Seamless-PV

D6.4 Performance risks and identification of related gaps in current standardisation frameworks of IPV products

T6.10 Progress on standardisation activities of IPV solutions

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Authors	Ainhoa Odriozola-Alberdi (TEC), Daniel Valencia-Caballero (TEC), Dominika Chudy (SUPSI)
Contributors	Pierluigi Bonomo (SUPSI), Fabio Parolini (SUPSI), Nerea Otaño-Aramendi (TEC), Manuel Vázquez-Suárez (TEC), Jon Oteiza (TEC), María Jimenez (ONYX), Jose Luis Diéguez (BECS), Nacho Torres (BECS), Mohamed Shalabi (SONO), Omar Stern (SONO), Jörg Palm (SONO), Sylvain Alarçon (AKUO)
Reviewer(s)	Fabio Parolini (SUPSI), Daniel Valencia-Caballero (TEC), Francesco Frontini (SUPSI), Eduardo Román-Medina (TEC), Xabier Olano Azkune (TEC)
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SEAMLESS-PV PROJECT

A novel manufacturing process for integrated photovoltaics

Integrated photovoltaics (IPVs) have proven their efficacy as building-integrated solutions and show promise across various sectors. Their adaptation to other industries or devices could offer surprising benefits. Unfortunately, the very need for adaptable IPV solutions hinders their expansion as their current manufacturing processes cannot create IPV solutions customised to each sector. The EU-funded SEAMLESS-PV project aims to tackle this by developing revolutionary tools for photovoltaic manufacturing as well as new IPV products that offer improved efficiency, adaptability and integrability while at the same time showcasing their cost-effectiveness in comparison to competitors.

The title of SEAMLESS-PV project is "*Development of advanced manufacturing equipment and processes aimed at the seamless integration of multifunctional PV solutions, enabling the deployment of IPV sectors*". SEAMLESS-PV is a Horizon Europe Innovation Action started in January 2023 that will continue through December 2026.

More information can be found at:

https://www.seamlesspv.eu/

https://cordis.europa.eu/project/id/101096126

EXECUTIVE SUMMARY

In the past few years, the interest for Integrated Photovoltaics (IPV) solutions has significantly grown. In the built environment, building-integrated photovoltaics (BIPV) has started to consolidate in the market, slowly but steadily gaining adoption and settling as a more mature, recognized and reliable technology. Following this trend, the increasing interest in IPV solutions has recently started to expand towards other applications, bringing synergies, innovation and added value to market segments such as infrastructures, transport, agriculture or urban environment, among others.

This way, the increasing adoption of photovoltaic (PV) technologies by different sectors is leading to the emergence of new PV integrated applications. As usual, innovation and progress go one step ahead of regulation and standardisation initiatives, which come at a later stage, once the irruption of these new applications start to consolidate in the market.

This report provides an analysis of the current standardisation framework in four different IPV sectors, namely BIPV, Infrastructure-integrated PV (IIPV), vehicle-integrated PV (VIPV) and agrivoltaics (AgriPV). In each case, the current applicable framework is presented, followed by an analysis and identification of missing gaps, representing potential amendments in the form of new testing procedures to be included in existing norms to take into consideration the presence of active parts (PV cells, junction boxes, cables, etc.). The final ambition is to progress towards an IPV-specific standardisation framework.

For the BIPV sector, this work is a continuation of an activity initiated in the frame of BIPVBOOST project (GA 817991). In SEAMLESS-PV, the same methodology will be implemented, extending the approach to new integrated PV applications.

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Project partners

Index

Tables

Figures

1 INTRODUCTION

The deployment of IPV solutions is expanding from the well-established BIPV to new applications in the infrastructure, transport or agricultural sectors. Due to the fast adoption of PV technology in these sectors, the market uptake of new applications is starting without a dedicated standardisation framework in place to establish the testing and evaluation procedures that guarantee reliability, stability and safety performances. Moreover, the establishment of a recognized standardisation framework in various IPV fields will reduce the perception risk in the use of these multifunctional products and ease the market penetration of these solutions.

This report provides an analysis of the current standardisation framework in four different IPV sectors, namely BIPV, Infrastructure-integrated PV (IIPV), Vehicle-integrated PV (VIPV) and Agriculture-Integrated PV (Agrivoltaics or AgriPV). In each case, the current applicable framework is presented, followed by an analysis and identification of missing gaps (missing requirements and/or testing procedures), essential elements disregarded by the current standards that should be included to correctly assess new performance risks introduced by active parts (PV cells, junction boxes, cables, etc.) in these new multifunctional IPV solutions.

The scope of this report is limited to the description of current standardisation frameworks and the identification and analysis of missing gaps. In a next step, in the frame of *Task 6.10. Progress on standardisation activities of IPV solutions* the consortium will propose amendments in existing reference norms, through the inclusion of new testing procedures in each sector (if needed). The final ambition is to progress towards an IPV-specific standardisation framework, allowing the implementation of testing sequences to accurately evaluate the performance of IPV products under a multifunctional perspective, encompassing reliability, stability, and safety characteristics applicable to each use case.

For the BIPV sector, this work represents a continuation of an activity initiated in the frame of BIPVBOOST project (GA 817991). In SEAMLESS-PV, the same methodology will be implemented, extending the approach to the new integrated PV applications.

1.1 Description of the deliverable content and purpose

This document aims to evaluate the existing standardization framework within each sector of integrated photovoltaics (IPVs), pinpointing key deficiencies that hinder the proper qualification of new multifunctional IPV products. By identifying challenges and illuminating areas requiring further development, it lays the groundwork for a future roadmap to tackle these obstacles effectively.

The main focus has been on BIPV and VIPV sectors, in the case of IIPV the analysis is focused on acoustic barrier Photovoltaics products, as is the only IIPV application that will be developed during the Seamless-PV project and, for the Agri sector, a first approach has been taken which as of today lack of reference standardisation frameworks. This deliverable is a first result of Task 6.10.

This document provides a broad overview of the subject. More detailed technical discussions will follow in deliverable D6.5, expected by Jul-24, and D6.6, expected by Jan-27. The subsequent document will elaborate on the proposed technical solutions and a validation matrix, providing a deeper understanding of each of the IPV technical specifications.

1.2 Reference material

- Seamless project. Deliverable D2.2. *Analysis of regulatory frameworks applicable to IPV systems*
- BIPVBOOST project. Deliverable D5.1: *Report on standardization, performance risks and identification of related gaps for a performance-based qualification in BIPV*
- BIPVBOOST project. Deliverable D5.2: *Report on the project developments of specific performance-based laboratory testing procedures for BIPV products*

1.3 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 SEAMLESS 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
Task 2.2	This task analyses the current regulatory framework applicable in BIPV, IIPV, VIPV and AGRI segments. D2.2. Analysis of regulatory frameworks applicable to IPV systems.
Task 2.3	D2.3 presents the technical specifications applicable to modules as a result of their particular use case identified in the market analysis (T2.1).
WP6	WP6 will develop products in different IPV segments. These will be used for the validation of new testing procedures in Task 6.10 and indoor testing activities of Task 6.11.

The public deliverable document D2.2 of the SEAMLESS-PV project, titled 'Analysis of Regulatory Frameworks Applicable to IPV Systems,' summarizes the current regulations frame. This deliverable document additionally provides a glimpse into the future of IPV standardization, comments on missing gaps in the regulatory framework, and suggests a roadmap for efficiently addressing these loopholes.

The D2.2 document focuses on the IPV regulatory framework across different market segments at both European and national (or regional) levels. The four primary IPV segments examined are Building Integrated PV (BIPV), Infrastructure Integrated PV (IIPV), Agrivoltaics (AgriPV), and Vehicle Integrated PV (VIPV). The document addresses an overview of European and national policies followed by detailed regulations for a given IPV segment. The document focuses on the main European markets (e.g., in alphabetical order, Belgium, France, Germany, Italy, Netherlands, Spain, and Switzerland).

Document D2.3 (not public), "Consolidation of technical specifications and requirements from IPV market segments and related use cases", presents instead the technical specifications applicable to modules as a result of their particular use both as a construction product and as a power generation unit. In this document, the regulatory framework applicable to BIPV modules is presented in the form of maps first for the EU in general and second for other specific countries.

1.4 List of acronyms

Table 1-2 explains the meaning of each of the acronyms used in this document.

Table 1-2 List of acronyms

Acronyms	Meaning
AgriPV	Agriculture combined with Photovoltaics (here, equivalent to Agrivoltaic)
BAPV	Building Attached Photovoltaics
BIPV	Building integrated photovoltaics
CPR	Construction Products Regulation
DoP	Declaration of Performance
EAD	European Assessment Document
EAER	Federal Department of Economic Affairs, Education and Research
EOTA	European Organization for Technical Assessment
EPBD	European Energy Performance of Buildings Directive
EU	European Union
IEA-PVPS	International Energy Agency - Photovoltaic Power Systems Programme
IGU	Insulated Glass Units (glass units with intermediate gas cavity for thermal insulation)
IIPV	Infrastructure integrated photovoltaics
IPVs	Integrated photovoltaics
KPI	Key Performance Indicator

LVD	Low Voltage Directive
MQT	Module Quality Test (each of the tests described in IEC 61215)
NB	Noise Barrier
NRD	Noise Reduction Device
OEM	Original Equipment Manufacturer
OJEU	Official Journal of the European Union
PC	Polycarbonate
PV	Photovoltaic
PV-IGU	Photovoltaic Insulated Glass Units
SERI	State Secretariat for Education, Research and Innovation
SHGC	Solar Heat Gain Coefficient
TC	Technical Committee
TS	Technical Specification
UNI	Ente Italiano di Normazione (Italian standardization body)
VIPV	Vehicle integrated photovoltaics

2 OVERVIEW OF THE CURRENT REGULATORY FRAMEWORK OF IPV SECTORS

2.1 General introduction

Over the past years the European Commission has intensified its initiatives to promote a green transition. This roadmap is focused on phasing out fossil fuels in favor of more sustainable and clean energy sources, aiming for a marked reduction in greenhouse gas emissions. Particular attention has been paid to the building sector: studies conducted by the Commission show that buildings are responsible for about 40 per cent of total EU energy consumption and 36 per cent of CO_2 emissions, being one of the largest energy consumer sectors at the European level.

To address this challenge, the European Energy Performance of Buildings Directive (EPBD) was introduced. This directive aims to ensure that new buildings constructed in the EU are almost completely energy-self-sufficient and that they make optimal use of solar energy. In this context, solar PV emerges as one of the most promising answers to the needs of the future. Indeed, the implementation of integrated photovoltaic (BIPV) systems is not only a solution for new buildings but also a way to renovate and improve the energy efficiency of existing buildings. An additional benefit offered by BIPVs is the opportunity to use building surfaces for energy production, thus avoiding the encumbrance of natural or landscaped areas.

Growing awareness of these benefits has stimulated an increasing demand for building-integrated photovoltaic (PV) systems. These systems are not only energy efficient but are also designed to be aesthetically pleasing, versatile, and multifunctional, combining efficiency with aesthetics. In addition, there has been an interest in applying this concept to other sectors such as infrastructure, vehicles, or agricultural activities.

It is essential to differentiate these applications from the conventional PV applied so far in buildings, infrastructures, and vehicles as an attached element (instead of really integrated).

A "conventional PV" module is defined according to the Glossary of the International Electrotechnical Commission in multiple standards as "the smallest complete environmentally protected assembly of interconnected cells" (IEC 61850-7-420:2021, IEC 60364-7-712:2017 RLV and IEC 62548:2016).

