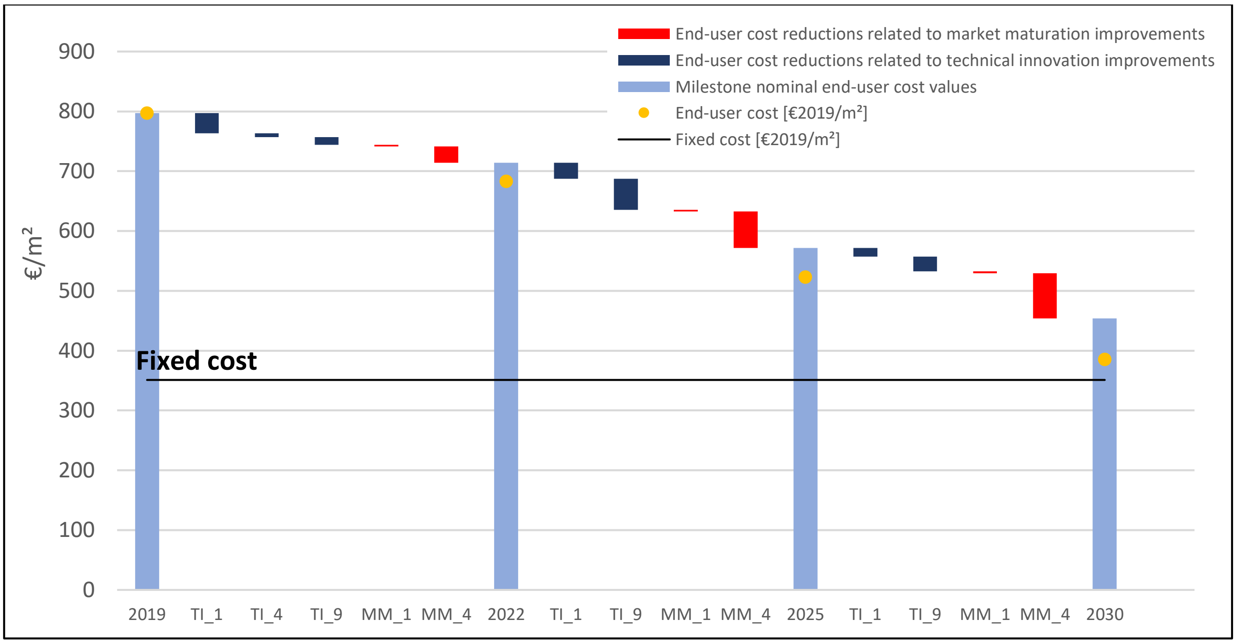

Figure 10.26 Nominal end-user cost decrease under the "technology-push" scenario for the reference case OB_b1

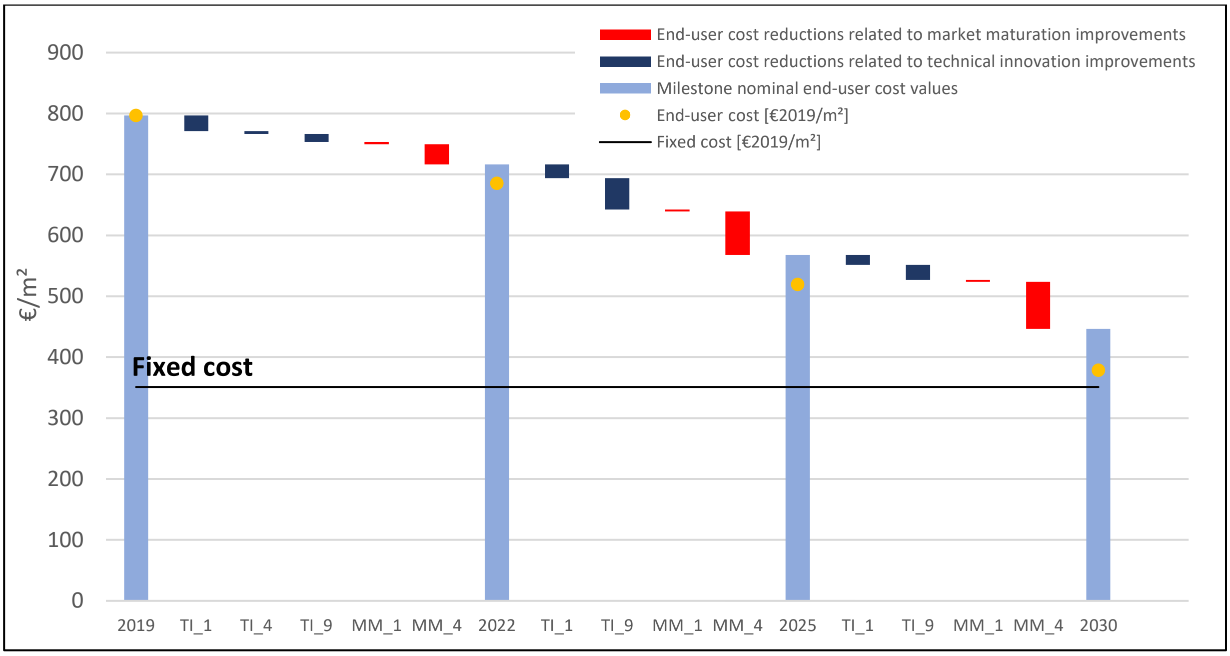

Figure 10.27 Nominal end-user cost decrease under the "demand-pull" scenario for the reference case OB_b1