A "conventional/standard" PV module is an electrical device engineered and certified for electricity generation without possessing any additional specific functionalities. Electrotechnical certifications, as per IEC standards, for such conventional PV modules do not encompass particular considerations for building or other applications. IEC 61215-1-4:2021+AMD1:2022 states that "the useful life of modules so qualified will depend on their design, their environment, and the conditions under which they are used."

IEC 61730-1:2023 also states that " This document defines the basic requirements for various applications of PV modules, but it cannot be considered to encompass all national or regional codes. Specific requirements, e.g., for building, floating, marine and vehicle applications, are not covered.

Several international definitions can be found for BIPV (Building Integrated Photovoltaics) modules and systems in the literature. The acronym BIPV refers to modules and systems integrated into the building. Integration is understood to mean that the photovoltaic element takes on the role of a building element or building product in addition to its sole and primary function of producing electricity. Concretely, what defines the BIPV product is its function and use as a functional building element, such as a roofing element, façade cladding, or glazed surfaces rather than a solar protection device (shading) or an architectural or "accessory" element such as canopies, balcony parapets, etc.

The definition in the case of infrastructure Integrated photovoltaic and vehicle integrated photovoltaics is very similar to that of BIPV, except that instead of complying with building applications they have to do it as infrastructure or vehicle.

The concept of IPV, therefore excludes all components such as standard "overlapped" photovoltaic modules, simply placed, or mounted on the building/infrastructure/vehicle, which perform the sole function of solar power generation without any other function. For the Agri sector the definition is not so well defined, and it changes from one nation to another.

2.2 Ongoing projects related to IPV standardisation

There are some initiatives related to IPV standardization, most of them focused on the BIPV sector. In this section, a brief explanation of each of these projects will be given:

BIPVBOOST – European R&D project

A comprehensive analysis but not exhaustive of the BIPV regulatory framework was performed in the frame of the BIPVBOOST project, in September 2019. The outcomes of this analysis were reported in D5.1: Report on standardization, performance risks, and identification of related gaps for a performance-based qualification in BIPV, publicly available for consultation.

MeZeroE – European R&D project

MEZeroE will establish an Open Innovation Test Bed (OITB) for nZEB Enabler Envelope technology Solutions (nEES). BIPV products are part of nEES. Via the OITB. nEES will be validated with advanced assessment methods connected to recognized protocols and a long-term vision, enabling easier access of the product to the market. The first step in the definition of the OITB was to analyse the needs of the stakeholders during the innovation of nEES. Part of the analysis was the certification and standardisation needs. This analysis is included in the public deliverable D2.1: Needs/requirements and barriers breaking innovation of building envelope products[1].

[1] D2.1Needs/Requirements and Barriers Breaking innovation of building envelope products. (2022, January). https://www.mezeroe.eu/sites/default/files/delivrables/D2.1_PUBLIC.pdf

In the MEZeroE community, there are 2 Pilot Measurement & Verification Lines (PM&VL) related to BIPV products in order to answer to the above-mentioned needs and enable easier access of the product to the market:

PM&VL1:

Beyond carrying out just the tests defined in the current standards, PM&VL1 has also the objective to give added value to the potential PM&VL clients offering them stronger evidence about the safety, reliability, and robustness of their products.

PM&VL3:

Beyond carrying out just the tests defined in the current standards, PM&VL3 include two added-value groups of tests:

- The first group of tests will focus on the lifetime of the BIPV products: One key aspect is that BIPV products need to guarantee a lifetime according to the one that current envelop products have. When BIPV acts as an envelope of the building, the PV part cannot be changed every time it degrades or stops delivering power, so the replacement of parts is not an ideal BIPV scenario.
- The second group of tests regards electrical safety issues: The electrical safety also becomes of utmost importance in buildings, as the users do not need to have any electrical knowledge and can be around the BIPV parts, so the electrical risk should be under control.

The knowledge obtained from MEZeroE will be useful to define a proper roadmap to fill the gaps in the BIPV product standardisation.

IEA PVPS

The IEA Photovoltaic Power Systems Technology Collaboration Programme (IEA PVPS TCP) conducts joint projects in the application of photovoltaic conversion of solar energy into electricity. Currently, eight research projects, so-called Tasks, are established within the IEA PVPS Programme. These are the task in IEA PVSP related to standardisation:

Task 13 Reliability and Performance of Photovoltaic (PV) Systems engages in focusing the international collaboration in improving the reliability of photovoltaic systems by collecting, analysing, and disseminating information on their technical performance and failures, providing a basis for their technical assessment, and developing practical recommendations for improving their performance. The sub-task 1.3 on testing strategies will provide a global survey of ongoing technical efforts aimed at improving testing strategies and the significance of tests and defining tests for emerging PV applications with specific load conditions. Sub-tasks 2.1 and 2.2 are respectively dedicated to the specific topics of Floating PV and Agrivoltaics.

Task 15 - Enabling Framework for the Development of BIPV. The overall objective of Task 15 of the IEA PVPS is to create an enabling framework to accelerate the penetration and deployment of BIPV products, BAPV products, and regular building envelope components, respecting mandatory, aesthetic, reliability, and financial issues. The goal of Subtask E (in phase two of the task ending in

2024) is to carry out pre-normative international research to develop new and optimised characterisation methods for BIPV modules and systems.

The third phase of Task 15 is currently in planning and will last for other 4 years (2024-2027). In this third part the aim will be to establish standards and certification protocols specific to BIPV systems or consider the integration of PV cells into conventional building products can help to ensure quality, performance, and safety. Comprehensive testing methodologies, performance standards, and certification frameworks tailored specifically for BIPV should be further investigated, particularly concerning fire behaviour, glare assessment, solar control (SHGC),shading resilience, and energy saving of BIPV.

Task 17 - PV & Transport focuses on the possible contributions of photovoltaic technologies to transport, as well as the expected market potential of photovoltaic applications in transport. This task began in 2018 and was renewed in 2021 for a second phase, which ends in 2024 with additional deliverables anticipated in Q1 2025. Subtask 1 involves activities related to identifying requirements, barriers, and solutions for PV-powered vehicles.

3 BIPV PRODUCTS STANDARDIZATION GAPS AND ROADMAP

3.1 BIPV regulatory framework

Because of its nature, BIPV often requires a specialized regulatory framework that must take into account building requirements and electrical requirements at the same time.

The following regulations must be followed in BIPV use cases:

International Electrotechnical Commission

At the international level for the photovoltaic industry, the main reference standards are:

- **IEC 61215:2021** parts 1 and 2, which establish the **requirements for design qualification** of terrestrial photovoltaic modules suitable for long-term operation in outdoor climates,
- **IEC 61730:2021** parts 1 and 2, which specify and describe respectively the basic construction and testing requirements for photovoltaic (PV) modules to ensure **safe electrical and mechanical operation**.
- **IEC 63092:2020** Part 1 and 2 specify the requirements for BIPV (building-integrated photovoltaics) modules and systems. The standard focuses on properties relevant to basic building requirements and applicable electrotechnical requirements. Part 1 addresses requirements on BIPV modules in the specific ways in which they are intended to be mounted but not on the mounting structure itself, which falls under Part 2. It is important to note that this international standard is based on what is prescribed in EN 50583-1, which refers to the European CPR Regulation, explained below in this section.

International Organization of Standardization

At the international level, for the building part, some ISO standards consider the behaviour of BIPV. For example, the **ISO/TS 18178:2018** technical specification is specially developed for building-integrated photovoltaics. It specifies the appearance, durability, safety requirements, test methods, and designation for laminated solar photovoltaic (PV) glass for use in buildings.

Construction Products CPR

According to European legislation, a construction product is defined as "any product or kit manufactured and placed on the market for permanent incorporation in construction works or parts thereof and the performance of which has an effect on the execution of construction works with respect to the basic requirements for construction works." The BIPV as a construction product must comply with **Regulation (EU) No. 305/2011** on Construction Products CPR. Its performance shall be defined according to the relevant essential characteristics expressed in CPR 305/2011 established in Annex I of the Regulation and listed below:

1. Mechanical strength and stability
2. Safety in case of fire

3. Hygiene, health, and environment
4. Safety and accessibility in use
5. Protection from noise
6. Energy conservation and heat retention
7. Sustainable use of natural resources

It is important to note that the purposes of CPR 305/2011/EEC are to set the conditions for placing construction products on the market, to establish provisions for the description of performance in relation to characteristics, and finally, to define the use of CE marking.

Low Voltage Directive

BIPV has an electrical part that produces energy, so in Europe, it must comply with the low Voltage Directive **(LVD) (2014/35/EU)**. This directive ensures that electrical equipment within certain voltage limits provides a high level of protection for European citizens.

European Standards

At the European level, in order to clarify and reinforce the concept of BIPV as a building product, in 2016 CENELEC Technical Committee 82 published a non-mandatory BIPV standard, EN 50583:2016 Photovoltaics in Buildings (Part 1: BIPV Modules and Part 2: BIPV System), which is currently under review. These standards refer in the definition of BIPV to the European Construction Products Regulation CPR 305/2011 and, therefore, for the definition of the essential performance of BIPV refer to the main building codes but at the same time provide a collection of electrotechnical standards relevant to BIPV products (e.g., Low Voltage Directive 2006/95/EC / or CENELEC standards). The standard is voluntary and not mandatory, and it clarifies the European context in which BIPV as a construction product is found.

3.1.1 The basic requirements of a BIPV product

The basic requirements of a BIPV product are set by the directives on safety, health, and environmental protection as valid for all construction products. In this sense, the harmonized standards define how to verify the requirements set by directives on safety, health, and environmental protection. In addition, each specific construction product or specific BIPV product will have essential characteristics that will relate to the basic requirements. Harmonized technical specifications are common to all countries and include tests, calculations, and other means of assessing performance in relation to the essential characteristics of construction products. Harmonized technical standards imply obligation in the affixing of the CE mark on the product. They are required directly by the European Commission from the technical bodies (CEN / CENELEC / ETSI) through mandates.

As an alternative to harmonized standards exist the EAD European Assessment Documents or EADs guidelines. They allow for voluntary certification with the possibility of voluntarily affixing the CE mark leading to ETA. The European Technical Assessment (ETA) provides an independent

Europe-wide procedure for assessing the essential performance characteristics of non-standard construction products.

With the introduction of the regulation, special Technical Assessment Bodies called TABs (Technical Assessment Bodies) were established at the national level and coordinated at the European scale by EOTA (European Organization for Technical Assessment).

Within this European framework, the CPR regulation sets general objectives, harmonized standards, and European guidelines define how to verify the requirements imposed, and member states set rules for the use of products on their territory. In fact, member states transposing the CPR must implement it but may set additional, more restrictive rules going beyond what is established.

In summary, EN 50583:2016 is the only European standard on BIPV to date and is not yet formalized and made harmonized (remains voluntary). At the international level, the IEC 63092:2020 is the reference standard for BIPV modules and systems. Both previous standards call for other regulation documents for specific aspects like the CPR 305/2011, Low Voltage directives, fire reaction rules or specific mechanical rules depending on the type of integration. In addition, ISO/TS 18178:2018 regulates PV laminated glass internationally.

3.2 Missing gaps

In the complex regulatory landscape previously described, the building-integrated photovoltaics (BIPV) industry faces numerous gaps and deficiencies that require timely action to fill them. The increasing number and complexity of BIPV products have led to the incorporation of electrically active and non-active materials, affecting various aspects such as energy performance, heat dissipation, mechanical behaviour, and fire safety.

Currently, there are no specific procedures that can comprehensively describe the behaviour of these innovative products. Projects such as BIPVBOOST and IEA PVPS (Task 15) have highlighted gaps in the existing regulatory framework. Current standards do not provide a clear definition of the requirements that should be evaluated for BIPV products, which perform different functions within the building envelope. These requirements need methodologies developed by other sectors, and there is no clear definition of the test methods that should be used to evaluate BIPV products. Often, methods defined for standard products do not apply to BIPV products and vice versa, making certification of such products difficult.

The certification process for BIPV products is not well developed as a harmonized sector, and manufacturers have to comply with requirements and tests derived from different sectors (such as building, glass, electrotechnical, local standards, etc.), making it difficult, expensive and time-consuming. This can hinder the development and market entry of BIPV products. Moreover, considering the high level of customization of BIPV in each project, manufacturers often have to adapt standard testing procedures, assume responsibilities in interpreting re-testing approaches and guidelines, and ensure the balance between quality and cost-effectiveness.

For example, for mechanical safety, the IEC requires specific tests such as the Static Mechanical load test (MQT 16) or the Hail test (MQT 17). In contrast, for construction aspects, the same tests are framed within the basic requirements for mechanical resistance and user safety. Often, BIPV products on the market must meet prescriptive approaches set by IEC standards as well as performance-based requirements defined by harmonized standards or reference guidelines in construction sector.

The BIPVBOOST project previously addressed this challenge by proposing an approach similar to that used in the construction industry, attempting to adapt the certification process to the specific requirements of BIPV products according to a performance-based approach.

Finally, an essential point to consider is that standard PV was initially developed for modules whose sole objective was to maximize energy production, without regard to architectural requirements. However, BIPV products vary greatly depending on their location in the building, their function, sizes, thicknesses, and project-specific components. This implies that product variations require frequent additional re-testing, which is not sustainable for BIPV manufacturing. Therefore, it is necessary to overcome this challenge by adapting current certification schemes to meet the specific flexibility and customization demands of BIPV products.

A vital aspect to be addressed in this context is fire safety, which requires a thorough review to ensure compliance and safety of BIPV products in fire situations.

3.2.1 Missing gaps related to mechanical safety

Mechanical requirements are usually meant as requirements of "safety and accessibility in use" among the essential characteristics for the products covered by the CPR, such as wind load resistance, resistance to horizontal point loads, impact resistance, mechanical resistance of the cladding and its fixings or subframe components.

Different investigations in the literature discuss about this topic. However, by examining these contributions, technical topics still highlight missing gaps, which call for further testing approaches. In contrast to the prescriptive approach usually adopted for standard PV, the construction sector uses a performance-based approach. Thus, the goal is to base them on reliability-based principles that have to be defined as a number of limit states. The "performance-based approach to design" usually relies on the use of engineering principles, calculations and/or appropriate software modelling tools to substantiate the proposed solution and to satisfy the limit-state. These are the missing gaps related to mechanical safety in regulation for BIPV products:

High operating temperature. A typical BIPV specific characteristic is the higher operating temperature, compared to the standard PV module. This is due to lower heat evacuation as a consequence of the integration configuration compared to common open PV, resulting in higher operating temperatures. Contrary to popular belief, the electrical PV effect does not increase the temperature. It reduces the operating temperature because a part of the energy is converted into electricity instead of heat. The temperature impacts on mechanical properties of some materials and thus the safety aspects. This should be investigated in different scenarios e.g., by considering the combined effect of temperature during impact resistance tests[2]. In addition, temperature can influence the mechanical properties of the PV-IGU (Photovoltaic Insulated Glass Units) cavity, the pressure of which is directly dependent on temperature and must be taken into account in the mechanical calculations[3].

Durability of materials. After establishing thermal classifications (Thermal Serviceability Limit States) and selecting appropriate severity levels following the guidelines of IEC TS 63126, conducting ageing sequences can help evaluate performance and safety limit states. This includes assessing electrical insulation and performance-related parameters during thermal cycling and accelerated ageing tests, which differ from standard PV ageing tests. Mechanical properties could be change over time.

In summary, the following gaps are identified in relation to BIPV systems and mechanical safety performance.

3.2.2 Missing gaps related to electrical safety

Evaluating the electrical safety and performance of a Building Integrated Photovoltaic (BIPV) system or component is a critical consideration when transitioning from conventional passive building materials to electrically active elements. There are specific technical requirements related to electrical safety that still highlight certain gaps in current technical discussions.

Electrical elements. Unlike traditional building products, BIPV products contain an electrical part that is not considered in building regulations. As an example, the regulatory framework for glass in buildings (ISO 12543, EN 12600) does not include any specific reference to electrical limit states or to the presence of PV cells. This electrical part plays a fundamental role in defining the safety of the BIPV product such as for electrical safety, which is necessary to include in the definition of the limit state as a key requirement, in addition to the construction aspect.

High operating temperature. One of the primary challenges is determining the reference and maximum operating temperatures for BIPV products. This is essential due to variations in thermal insulation and shading conditions, which may lead to elevated temperatures and potential overheating risks. BIPV products face more complex stress conditions compared to traditional photovoltaic products, such as reduced cooling and different shading scenarios. Defining temperature-related limit states (thermal classification) for performance assessment is a fundamental step. As this could cause electrical and durability issues.

It is also necessary to ensure the suitability and durability of materials and components used in BIPV construction to function as intended, even at higher temperatures (as defined in section 3.2.1). This is crucial for maintaining electrical safety. For instance, polymeric materials like the

[2] P. Bonomo et al. Impact resistance of BIPV systems: New testing procedure for performance assessment of multifunctional products. Link: https://doi.org/10.1002/ese3.1364

[3] EN 16612:2020. Glass in building - Determination of the lateral load resistance of glass panes by calculation

encapsulant, are responsible for electrical insulation while their durability is sensitive to high temperature. It must be considered that the expected life span and difficulty of replacement impose greater reliability than standard modules in some cases that have become commodities.

Thermal stresses. Another important aspect of BIPV products is the protective devices like bypass diodes, that should withstand the increased thermal stresses. These stresses can arise from unconventional shading conditions and reduced heat dissipation. Testing should be carried out in conjunction with the thermal ageing sequences described earlier to evaluate the effectiveness of these critical protective devices under combined stress scenarios.

3.2.3 Missing gaps related to fire safety

The BIPV market is growing rapidly, and standards are lagging behind the technology. In particular, fire safety represents one of the biggest challenges and barriers to the evolution of these systems.

High variety of fire standards. One of the main obstacles facing the BIPV industry is the wide variety of fire safety standards that exist in different countries and regions, as fire safety is a matter of National or Local Regulations. On the one hand, PV installations must comply with very specific fire safety regulations and construction requirements, which vary greatly depending on the location. On the other hand, there are certain classification requirements that apply worldwide. This creates a complex landscape in which it is vital for manufacturers and suppliers of BIPV products to understand and comply with a multitude of standards in different markets. This means that products need sometimes be re-tested in different countries[4].

Aside from the differences between the various codes, BIPV systems are technologically complex because they add fire safety hazards to building facades and roofs that are not currently addressed in the building codes.

Fire ignition source. A fire in a building can start both inside the building and/or within the façade/roof in the case of a BIPV, as they are electrically active. The first risk is the only one covered by current regulations. In the case of BIPVs, it is important to analyse these two risk hazards.

Different products in one. As seen in D2.3, some standards are specific for a particular product or material but do not consider the risk of combining several of them in the same structure. Standards should consider test specimens of the whole system since the fire behaviour can be altered by small changes in materials and system configurations, and it is very likely that the assembly of different products will not act in the same way as isolated products.

[4] Yang, R., Zang, Y., Yang, J., Wakefield, R., Nguyen, K., Shi, L., … & Deng, X. (2023). Fire safety requirements for building integrated photovoltaics (BIPV): A cross-country comparison. Renewable and Sustainable Energy Reviews, 173, 113112

Not realistic heat flux levels during testing. Apart from that, a full-scale experiment on combustible facade systems[5] showed that these systems could be exposed to heat flux levels of more than 100 kW/m^2, and maximum temperatures of 1000 °C. This is problematic, as existing tests on the fire action of a facade consider lower heat flux levels and maximum temperatures around 700 °C.

Active elements. In addition, probably one of the biggest concerns with BIPVs is that, during a fire with daylighting, the modules continue to generate electricity, which increases the severity of the event and the risk of electric shock, creating a risk to firefighters and building occupants. The fire risk must be assessed when the panels are still active, but the currently regulated tests do not take this into account.

Toxicity. Besides, when a BIPV element reaches high temperatures, the combustion products and fine particles from the PVs are released in a smoke cloud that could be toxic. These elements should be tested to ensure that they are not harmful before they are installed in a building.

In summary, the following gaps are identified in relation to BIPV systems and fire safety performance:

- Both building and solar industry codes need to be met. A unification of regulations would make it easier for manufacturers to produce and sell products in different countries.
- Update and adequation of building codes considering BIPV technology is needed. Current BIPV standards are quite limited in addressing the fire safety of BIPV facades/roofs as building elements/systems, as fire safety requirements/testing methods are referred to local building codes/standards, which are developed for conventional building systems.
- Current fire safety testing and performance requirements need to be re-evaluated in the adoption of BIPV façade systems so that they reflect the actual burning behaviour of PV modules when electrically active or in operation.
- Current test standards usually simulate external fire scenarios, meaning an external fire that affects the PV systems. Internal fire scenarios should be further evaluated (e.g., short circuits, overheating, etc.), in order to address all the existing fire hazards when implementing PV systems in the buildings.
- New standards and test methods are needed to address fire spread and toxic smoke emission and infiltration risks specific to BIPV elements.

[5] Srivastava, G., Nakrani, D., & Ghoroi, C. (2020). Performance of combustible facade systems with glass, ACP and firestops in full-scale, real fire experiments. Fire technology, 56, 1575-1598.

3.3 Roadmap

Building-Integrated Photovoltaics (BIPV) represents the most advanced sector of integrated photovoltaics, with international standards under development to test BIPV products as integral components of construction buildings, simultaneously serving as electricity generators. One of the most intricate challenges in standardizing BIPV testing arises from the dual role of these products.

To facilitate simultaneous testing, there is a need for developing new testing procedures that address the most puzzling technical questions. These questions encompass a wide array of technical aspects, including fire safety, shading effects, mechanical integrity, and addressing the diversity of BIPV products in terms of shapes and electrical ratings.

To create a well-rounded roadmap for BIPV testing standardization, both scientific and industrial partners are actively working in the Seamless-PV project. The industrial partners have firsthand insights into the current state of the market and can identify urgent gaps that need to be addressed in standardization, while the scientific institutions will refine the testing methods.

The following stage of the roadmap will involve validating the established workflow using various BIPV products. It will evaluate how well the approach represents the challenges of BIPV products in real-world operations. This validation process will assess the impact of our standardized testing methods on the overall product's lifetime and performance.

In conclusion, the future roadmap for BIPV testing standardization is geared toward ensuring that BIPV systems remain safe, efficient, and resilient under a wide array of conditions. With an industry-focused, collaborative approach, we aim to develop and validate testing procedures that address the most pressing concerns of the BIPV sector, all while accommodating the diverse and evolving nature of BIPV products.

3.4 Summary

Regulatory Framework		Missing Gaps	Roadmap
BIPV product: EN 50583	Electrical functionality framework - IEC 61215 - IEC 61730 - IEC 63092 - LVD 2014/35/EU	BIPV products are at higher temperatures than conventional PV, this is not considered, and it can affect: - Durability of materials - Bypass performance with thermal stresses	- Develop new testing procedures to facilitate simultaneous testing. - Create a well-rounded roadmap for BIPV testing standardization - Create a testing that represents products in real-world operation
	Laminated solar photovoltaic glass for buildings: - ISO/TS 18178	Electrical components are not considered in the regulation.	
	Construction product performance: CPR 305/2011	There is a lack of unification of regulations and requirements between nations, creating a complex regulatory framework. The high operating temperatures of BIPV are not considered in the testing of construction products and this may affect: - Mechanical safety - Durability When validating building products against fire there are different aspects of BIPV that are not considered: - They can be a fire ignition source - They are active elements - There are different products in one - Testing conditions are not realistic - Toxicity of the smoke	

Table 3-1 Summary of BIPV regulatory framework, missing gaps, and roadmap

4 IIPV product standardization: PVNB

4.1 IIPV regulatory framework (PVNB)

Infrastructure integrated photovoltaics (IIPV) has no harmonized definition per se in Europe, but we see mentions of specific PV cases that can come under the IIPV categorization, namely PV along highways such as PV noise barriers (PVNB), or carports. In this section, these "pre-definitions" of IIPV across countries are listed, as well as regulations or support schemes applying to these segments.

Focusing on PVNBs, the use case in the infrastructure segment of SEAMLESS-PV, and the applicable regulatory framework for noise barriers in Europe are summarized next. Even if there is no specific reference to PV noise barriers, it is expected that a future amendment would be based on the current normative framework, as is being the case for BIPV. As of today, the applicable regulatory framework for PVNB would therefore be based on the current regulatory framework for noise barriers, complemented with PV-specific regulatory and standardization frameworks.

International Electrotechnical Commission

For the photovoltaic industry, the main reference standards are **IEC 61215:2021** parts 1 and 2, which establish the **requirements for design qualification** of terrestrial photovoltaic modules suitable for long-term operation in outdoor climates, and **IEC 61730:2021** parts 1 and 2 which specify and describe respectively the basic construction and testing requirements for photovoltaic (PV) modules to ensure **safe electrical and mechanical operation**.

Low Voltage Directive

IIPV as photovoltaic modules are subject to electrical requirements. In Europe, it must comply with the Low Voltage Directive LVD (2014/35/EU).

Construction Products CPR

In the EU, noise barriers for road infrastructure are construction products, and consequently fall under the Construction Product Regulation (CPR 305/2011). CPR covers construction products in two different ways: stated requirements are compulsory when a harmonized standard is in force, while in the absence of it, they become voluntary.

Harmonized European Standard

Among categories belonging to road equipment, noise barriers are regulated by the **harmonized standard hEN 14388 published in the Official Journal of the European Union (OJEU)** and, therefore, their fulfilment is compulsory.

Below, the regulatory framework for noise reducing devices (NRD) and the CE marking process applicable to NRDs are presented.

4.1.1 European Noise Directive (END: Directive 2002/49/EC)

This Directive aims to define a common approach intended to avoid, prevent, or reduce those harmful effects that derive from exposure to environmental noise. The following actions are to be implemented progressively:

- (a) the determination of exposure to environmental noise, through noise mapping
- (b) ensuring that information on environmental noise and its effects is made available to the public
- (c) adoption of action plans by the Member States, based upon noise-mapping results, with a view to preventing and reducing environmental and to preserving environmental noise quality where it is good.

Article 2 defines the application scope of this Directive, which shall apply namely to environmental noise to which humans are exposed in built-up areas, in public parks or other quiet areas in an agglomeration, in quiet areas in open country, near schools, hospitals, and other noise-sensitive buildings and areas. The Directive shall not apply to noise that is caused by the exposed person himself, noise from domestic activities, noise created by neighbours, noise at workplaces, noise inside means of transport, or due to military activities in military areas.

4.1.2 CE marking (hEN 14388)

The CE marking process (i.e., conformity with European health, safety, and environmental protection standards) for noise reduction devices (NRDs) relies on the harmonized standard *EN 14388:2015 - Road traffic noise reducing devices – Specifications*. Manufacturers must provide the declaration of performance (DoP) for the essential requirements defined by the standard and affix the CE marking, thus taking responsibility for the declared performances. The scope is restricted to "noise barriers", "cladding", "coverings" and their structural and acoustic elements which act solely on noise propagation:

- Noise barriers: NRDs that obstruct the direct transmission of airborne sound emanating from road traffic.
- Claddings: NRDs that are attached to a wall or other structure and reduce the amount of sound reflected.
- Road covers: NRDs that either span or overhang the road.

Declaration of Performance (DoP):
According to CPR, CE marking is a harmonized way to declare the performance of construction products so that they can circulate within the common market. Performance has to be declared for the essential characteristics listed in Annex ZA of the harmonized standard.
Annex ZA is part of the harmonized standard that identifies essential characteristics and provides the Assessment and Verification of Constancy of Performance (AVCP) to which the products need to be submitted before the manufacturer is entitled to draw up a Declaration of Performance (DoP) and to affix the CE marking.

The full NRD (complete system, not specific parts of it -e.g., acoustic panel-) is the product to be incorporated into a road infrastructure and its performance has to be declared for the following essential characteristics:

- Noise reduction
- Stability requirements (wind load and dynamic load of passing vehicles)
- Safety in use: resistance to impacts, light reflection.
- Fire behaviour
- Long term performance
- Sustainable use of natural resources

Requirements:
EN 14388 does not fix product requirements unless threshold values are established within the standards by the Mandate; Authorities or Member States are in charge of establishing requirements. The use of construction products requires bearing the CE marking and that the declared performances correspond to the requirements for such use in that Member State.
The applicable standards to show evidence of compliance with essential characteristics is described next:

Noise reduction

- Acoustic screens to be installed in **diffuse field conditions**:
  - Sound insulation required for diffuse field applications: measurements of the airborne noise insulation index DL_R carried out in accordance with EN ISO 10140-3 and as indicated in EN 1793-2
  - Sound absorption required for diffuse field applications: The sound absorption index DL_α of the screen shall be determined on the basis of measurements carried out in accordance with EN ISO 354 and as indicated in EN 1793-1.
- Acoustic screens to be installed in **direct field conditions**:
  - Sound insulation required for direct field applications: The airborne noise insulation index DL SI, corresponding to the area of acoustic elements and the airborne noise insulation index $DL_{SI,P}$ corresponding to the area of the support posts, will be determined as indicated in the EN 1793-6 standard.
  - Acoustic reflection for direct field applications: The overall sound reflection index DL_{RI} of the noise reducing device shall be determined as indicated in EN 1793-5.

Stability requirements

In general, acoustic screens will consist of modular panels arranged between the standard steel profiles, which constitute the frame or support structure. Both the panels and the support structure must be dimensioned, at least, in accordance with the provisions of the **EN 1794-1** and **EN 1794-2** standards, and without prejudice to greater requirements required in any other applicable standard.

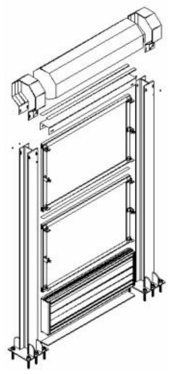
The behaviour under static loads (wind load and dynamic load of passing vehicles), risk of detachment, snow loads, and impact behaviour are characteristics to be verified according to the standards above for the DoP.

Safety in use
Phenomena described in EN 1794-2 should be considered. When the project requires so, evidence of the performance of the test described in the EN 1794-2 Annex D (light reflection) standard must be presented. Declared values must satisfy the requirements established to achieve the class required by the designer, as detailed in Table D.1 (glare class). Annex E (transparency) could be also of interest.

Fire behaviour
Evidence of the performance of the test described in the **EN 1794-3** standard must be presented. The test is performed with a localised source of fire close to the face of the panel. Declared values must satisfy the requirements established to reach, at least, the class that is applicable according to Table A.1 of Annex A, of the aforementioned standard.

Long term performance
Long-term acoustic and mechanical characteristics are tested according to **EN 14389-1** and **EN 14389-2**, respectively. Annex A lists typical environmental conditions selected for road traffic noise reducing devices from **EN 60721-3-4**. The corresponding working life in years shall be defined under the exposure classes, together with the value expressed in the decibel of the acoustic performances at the end of the working life. Where material standards exist, long term performance shall be assessed using them (see Annex B), which for photovoltaics are detailed in IEC 61215 and IEC 61730.

4.2 Missing gaps of PV noise barriers



The noise barrier system is an exterior structure designed to protect inhabitants of sensitive land use areas from noise pollution, they are normally conceives as a road and rail equipment that requires CE marking. Thus, manufacturers are asked to:

- Declare noise barrier (NB) performance of essential characteristics.
- Affix the CE marking, i.e., to take responsibility for the conformity of the NB with the declared performances.

The performance of the noise barrier system must be assessed, as it is not just a collection of individual components, but a technical data sheet. The implications of linking a photovoltaic generation system to an acoustic barrier must be addressed as a system considering all additional equipment.

The legislation on noise barriers, with the necessary additions, is considered to be the basis for future certification of photovoltaic noise barriers (PVNB). Thus, the EN-14388 standard is taken as a starting point, where the requirements for the certification of noise barriers are indicated.

In the following paragraphs, the EN-14388 main points have been revised for detecting the potential gaps to be applied for noise barriers integrating PV elements, as the standard for road noise barriers is not designed for including electrical elements like PV. Integration of PV entails additional risks that should be considered.

Spanish consideration: The technical instructions for Spanish road and railway infrastructure go beyond the European standard. They describe requirements for metal, polymers, and concrete noise barriers but do not include glass as material option.

4.2.1 Missing gaps related to mechanical safety

To ensure mechanical safety, manufacturers shall declare the maximum loads that noise barriers can withstand provided the maximum deflection of posts and panels is not exceeded, considering the wind load and variable loads due to passing vehicles.

Electrical elements. When testing/calculating resistance to maximum normal and bending all parts should be in the test, including wiring and connections in the modules to be tested. Apart from that, the durability test of the Noise Barrier should be compared with ageing test of PV, the ageing could affect the mechanical safety.

High operating temperature. PV elements due to irradiation absorption the PVNB panels operate in higher temperatures that could impact the mechanical properties of the polymers involved in the PV material (encapsulant in the case of PV laminated glass), and this is not considered in the regulation. It is necessary also to define whether the test temperature range is suitable for items such as PVNBs that have operating ranges above ambient temperature.

Critical points due to perforations. PVNB panels have in comparison to conventional NB some more critical points due to perforations (e.g., glass holes) that may cause stresses in the parts susceptible to failure in impact tests, this must also be taken into consideration in the design.

Duplicate test. The durability test of the Noise Barrier should be compared with the ageing test of PV. It must be coordinated so as not to duplicate tests. The ageing could affect the mechanical and/or electrical safety.

4.2.2 Missing gaps related to electrical safety

PVNB being an electrically active part it is important to ensure electrical safety, however, apart from having IEC standards some aspects should be considered.

Electrical charges. PVNB has the risk of transmission of electrical charges to vehicles or people due to system breakdown. Analyze the implications of electric shocks after vehicle shock, and work on design so that the shocks are compatible with use, or on breakage prevention systems should be done. There is no test to verify the problem or limits of the condition. The latter tests described in EN 1794-1 annex C and D should be performed with the PV panels activated for the PVNB case. Apart from that, in the DoP of the noise barrier system Structural performance: errant vehicles impact, Crash test to be performed according to EN 1317 in case of integrated noise and safety barrier, it would be recommended to include information about the potential voltage transfer to a vehicle shocking the barrier.

The danger of falling debris test that is carried out would be recommended to perform the test applying voltage to the PV modules while the voltage of the hammer is monitored. Thus, assessing whether the voltage could be transferred to a vehicle shocking the barrier.

Duplicate test. The ageing test of PV should be compared with the durability test of the Noise Barrier. The ageing could also affect electrical safety. As the ageing test affects mechanical and electrical characteristics, it must be coordinated so as not to duplicate tests.

4.2.3 Missing gaps related to fire safety

The EN 1794-3 fire performance standard for road noise barriers is not designed for including electrical elements like PV. Integration of PV entails additional risks that should be considered.

PVNBs generate electricity and in case of a fire, the active cells can contribute to increase the severity of the event. This risk is not considered in the current regulations.

Electrical elements and their position: converting the panels into electricity generators involves the use of different elements, most of which are usually combustible like cables, encapsulants, connectors, inverters, junction boxes, etc. Their location is not specified in the current description of the test, so different results could be obtained by evaluating the same system but changing the position of these components. Some of these elements can alter the test results, such as the location of the junction box or the length of the cables. It is considered appropriate to provide a better definition of the characteristics of the PVNB samples so that different tests vary as little as possible and to ensure that the results are comparable between them, enabling a correct evaluation of the results.

Fire ignition source: in addition to the risk of an external fire, there is also the possibility of an internal electrical fire. This can be caused by an electric failure (covered by EN IEC 61215-1-1 standard) but can also be generated by a vehicle crash event that modifies the electrical connections causing hot spots or electrical arcs.

4.2.4 Other relevant aspects:

Not homogeneous PV areas. The optical properties of PV glass might not be homogeneous (areas with and without solar cells). Thus, it should be discussed whether area-weighted values or maximum values should be considered. Apart from that, no specific aspects are to be considered but every element (also the PV parts) in the analysis of optical properties.

4.3 Roadmap

The analysis carried out in the previous section shows that there are certain gaps in the noise barriers regulation to enable new PVNBs to be certified or simply placed on the market, beyond the design considerations that have been detected as a result of the regulatory requirements.

Design considerations for PVNBs based on regulation review:

- PV panel length compatibility with maximum allowable deformation without breakage.
- Avoid high DC voltages during operation. System design that limits maximum loads to avoid dangerous discharges to vehicles or people in case of breakage (for instance incorporating microinverters).
- Design of the system preventing the panels from being at ground level, avoiding problems of weed fire, blows due to falling stones in circulation, and dirt accumulation that can cause PV mismatch.
- Design panels that avoid unwanted reflections, for example by texturing the panel facing the road (e.g., using an acid etched glass), or even both faces to avoid reflections in homes.
- Take into consideration the need for the product to always be behind or on anti-collision barriers, which absorb the blow and prevent the panel from breaking as much as possible.
- Take into account the possible need for safety pieces that prevent detached pieces from falling onto the track.

- Avoid, as much as possible, the existence of fragile points in the panel that could weaken the system in the event of impacts (for example, glass holes for junction box).
- Consider that the tests are carried out on the complete system and that all electrical systems, drainage, watertight joints, etc. must be considered for product certification.
- Considerations related to safety aspects such as emergency doors in the system, compatible with the PVNB system.

According to a consultation made with a member of the CEN/TC 226/WG 6 committee (responsible for EN 14388 standard), nowadays they are not working on **photovoltaic noise barriers**. To their knowledge, there is no public technical document on this, at least in EU countries.

Thus, considering also the previous missing gaps, the following actions are proposed:

- Open a line of communication with the CEN/TC 226/WG 6 committee during the project, to help guide the needs of tests adapted to this product. Propose the glass, and PV glass in particular, as an alternative material to be used in noise barriers, including this option in the Spanish technical instructions.
- Analyze the changes that are needed in the current test descriptions:
    - Performed fire test with activated PV panels (i.e., applying voltage).
    - Load tests and effects of temperature.
    - Load tests and maximum allowable deformations for a glass base element.
    - New electrical safety test in the event of a vehicle crash. Activate PV panels by introducing voltage during the test while the voltage is monitored in the loading or impact element.

4.4 Summary

Table 4-1 Summary of PVNB regulatory framework, missing gaps and roadmap

Regulatory Framework	Missing Gaps	Roadmap
Electrical part framework: - IEC: 61215 - IEC: 61730 - LVD 2014/35/EU	Ageing tests are considered also in mechanical characteristic validation test, this test is duplicated	Open a line of communication with CEN/TC 226/WG 6 committee. Guide test adapted to this product. Analyse the changes in the current test description: - Performed fire test with activated PV panels (i.e., applying voltage). - Load tests and effects of temperature. - Load tests and maximum allowable deformations for a glass base element. - New electrical safety test in the event of a vehicle crash. Activate PV panels by introducing voltage
CPR 305/2011 – Construction product performance	Adding PV elements in the NB, some aspects should be considered: - Electrical elements in mechanical validations. - High operating temperature, this could affect to mechanical properties and durability. - Critical points due to perforations to add electrical elements in the product. - Transfer of electrical charges to the vehicle in crash accident situation - The panels could be fire ignition source. - New configuration needed to test the products with electrical elements in fire test. - NB could be fire ignition source. - Missing information about how to test non-homogeneous properties in the panels.	
hEN 14388		

		during the test while the voltage is monitored in the loading or impact element. - Take into account the electrification charges could be after a crash.

5 VIPV PRODUCTS

5.1 VIPV regulatory framework

Currently, there is no regulatory framework specifically defined for vehicle integrated photovoltaics (VIPV). However, the automotive Original Equipment Manufacturers OEMs are adapting the EV's (Electric Vehicles) directives to fit the VIPV technologies.

International Electrotechnical Commission

Like the other IIPVs analyzed in this document, Vehicle-mounted PVs have to fulfil terrestrial PV aspects that are IEC 61730:2023 parts 1 and 2, Photovoltaic (PV) module safety qualification and IEC 61215:2021 parts 1 and 2, Terrestrial photovoltaic (PV) modules – Design qualification and type approval.

International standard organization

Apart from PV characteristics, the VIPV has some other regulations as an automotive component (electrical and electronic equipment, glass), the most interesting standard for these applications is ISO 16750 - Environmental conditions and testing for electrical and electronic equipment. This standard has different parts, each one dedicated to different loads: part 2 - Electrical loads, part 3 - Mechanical loads, part 4 - Climatic loads, and part 5- Chemical loads.

The following EU regulations must be followed in VIPV use cases:

Electromagnetic compatibility

All the power electronics components for VIPV e.g., Maximum power point tracker (MPPT) and DC/DC converters must follow the ECE Regulation 10 - "Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility".

Low voltage directive

The VIPV modules installed on the vehicle should be below 60V and follow the low voltage directive (LVD) (2014/35/EU). LVD ensures that electrical equipment within certain voltage limits provides a high level of protection for European citizens, and benefits fully from the single market.

Noise Emission from vehicles

The surface/structure of the vehicle would have an impact on the noise emissions from the vehicle while driving. It is important that the surface of the VIPV mustn't exceed the permitted limitation in the *ERE R51 –" Uniform provisions concerning the approval of motor vehicles having at least four wheels with regard to their sound emissions [2018/798]*".

Masses and dimensions of motor vehicles

The PV integrated or applied on a vehicle must respect the maximum allowed mass and dimensions of the motor vehicle according to EU regulation number *1230/2012 "Type-approval requirements for masses and dimensions of motor vehicles and their trailers*".

Pedestrian safety performance

As the VIPV represents the external area/surface of the vehicle. It is important to respect pedestrian safety according to the *UN Regulation number 127 - "Uniform provisions concerning the approval of motor vehicles with regard to their pedestrian safety performance"*.

Electrical safety

In order to avoid injuries due to electrical failures, VIPV applications must be compliant with the ECE R100 regulation for electrical safety. This regulation relates to the necessary protection against direct or indirect contact with high voltage live parts, against electrical shocks and water effects as well as marking of HV components.

Protection against Cyberattacks

The protection of vehicles against cyber-attacks is covered by the ECE regulation R155 which focuses on cybersecurity relevance assessment, supplier cybersecurity interface agreement, and threat analysis and risk assessment (TARA).

Recycling

The topic of reusability and recyclability of approved type vehicles is covered by the directive 2005/64/EU prohibits the use of hazardous substances, markings of plastics, and elastomer products and indicates the needed recycling rates. PV modules onboard are considered part of the vehicles and thus, they count on the amount of material to be recycled.

These regulations, however, depend on the type of vehicle considered. In this section, we have summarised the regulations applicable for the 3 use cases relevant to this project: passenger vehicle, truck wind deflector, and bus shoulder Figure 5-1,

<table>
<tr><th>Type (standard, policy, traffic rules, etc.)</th><th>Name (for reference)</th><th>Category (fire, safety, impact, etc.)</th><th>Translation into technical specification (value)</th></tr>
<tr><td>Standard</td><td>UL 94 V0 (Required in the US, but not EU)</td><td>Fire</td><td>burning stops within 10 seconds on a vertical specimen; drips of particles allowed as long as they are not infl</td></tr>
<tr><td>Standard</td><td>IEC 61215 and IEC 61730</td><td>Design qualification and type approval</td><td>UV Resistance, humidity test, Thermal cycling, fire resistance, mechanical tests, chemical tests</td></tr>
<tr><td>Regulation</td><td>ECE R 10</td><td>Electromagnetic Compatitibility</td><td>The MCU unit must fulfill ECE R10 requirements</td></tr>
<tr><td>Directive</td><td>2014/35/EU</td><td>Low Voltage Directive</td><td>The electrical system must fullfill the 2014/35/EU requirements</td></tr>
<tr><td>Regulation</td><td>ECE R 51</td><td>Noise emissions from vehicles of classes M and N</td><td>
<table>
<tr><th rowspan="2">Vehicle Category</th><th rowspan="2">Vehicles used for the carriage of goods</th><th colspan="3">Limit values (dB(A))</th></tr>
<tr><th>Phase 1</th><th>Phase 2</th><th>Phase 3</th></tr>
<tr><td rowspan="2">N_1</td><td>M ≤ 2.5t</td><td>72</td><td>71</td><td>69</td></tr>
<tr><td>M > 2.5t</td><td>74</td><td>73</td><td>71</td></tr>
<tr><td rowspan="2">N_2</td><td>Pn ≤ 135kW</td><td>77</td><td>75</td><td>74</td></tr>
<tr><td>Pn > 135kW</td><td>78</td><td>76</td><td>75</td></tr>
<tr><td rowspan="3">N_3</td><td>P_n ≤ 150kW</td><td>79</td><td>77</td><td>76</td></tr>
<tr><td>150kW < P_n ≤ 250kW</td><td>81</td><td>79</td><td>77</td></tr>
<tr><td>P_n > 250kW</td><td>82</td><td>81</td><td>79</td></tr>
</table>
</td></tr>
<tr><td>Regulation</td><td>(EU) No. 1230/2012</td><td>Type-approval requirements for masses and dimensions of motor vehicles and their trailers</td><td>VEHICLES OF CATEGORY N1
Length: 12.00m.
Width:
N1: 2.55m;
N1: 2.60m for vehicles fitted with a bodywork with insulated walls of at least 45mm thick, as referred to in A
Annex II to Directive 2007/46/EC;
Height: 4.00m.
VEHICLES OF CATEGORY N2 AND N3
Length: 12.00m.
Width:
(a) 2.55m for any vehicle;
(b) 2.60m for vehicles fitted with a bodywork with insulated walls of at least 45mm thick,having bodywork co
Appendix 2 to Annex II to Directive 2007/46/EC;
Height: 4.00m</td></tr>
<tr><td>Standard</td><td>DIN 52306 and DIN 25307</td><td>External vehicle parts must be shatterproof.</td><td>The splinter resistance test is based on DIN 52306 and DIN 25307</td></tr>
<tr><td>Regulation</td><td>ECE R29</td><td>impact: protection of the occupants of the cab of a commercial vehicle</td><td>Roof strength test "7.4.5. A static load shall be applied by the loading device to the roof of the cab, correspon
mass authorised for the front axle or axles of the vehicle, subject to a maximum of 98 kN."</td></tr>
<tr><td>Regulation</td><td>ECE R 100</td><td>Electrical Safety</td><td>- Protection against direct contact with high voltage live parts, the protection IPXXB (electrical protection co
-Protection against indirect contact
- Marking of HV components
- Protection against electrical shock
-Protection against water effects</td></tr>
<tr><td>Regulation</td><td>ECE R 155</td><td>Protection of vehicle against cyberattacks</td><td>Focus on processes (management systems)
1) Cyber Security Relevance Assessment
2) Supplier Cybersecurity Interface Agreement (Supplier CIA)
3) Threat Analysis and Risk Assessment (TARA)</td></tr>
<tr><td>Regulation</td><td>ECE R 156</td><td>Software update and software update management system</td><td>Focus on processes (management systems)</td></tr>
</table>

, and Figure 5-3. In all three cases, standards from automotive and PV are combined due to a lack of specific VIPV regulations.

Passenger Car

Type (standard, policy, traffic rules, etc.)	Name (for reference)	Category (fire, safety, impact, etc.)	Translation into technical specification (value)	Parts affected
Standard	UL 94 V0 *(Required in the US, but not EU)*	Fire	burning stops within 10 seconds on a vertical specimen; drips of particles allowed as long as they are not inflamed	
Standard	IEC 61215 and IEC 61730	Design qualification and type approval	UV Resistance, humidity test, Thermal cycling, fire resistance, mechanical tests, chemical tests and additional tests sequences and combined tests	PV modules
Regulation	ECE R 10	Electromagnetic Compatitibility	The MCU (Multi-channel MPPT) unit must fulfill ECE R10 requirements	MCU
Directive	2014/35/EU	Low Voltage Directive	The electrical system must fullfill the 2014/35/EU requirements, only PV with less than 60V	ECUs
Regulation	ECE R 51	Noise emissions from vehicles of classes M and N	*Vehicle Category* / *Vehicles used for the Carriage of Passengers* / *Limit Values (dB(A))*: *Phase 1* / *Phase 2* / *Phase 3* M_1: PMR ≤120: 72 / 70 / 68 120 <PMR ≤160: 73 / 71 / 69 PMR >160: 75 / 73 / 71 PMR >200, number of seats ≤4, R Point height <450mm from the ground: 75 / 74 / 72	PV modules integration
Regulation	(EU) No. 1230/2012	Type-approval requirements for masses and dimensions of motor vehicles and their trailers	VEHICLES OF CATEGORY M1 Length: 12.00m Width: 2.55m Height: 4.00m	PV modules integration
Regulation	ECE R 26	Uniform provisions concerning the approval of vehicles with regards to their external projections	H is the maximum value of the distance, measured along a straight line passing through the centre of the 165 mm diameter circle between the circumference of the aforesaid circle and the external contour of the projection In cases where it is not possible for a 100 mm diameter circle to contact externally part of the external outline of the external surface at the section under consideration, the surface outline in this area will be assumed to be that formed by the circumference of the 100 mm diameter circle between its tangent points with the external outline	PV modules integration
Regulation	ECE R 127	impact: Pedestrian safety performance (PedPro)	Tests of Annex 5: Flexible Lower Legform Impactor Upper Legform to Bumper Child Headform Adult Headform	PV modules
Regulation	ECE R 100	Electrical Safety	- Protection against direct contact with high voltage live parts, the protection IPXXB (electrical protection code) shall be provided. -Protection against indirect contact - Marking of HV components - Protection against electrical shock -Protection against water effects	ECUs (in particular HV)
Regulation	ECE R 155	Protection of vehicle against cyberattacks	Focus on processes (management systems) 1) Cyber Security Relevance Assessment 2) Supplier Cybersecurity Interface Agreement (Supplier CIA) 3) Threat Analysis and Risk Assessment (TARA)	E/E items or components that are security relevant (Decision based on Cyber Security Relevance Assessment)
Regulation	ECE R 156	Software update and software update management system	Focus on processes (management systems)	ECUs
Directive	Directive 2005/64/EC	Recycling	- prohibits the use of hazardous substances - Marking of Plastics and Elastomer Products - Recycling rates	Whole system
Standard	ISO 26262	Function safety	Depends on the functions and the implementation of the product	ECUs

Figure 5-1 Standards, regulations, and directives applicable to passenger cars

Trucks

<table>
<tr><th>Type (standard, policy, traffic rules, etc.)</th><th>Name (for reference)</th><th>Category (fire, safety, impact, etc.)</th><th>Translation into technical specification (value)</th><th>Parts affected</th></tr>
<tr><td>Standard</td><td>UL 94 V0 (Required in the US, but not EU)</td><td>Fire</td><td>burning stops within 10 seconds on a vertical specimen; drips of particles allowed as long as they are not inflamed</td><td></td></tr>
<tr><td>Standard</td><td>IEC 61215 and IEC 61730</td><td>Design qualification and type approval</td><td>UV Resistance, humidity test, Thermal cycling, fire resistance, mechanical tests, chemical tests</td><td>modules</td></tr>
<tr><td>Regulation</td><td>ECE R 10</td><td>Electromagnetic Compatitibility</td><td>The MCU unit must fulfill ECE R10 requirements</td><td>MCU</td></tr>
<tr><td>Directive</td><td>2014/35/EU</td><td>Low Voltage Directive</td><td>The electrical system must fullfill the 2014/35/EU requirements</td><td>ECUs</td></tr>
<tr><td>Regulation</td><td>ECE R 51</td><td>Noise emissions from vehicles of classes M and N</td><td><table>
<tr><th rowspan="2">Vehicle Category</th><th rowspan="2">Vehicles used for the carriage of goods</th><th colspan="3">Limit values (dB(A))</th></tr>
<tr><th>Phase 1</th><th>Phase 2</th><th>Phase 3</th></tr>
<tr><td rowspan="2">N_1</td><td>M ≤ 2.5t</td><td>72</td><td>71</td><td>69</td></tr>
<tr><td>M > 2.5t</td><td>74</td><td>73</td><td>71</td></tr>
<tr><td rowspan="2">N_2</td><td>Pn ≤ 135kW</td><td>77</td><td>75</td><td>74</td></tr>
<tr><td>Pn > 135kW</td><td>78</td><td>76</td><td>75</td></tr>
<tr><td rowspan="3">N_3</td><td>P_n ≤ 150kW</td><td>79</td><td>77</td><td>76</td></tr>
<tr><td>150kW < P_n ≤ 250kW</td><td>81</td><td>79</td><td>77</td></tr>
<tr><td>P_n > 250kW</td><td>82</td><td>81</td><td>79</td></tr>
</table></td><td>modules integration</td></tr>
<tr><td>Regulation</td><td>(EU) No. 1230/2012</td><td>Type-approval requirements for masses and dimensions of motor vehicles and their trailers</td><td>VEHICLES OF CATEGORY N1
Length: 12.00m.
Width:
N1: 2.55m;
N1: 2.60m for vehicles fitted with a bodywork with insulated walls of at least 45mm thick, as referred to in Appendix 2 of Part C of Annex II to Directive 2007/46/EC;
Height: 4.00m.
VEHICLES OF CATEGORY N2 AND N3
Length: 12.00m.
Width:
(a) 2.55m for any vehicle;
(b) 2.60m for vehicles fitted with a bodywork with insulated walls of at least 45mm thick,having bodywork code 04 or 05 of Appendix 2 to Annex II to Directive 2007/46/EC;
Height: 4.00m</td><td>modules integration</td></tr>
<tr><td>Standard</td><td>DIN 52306 and DIN 25307</td><td>External vehicle parts must be shatterproof.</td><td>The splinter resistance test is based on DIN 52306 and DIN 25307</td><td>modules</td></tr>
<tr><td>Regulation</td><td>ECE R29</td><td>impact: protection of the occupants of the cab of a commercial vehicle</td><td>Roof strength test "7.4.5. A static load shall be applied by the loading device to the roof of the cab, corresponding to the maximum mass authorised for the front axle or axles of the vehicle, subject to a maximum of 98 kN."</td><td>modules</td></tr>
<tr><td>Regulation</td><td>ECE R 100</td><td>Electrical Safety</td><td>- Protection against direct contact with high voltage live parts, the protection IPXXB (electrical protection code) shall be provided.
-Protection against indirect contact
- Marking of HV components
- Protection against electrical shock
-Protection against water effects</td><td>ECUs (in particular HV)</td></tr>
<tr><td>Regulation</td><td>ECE R 155</td><td>Protection of vehicle against cyberattacks</td><td>Focus on processes (management systems)
1) Cyber Security Relevance Assessment
2) Supplier Cybersecurity Interface Agreement (Supplier CIA)
3) Threat Analysis and Risk Assessment (TARA)</td><td>E/E Items or Components that are security relevant (Decision based on Cyber Security Relevance Assessment)</td></tr>
<tr><td>Regulation</td><td>ECE R 156</td><td>Software update and software update management system</td><td>Focus on processes (management systems)</td><td>ECUs</td></tr>
</table>

Figure 5-2 Standards, regulations, and directives applicable to truck wind deflectors

Bus Shoulder

Type (standard, policy, traffic rules, etc.)	Name (for reference)	Category (fire, safety, impact, etc.)	Translation into technical specification (value)	Parts affected
Standard	UL 94 V0	Fire	Burning stops within 10 seconds on a vertical specimen; drips of particles allowed as long as they are not inflamed	
Standard	IEC 61215 and IEC 61730	Design qualification and type approval	UV Resistance, humidity test, Thermal cycling, fire resistance, mechanical tests, chemical tests	modules
Regulation	ECE R 10	Electromagnetic Compatitibility	The MCU unit must fulfill ECE R10 requirements	MCU
Directive	2014/35/EU	Low Voltage Directive	The electrical system must fullfill the 2014/35/EU requirements	ECUs
Regulation	ECE R 51	Noise emissions from vehicles of classes M and N	M_2 — $M \le 2.5t$: 72, 70, 69 M_2 — $2.5t < M \le 3.5t$: 74, 72, 71 M_2 — $M > 3.5t$; $P_n \le 135kW$: 75, 73, 72 M_2 — $M > 3.5t$; $P_n > 135kW$: 75, 74, 72 M_3 — $Pn \le 150kW$: 76, 74, 73 M_3 — $150kW < P_n \le 250kW$: 78, 77, 76 M_3 — $P_n > 250kW$: 80, 78, 77	modules integration
Regulation	(EU) No. 1230/2012	Type-approval requirements for masses and dimensions of motor vehicles and their trailers	VEHICLES OF CATEGORY M2 AND M3 Length (a) Vehicle with two axles and one section: 13.50m (b) Vehicle with three or more axles and one section: 15.00m (c) Articulated vehicle: 18.75m Width: 2.55m; Height: 4.00m	modules integration
Regulation	ECE R 118	Burning behaviour of materials	Burning behavior of MCU: - Burning rate in horizontal direction (UN R-118 An. 6) - Melting behaviour (UN R-118 An. 7) - Burning rate in vertical direction (UN R-118 An. 8) Burning behavior of cables: Determine the resistance to flame propagation of electrical cables (UN R-118 An. 10)	MCU and cables
Regulation	ECE R 107	Uniform provisions concerning the approval of category M2 or M3 vehicles with regard to their general construction	If the bus is equiped with escape hatches. The requirements according to R107 Annex 3 point 7.6.1.12. shall be taken into account.	whole system
Regulation	DIN 52306 and DIN 25307	External vehicle parts must be shatterproof.	The splinter resistance test is based on DIN 52306 and DIN 25307	modules
Regulation	ECE R 100	Electrical Safety	- Protection against direct contact with high voltage live parts, the protection IPXXB (electrical protection code) shall be provided. -Protection against indirect contact - Marking of HV components - Protection against electrical shock -Protection against water effects	ECUs (in particular HV)
Regulation	ECE R 155	Protection of vehicle against cyberattacks	Focus on processes (management systems) 1) Cyber Security Relevance Assessment 2) Supplier Cybersecurity Interface Agreement (Supplier CIA) 3) Threat Analysis and Risk Assessment (TARA)	E/E Items or Components that are security relevant (Decision based on Cyber Security Relevance Assessment)
Regulation	ECE R 156	Software update and software update management system	Focus on processes (management systems)	ECUs

Figure 5-3 Standards, regulations, and directives applicable to bus shoulders

5.2 Missing gaps

Since vehicle integrated photovoltaics is still a relatively new field with only a few PV vehicles on the road, there is still a lack of dedicated norms or regulations that apply to this field. Therefore, car manufacturers need to combine standards from different fields, mostly from automotive and photovoltaics, to ensure that VIPV systems are working reliably and most importantly in a safe manner. This includes the complete PV system such as the PV modules, junction boxes, cabling, electrical connectors, power electronics, and every other component which is additionally mounted on the vehicle. All of these should be in conformance with the various PV and automotive regulations. However, in bringing these two together with a single product there are different problems or characteristics that are not addressed by either of the relevant regulations.

5.2.1 Mechanical Safety

Mechanical robustness. VIPVs are tested to ensure the mechanical robustness of PV modules that could guarantee the proper functioning of VIPVs in everyday use by simulating the stresses generated by high-speed currents. However, being a vehicle, there is a risk of accidentally overturning the car, and the vehicle remains in the inverted position. For these cases, the PV module should be able to withstand these mechanical loads, which are not currently considered in the current regulations.

Vibration loads. The same applies to vibrations caused by opening doors or driving on poor road conditions, which are also not taken into account by conventional modules, as they do not withstand such vibrations. This is one of the issues that worries the PV community in terms of assuring the durability and reliability of PV modules onboard.

5.2.2 Electrical Safety

Hot spot formation. In particular, the topic of hot spot formation on the panels, which is more critical for polymer/polymer panels, typically used in VIPV, is a very relevant topic that has not been sufficiently studied until now. This could be caused by defects in the solar cells such as shunts and cell breakage, but also due to shading effects which are very common and mostly unpredictable in this type of application. The latter not only affects reliability and safety but also system performance and therefore would be important to consider more extensively in the future.

5.2.3 Other aspects

Chemically aggressive environments. VIPVs, being mobile, are exposed to different environments and consequently to different chemicals that could be aggressive e.g., near sea locations, which is not taken into account in conventional PV modules or only when they are located in a specific location. Abrasive products used for cleaning outer parts in buses and trucks will also impact PV modules.

5.3 Roadmap

Due to the increased interest in vehicle integrated photovoltaics, triggered by the necessity to transition into more sustainable mobility with lower emissions in the future, there have been several proposals for safety qualification procedures and standards for this field taking into account the missing gaps mentioned previously in this document. One example of such a proposal was published by the Fraunhofer Institute for Solar Energy Systems and TNO in 2021[6].

In that article, they compare various norms from automotive and photovoltaics and propose a sequence of measurements especially designed for vehicle integrated PV applications. The following flow diagram was presented in the publication Figure 5-4.

A dedicated standard specific to VIPV including test sequences with clear acceptance criteria and certifications will be indispensable to ease the future proliferation of solar vehicles.

[6] Markert, J., Kutter, C., Newman, B., Gebhardt, P., & Heinrich, M. (2021). Proposal for a Safety Qualification Program for Vehicle-Integrated PV Modules. *Sustainability*, *13*(23), 13341.

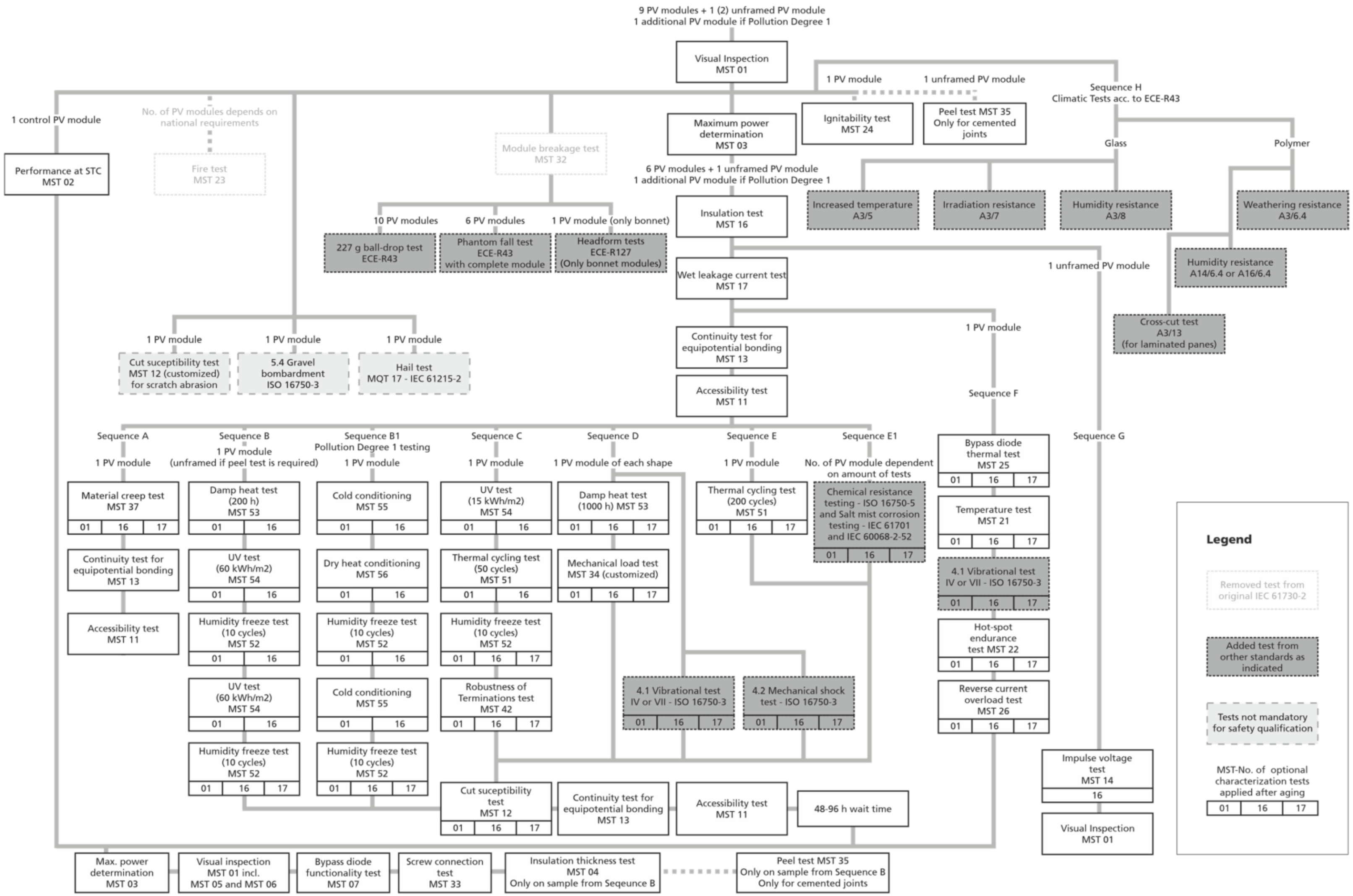


Figure 5-4 Flow chart of test sequences for VIPV presented by the Fraunhofer Institute for Solar Energy Research and TNO[6]

5.4 Summary

Table 5-1 Summary of VIPV regulatory framework, missing gaps and roadmap

<table>
<tr><th>Regulatory Framework</th><th>Missing Gaps</th><th>Roadmap</th></tr>
<tr>
<td>Electrical functionality framework:
- IEC 61730
- IEC 61215
- LVD 2014/35/EU</td>
<td>Consider mechanical load for vehicle use that are not taken into account in conventional PV. For example:
- Mechanical loads in upside down position because of an accident
- Vibrations for bad road conditions
VIPVs are exposed to different environments that could be aggressive, this is not taken into account in conventional PV modules or only when they are located in a specific location</td>
<td rowspan="2">- Lack of dedicated norms or regulations which apply to this field, as it is a relatively new field.
- Study more the hot spot formation in polymer/polymer panels.
Specific regulation related to this field, considering the missing gaps:
- Consider mechanical loads in inverted positions.
- Vibration loads: Consider vibration loads (to simulate door closing impact or poor condition driving road)</td>
</tr>
<tr>
<td>Automotive functionality framework:
- ISO 16750
- ECE 10
- ERE R51
- EU R 1230/2012
- UN R127
- ECE R100
- ECE R155
- Directive 2005/64/EU</td>
<td>Hot spot formation is not considered, and for polymer/polymer panels, that are common in VIPVs are not yet fully studied.</td>
</tr>
</table>

6 AGRIPV PRODUCT STANDARDIZATION

6.1 AgriPV regulatory framework

Agrivoltaics (AgriPV) have various degrees of definition depending on the country. However, in practice, it can be defined as the combined use of land for both agricultural and PV production activities. AgriPV projects are at the crossroads of various topics:

- Agricultural production
- Renewable energy production
- Environmental issues
- Water management

This leads to adding complexity over the development of these projects due to the number of stakeholders implicated. AgriPV projects can be a huge opportunity for either renewable energy development but also agricultural stakeholders. The AgriPV systems could involve different types of installations. Thus, in 2022, a classification was proposed which is shown in Figure 6-1.

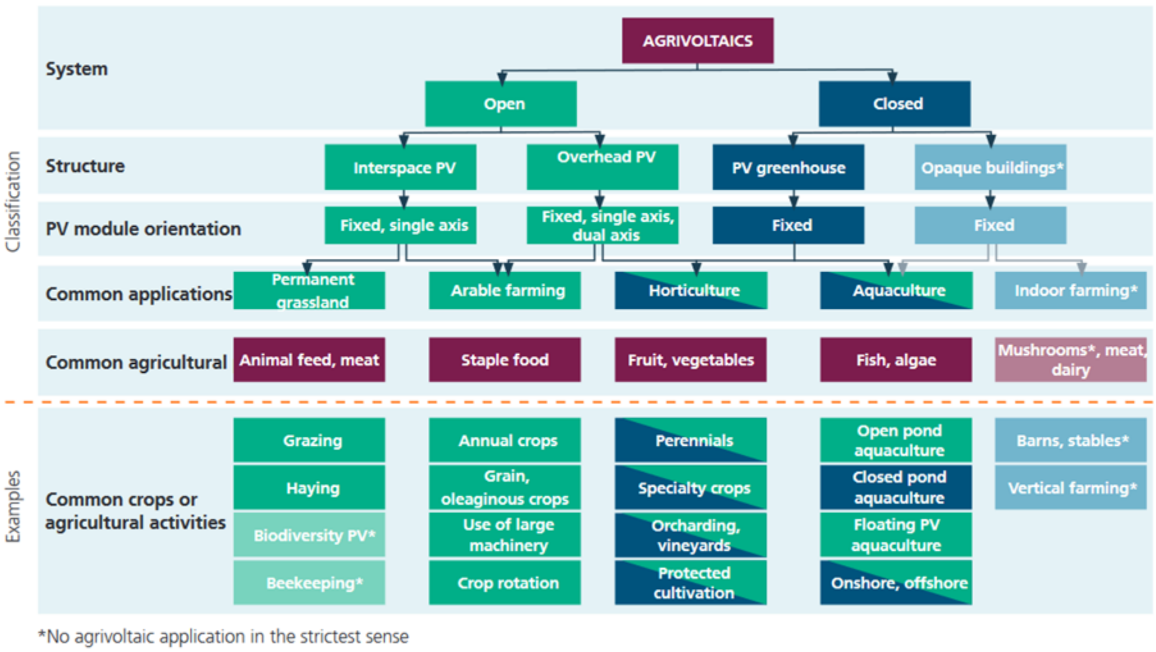


Figure 6-1 Proposed classification of agrivoltaic systems in April 2022 by Fraunhofer ISE

The degree of definition and regulation of AgriPV projects highly depends on the country of interest, Table 6-1 aims at giving a quick overview of the differences between European countries.

Table 6-1 AgriPV definition differences between European countries

		Applications considered in the definition				
Country	**Definition of AgriPV**	**Greenhouses**	**Grazing**	**Interval**	**Vertical**	**Elevated**
Belgium - Brussels	No definition					
Belgium - Flanders	Generation of solar energy on structures above agricultural crops or between crop rows. For local use or delivery to the grid depending on scale. (KULeuven definition)			X	X	X
Belgium – Wallonia	No definition					
France	A solar PV system can be considered agrivoltaic when the solar PV modules are located on the same area of plot as the agricultural production, and when they impact the agricultural production by providing one of the services listed below, without inducing any significant degradation of the agricultural production, or any farm income loss. Services: Climate change adaptation; Hazard protection; Animal welfare; Specific agronomic. The agrivoltaic project must also ensure its agricultural vocation, guarantee the sustainability of the agricultural site throughout its lifetime [..] its reversibility and its adequacy with local and territorial development, while limiting its impact on the environment, the soil and landscapes. [..]	X	X	X	X	X
Germany	Agrivoltaics is the combined use of the same land area for agricultural production as the primary use. and for electricity PV production as the secondary use. (DIN SPEC 91434 definition, referred to by Germany's Renewable Energy		X	X	X	X

	Sources Act (EEG), to define support schemes.)					
Italy	Refers to a photovoltaic system that adopts solutions aimed at preserving the continuity of agricultural and pastoral farming activities, on installation site. Agrivoltaic systems that can, at a minimum, ensure interaction between energy production and agricultural production.	X	X	X	X	X
Netherlands	A form of sustainable agriculture in which crops are grown under panels that generate solar energy, allowing for efficient use of available land and solar energy. The dual use of land must be granted, and the PV production should not affect the agricultural activity. The National Environmental Vision (NOVI) includes a preference for solar energy on roofs. Only in the last instance can we install solar panels on agricultural and natural land.		If grazing activity happens below the PV system (e.g., shelter)			X
Spain	No definition					
Switzerland	Agrivoltaic installations are only allowed in zones where the impact on the landscape is of little importance. Additionally, installation on protected zones can be subject to an obligation for further authorizations					

Regulatory frameworks for AgriPV in different European countries have been described precisely in the public deliverable "D.2.2 – Analysis of regulatory framework applicable to IPV systems" of this project (Seamless-PV). However, this is a general overview of AgriPV Regulatory frameworks:

International Electrical Commission

Regarding electrical safety, AgriPV has to fulfil terrestrial PV aspects that are IEC 61730:2023 and IEC 61215:2021. Apart from that there are some regulations more specific related to Agri that are IEC 60364-7-705:2006 specifies requirements for agricultural and horticultural premises installations or locations, this is used for reference (alternatively HD 60364-7-705:2011), and IEC 62716:2013, this standard describes test sequences useful for determining the resistance of PV modules to ammonia, this norm is the special interest in livestock Agri application. and IEC 62716, this standard describes test sequences useful for determining the resistance of photovoltaic modules to ammonia, this standard is of particular interest in the livestock farming application.

Low Voltage Electrical

In Europe, photovoltaic modules are subject to electrical requirements through their certification under the “Low Voltage Directive 2014/35/EU”, AgriPV is not an exception.

However, unlike other IPV segments, few additional requirements coming from regulations apply to AgriPV modules compared to regular PV modules. National regulations sometimes consider special support schemes or conditions for the realization of a specific project.

Construction Product

Some AgriPV systems (e.g., livestock shed), could be classified as structural installations. Those, generally use glass/glass photovoltaic modules and are subject to the requirements for construction products relating to the use of glass in the construction industry under the “Construction Products Regulation (EU) 305/2011”.

European normative

In greenhouse application EN 16153:2013+A1:2015 norm is used, this European Standard specifies the requirements for translucent multiwall flat polycarbonate (PC) sheets for use for indoor and outdoor use in walls, roofs, and ceilings. In addition, EN 13031-1:2020 is applied regulates mechanical actions on greenhouses, calculation bases, ultimate service states, tests, durability, maintenance, and repair.

German Technical Building Regulations

Unlike conventional ground-mounted PV systems, agrivoltaic systems are expected to be navigated by machinery. To ensure that it is safe to work under the glass/glass PV modules, the planning, measurement, and design of the PV modules is subject to particular requirements. These are set out in the Administrative Provisions of the Technical Building Regulations (Verwaltungsvorschriften der Technischen Baubestimmungen, VwV TB) of each of the federal states in the case of Germany. In addition, the requirements regarding the usability of construction products set out in the building code of each state (Landesbauordnung, LBO) must be observed.

Italian National Standardization

At the moment, the only existing standard developed specifically for AgriPV is UNI/PdR 148:2023 “Sistemi agrivoltaici - Integrazione di attività agricole e impianti fotovoltaici”, recently developed by the Italian institution UNI. Thus, there is no common European standard for AgriPV and there are no national standards other than the Italian standard.

6.2 Missing gaps

Regulatory frameworks regarding AgriPV projects need to be detailed and standardised at a European level to be able to assess the benefits of these projects on agriculture.

Each European country has its technical requirements to allow the permitting of the projects:

- Minimum height,
- Ground covering ratio
- % of lost in yield allowed
- % of lost arable land compared to project area

To define these criteria, governments rely on agricultural stakeholders, scientific studies on working installations and scientific literature. However, the diversity of parameters to assess in each project leads to difficulty in the implementation of general requirements.

There is a huge variety in the technologies of panels that are used in AgriPV:

- Elevated panels: fixed of tracking
- Vertical panels
- Fixed structure for grazing
- Greenhouses

Each structure has a different shading profile that can impact in various ways crop yield. The use of classic or semi-transparent panels is also something to integrate.

From the electrical viewpoint, further work should be done in the protection against electrical shock and fire. In this sense, a particular gap was detected by Statkraft company in 2022, in the framework of the IEC standardization body on Electrical Safety of PV systems in agricultural settings. The gap is related to the electrical protections described in IEC 60364-7-705:2006 and its unsuitability for PV installations. The document is now under revision for AgriPV purposes.

The diversity of pedoclimatic conditions (classification by soil type and climate) adds up to the diversity of PV. Soil composition and hydric stress play an important role in the final impact of the PV structures on agricultural parameters (yield, quality of crops…).

Finally, agricultural practices are key in the analysis: the type of crops that are used but also technical arrangements.

All of these parameters harden the analysis and implementation of a general framework. Feedbacks from more working installations are needed but also tools to assess the impact of each project depending on its characteristics. Critical gaps are also to be noted in the requirements of these projects, often based on traditional PV plants.

6.3 Roadmap

AgriPV projects are developing across Europe at a high pace. Local authorities often tend to assess these projects based on traditional ground mounted PV plant requirements. Adaptation of the already implemented framework is crucial to the development of these kinds of projects.

When designing an AgriPV project, different aspects have to be taken into account:

- Land Regulation
- Agricultural sustainability
- Remuneration systems
- Fire risk management
- Electrical risk management

All these aspects and factors to be taken into account change considerably from one country to another, even from one project to another within the same country, for example depending on crops. This makes the process very difficult; efforts should be made to facilitate this.

Beyond this, the impact of these risks on PV installations should be further studied, as there is not much knowledge on this issue to date. The gaps already identified in relation to electrical protections are being further studied by TC64 (responsible for this standard).

6.4 Summary

Table 6-2 Summary of AgriPV regulatory framework, missing gaps and roadmap

<table>
<tr><th>Regulatory Framework</th><th>Missing gaps</th><th>Roadmap</th></tr>
<tr><td>Electrical part:
- IEC 61215
- IEC 61730
- IEC 60364
- IEC 62716
- LVD 2014/35/EU</td><td>- Electrical protections described in IEC 60364-7 its unsuitable for Agri purposes.</td><td rowspan="3">- Change the IEC 60364 norm to be applicable.
- The risks of adding PV installations in Agri activities should be further studied.
- Adaptation of the already implemented framework.</td></tr>
<tr><td>Regulatory related to Agricultural activity*:
- EN 16153 – Light transmitting
- UNE-EN 16153:2013+A1:2015
*There is no specific regulation</td><td>Regulation is missing, and the diversity of parameter, made difficult the implementation of general requirements.</td></tr>
<tr><td>Regulatory specific to AgriPV in Italy:
UNI/PdR 148:2023</td><td>Deeper analysis is needed</td></tr>
</table>

7 CONCLUSIONS

With the work carried out, it can be concluded that the current regulation of IPV products is not sufficient and lags behind the technology. Further research is needed to create, improve, and unify the regulatory framework in Europe for each of these products in order to ensure the safety of these technologies and to facilitate the entry of these products into the market.

In a general overview, it was found that the more technologically mature the products are, the more they are regulated, as in the case of BIPV for which there are European and international technical standards such as EN50583 or IEC63609. This knowledge also makes legal loopholes more visible and easier to identify and therefore facilitates the planning the future work to progress towards an IPV-specific standardisation framework. On the contrary, in less mature products, regulation is still not well defined, and gaps are not identified, so there is still a long way to go, AgriPV being the clearest example of this among the sectors analysed in this report. For Agri-PV and VIPV the IEA PVPS Program is running a new working group and a task respectively to clarify expected/possible benefits and requirements for PV-powered vehicles and AIPV and to identify barriers and solutions to satisfy the requirements.

The findings of this work will serve to define the standardisation activities in task 6.10 of the Seamless-PV project, but beyond that it will also guide product developers through the needs and specificities of each IPV segment, to help manufacturers assess the compliance of their products with the standards and what considerations they need to take into account when designing their solutions. Most importantly, this analysis is a step on the long road toward establishing a recognised standardisation framework in different IPV domains that will reduce the perception of risk and facilitate the market penetration of these technologies.

Seamless-PV

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Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

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Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI