Seamless-PV

D2.1 – IPV market analysis and identification of stakeholders' needs

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SEAMLESS-PV PROJECT

A novel manufacturing process for integrated photovoltaics

Integrated photovoltaics (IPVs) have demonstrated their success and impact in their use as building-integrated photovoltaics. They are also considered promising in several other 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

Four main segments for IPV are listed, described and analysed in this deliverable:

- Building Integrated PV (BIPV),
- Infrastructure Integrated PV (IIPV),
- Agri PV (APV)
- Vehicle Integrated PV (VIPV)

BIPV can be considered the most mature integrated PV segment. Installed capacity for BIPV is mainly driven by simplified BIPV for residential roof installations. In addition to the abovementioned drivers, the BIPV segment has also developed in some cases pushed by specific and attractive incentives (mostly around one decade ago in France, Italy and Switzerland). Available solutions in this segment showcase a great variety of technical, economic and visual characteristics from in-roof mounting PV systems relying on conventional PV modules through the use of specific mounting structures through building accessories-integrated PV to patterned, coloured and semi-transparent BIPV façades. [1] [2] [3]

BIPV stakeholders include construction product manufacturers, BIPV product manufacturers, PV layer manufacturers, consultant/BIPV experts, architects, construction and engineering companies, authorities, landlords or project developers.

Taking into account the market potential[1], the cost sensitivity and the need for specific requirements, it is identified that the following BIPV subsegments are the most relevant to SEAMLESS-PV

- Discontinuous BIPV roofing (roof tiling solutions)
- Skylights
- Curtain wall façade
- Rainscreen façade
- Insulating façade cladding
- Balustrades, balconies and other accessories

Other analysed BIPV segments included simplified BIPV roofing which do not require any specific requirements and are the most cost sensitive.

IIPV leverages surfaces on urban- and transport-related infrastructures (lights, bus shelter, roads, …) On some IIPV segments, MW-scale installations are already being seen, primarily driven by PV noise barriers and commercial carports. [4] [5] In addition to IPV-specific drivers, regulatory push can be mentioned as in some countries, obligation to install solar carports for new large parking lots are being introduced or have already entered into force.
IIPV stakeholders include mounting system manufacturers, IIPV product manufacturers, construction and engineering companies, project developers, noise barriers designers / manufacturers, road / rail managing companies or carport owners.

[1] Market potential refers to the expected short to medium term market development perspectives of a given segment or use case and is based on a qualitative assessment as a quantitative market potential assessment per IPV segment will be conducted in Task 2.4

Taking into account the market potential, the cost sensitivity and the need for specific requirements, it is identified that the following IIPV subsegments are the most relevant to SEAMLESS-PV

- PV noise barriers
- Commercial carports
- Residential carports

Other analysed IIPV segments included PV road roofing, PV road pavement and rails crossties, bus shelters and public lighting which are considered as little relevant in the frame of the SEAMLESS-PV project because of limited need for specific requirements and limited market potential.

Agri PV systems are characterised by the colocation of an agricultural activity and a PV production activity. AgriPV technologies which resemble conventional ground-mounted PV can be considered as very mature but often fail to meet the criteria to categorize as AgriPV. According to definitions in Italy for example, as per law, two main AgriPV configurations are defined: PV systems with elevated modules (minimum height 2,1m) and PV systems deployed between crop rows (fixed or trackers). In France, according to the national agency ADEME a solar PV system can be considered AgriPV when the solar PV modules are collocated with the agricultural production, and provide one of the following services without inducing any significant degradation of the agricultural production or any farm income loss (climate change adaptation, hazard protection, animal welfare, …). Additional constraints apply such as the possible involvement of farmers in the project design or investment, sustainability, reversibility and adequacy with local and territorial development. Other technologies are also developing although they can be considered less mature especially with regards to the knowledge of synergies between the agricultural and the PV production activities (quantification of co-benefits, most suited crops, system design optimization, dynamic shading management optimization). The main drivers for APV are land resource optimization, diversification of income streams for farmers and protection of crops from droughts and other climatic event. In the present deliverable, a lose definition of AgriPV (simultaneous agricultural crop production and PV electricity generation), also used by Fraunhofer ISE, is taken with the aim to present a greater number of PV system designs. [5]

APV stakeholders include mounting system manufacturers, AgriPV product manufacturers, agronomists, EPCs, farmers, project developers, dynamic shading management system manufacturers or optimization solution providers.

Taking into account the market potential, the cost sensitivity and the need for specific requirements, it is identified that the following APV subsegments are the most relevant to SEAMLESS-PV

- Vertical PV
- Elevated PV (no tracking)
- Elevated PV (with tracking)
- PV Greenhouses

Other analysed APV segments included ground-mounted PV with grazing which are considered as little relevant in the frame of the SEAMLESS-PV project because of limited need for specific requirements.

VIPV still remains limited although numerous established automotive manufacturers, including Nissan, Hyundai, and Fisker, now offer VIPV integration as an optional feature in their vehicles. Simultaneously, pioneering and innovative companies like Lightyear and Sono Motors have taken the lead by bringing to market their first vehicles designed with PV integration as a fundamental component.

VIPV stakeholders include vehicle designers, polymer solar panel manufacturers, vehicle body manufacturers, VIPV product manufacturers or vehicle assemblers.

Taking into account the market potential, the cost sensitivity and the need for specific requirements, it is identified that the following VIPV subsegments are the most relevant to SEAMLESS-PV

- Passenger cars
- Buses
- Commercial Vehicles (further differentiation will be made to distinguish between Light Commercial Electric Vehicles and Heavy Commercial Electric Vehicles, recognizing the distinct challenges that each of these subcategories presents).

Other analysed VIPV segments included boat-integrated PV, train-integrated PV, aircraft-integrated PV or cargo bike-integrated PV which are considered as little relevant in the frame of the SEAMLESS-PV project because of their limited commercial potential.

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Index

List of tables

List of figures

1 INTRODUCTION

1.1 Description of the deliverable content purpose

The aim of this deliverable is to provide a detailed inventory and characterization of IPV market use cases, mapping of involved stakeholders in the value chain(s), as well as drivers and obstacles. The work conducted can then serve as a basis for subsequent SEAMLESS-PV deliverables (e.g., D1.1).

First an inventory and description of IPV market segments (BIPV, IIPV, VIPV, AGRIPV), is provided with insights on their development status and maturity in Europe.

Then typical use cases for each of these market segments are defined and characterized in terms of type of products, configurations, performances, cost range, size, aesthetics, objectives and synergies of use. The market segment is further analysed by focusing on the market potential (this refers to the expected short to medium term market development perspectives of a given segment or use case and is based on a qualitative assessment as a quantitative market potential assessment per IPV segment will be conducted in Task 2.4), the cost sensitivity and the special requirements needs. A SWOT analysis is also included allowing to identify key drivers and obstacles to development. This IPV use cases analysis allow to highlight where technical gaps which could benefit from innovative flexible production lines developed within the SEAMLESS-PV project exist.

Eventually, for each of these market segments the involved stakeholders along the entire value chain are mapped, and their role, their needs and their expectations are presented.

1.2 Reference Material

Not applicable

1.3 Relation with other activities in the project

The short listed IPV use cases in this deliverable will serve as the basis for the work in several other work packages and tasks.

1.4 Abbreviation list

Table 1.1. Abbreviation list

Abbreviation	Meaning
APV	Agri PV
BAPV	Building Applied PV
BIPV	Building Integrated PV
EV	Electric Vehicle
IIPV	Infrastructure Integrated PV
IPV	Integrated PV
O&M	Operation and Maintenance

PVNB	PV Noise Barrier
VIPV	Vehicle Integrated PV

2 IPV OVERVIEW

Four main segments for IPV are considered in this deliverable:

- Building Integrated PV (BIPV),
- Infrastructure Integrated PV (IIPV),
- Agriculture Integrated PV (AgriPV or APV)
- Vehicle Integrated PV (VIPV).

With the exception of VIPV, the development of integrated PV (IPV) is mainly motivated by scarcity of available surfaces to deploy mainstream PV. Integrated PV aims at leveraging dual use, at limiting land artificialisation and reduce conflict with other economic activities such as agriculture. Hence, IPV has mostly developed in countries or regions where population density is high or where land is scarce or very expensive. Additional drivers for the IPV market segments such as aesthetics, or more specifically charging frequency reduction for VIPV and co-benefits (water usage reduction, protection from hail and rain) for AgriPV can be added.

BIPV can be considered the most mature integrated PV segment driven by simplified BIPV for residential roof installations. In addition to the abovementioned drivers, the BIPV segment has also developed in some cases pushed by specific and attractive incentives (mostly around one decade ago in France, Italy and Switzerland). Available solutions in this segment showcase a great variety of technical, economic and visual characteristics from in-roof mounting PV systems to patterned, coloured and semi-transparent BIPV façades.

IIPV leverages surfaces on urban- and transport-related infrastructures (lights, bus shelter, roads, …) On some IIPV segments, MW-scale installations are already being seen, primarily driven by PV noise barriers and commercial carports. In addition to IPV-specific drivers, regulatory push can be mentioned as in some countries, obligation to install solar carports for new large parking lots are being introduced or have already entered into force.

The term "AgriPV" has stirred some debate regarding its definition and the corresponding legal framework in various countries. In certain member states, AgriPV systems are defined as solutions that are integrated into existing agricultural activities or where agriculture serves as the primary focus. In Italy for example, definitions of agrivoltaics have been introduced by the law of 29 July 2021. Agri PV are "innovative integrative solutions, with elevated PV modules which do not compromise agricultural activities on the ground and with the constraint that the area of non-agricultural activity is limited to a maximum of 30% of the total project area. Two main AgriPV configurations are defined: PV systems with elevated modules (minimum height 2,1m) and PV systems deployed between crop rows (fixed or trackers). In France, according to the national agency ADEME a solar PV system can be considered AgriPV when the solar PV modules are collocated with the agricultural production, and provide one of the following services without inducing any significant degradation of the agricultural production or any farm income loss (climate change adaptation, hazard protection, animal welfare, …). Additional constraints apply such as the possible involvement of farmers in the project design or investment, sustainability, reversibility and adequacy with local and territorial development. Some AgriPV technologies which resemble conventional ground-mounted PV can be considered as very mature but often fail to meet the criteria to categorize as AgriPV. Other technologies are also developing although they can be considered less mature especially with regards to the knowledge of synergies between the agricultural and the PV production activities (quantification of co-benefits, most suited crops, system design optimization, dynamic shading management optimization). The main drivers for APV are land resource optimization, diversification of income streams for farmers and protection of crops from droughts and other climatic event. In the present deliverable, a lose definition of AgriPV (simultaneous agricultural crop production and PV electricity generation), also used by Fraunhofer ISE, is taken with the aim to present a greater number of PV system designs. [5]

VIPV still remains limited although numerous established automotive manufacturers, including Nissan, Hyundai, and Fisker, now offer VIPV integration as an optional feature in their vehicles. Simultaneously, pioneering and innovative companies like Lightyear and Sono Motors have taken the lead by bringing to market their first vehicles designed with PV integration as a fundamental component.

Although market development pace and status differ depending on the considered IPV segment, and the country their market is globally limitedly developed today compared to conventional PV applications such as BAPV (Building Applied Photovoltaics) or ground-mounted PV. In most countries there are no IPV-specific incentives thus making it very difficult or impossible to precisely track installed capacity in these segments specifically. Estimates show that around 14 GWp as AgriPV was installed worldwide as of 2021 [5] most of which installed in China and Japan, with only a few tens of MW in Europe in 2021 [5] Researchers in Mass-IPV project estimated the cumulative BIPV market in Europe in 2022 at around 7 GW [6] The market potential for IPV applications will be investigated in more details in the frame of Task 2.4.

3 BIPV

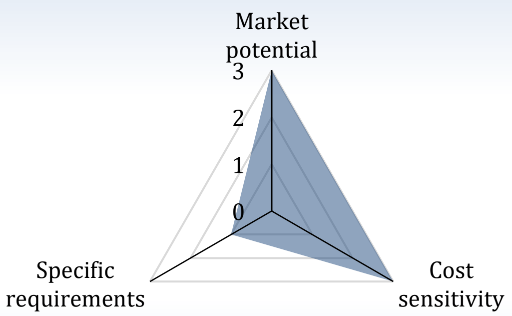
3.1 BIPV use cases

3.1.1 Discontinuous BIPV roofing (e.g. simplified BIPV roofing)

According to the IEAPVPS Task 15 categorization, discontinuous BIPV roofing is "typically a pitched/sloped opaque envelope part consisting of small elements (tiles, slates, shingles, etc.)". [7] Among discontinuous BIPV roofing, simplified BIPV roofing encompasses two systems that are more adapted than traditional building applied PV (BAPV) but cannot be considered as "full" BIPV.

- In-roof mounting systems, which are roofing systems designed to welcome conventional, rigid PV modules, which can be frameless or not. While these systems fulfil some functions usually devoted to other building materials (thus fitting the dual functionality criteria of integrated PV systems), their aesthetical integration is not optimal due to the use of regular modules.
- Lightweight modules, which are designed to fit existing roofs (often seamed metal roofing) with limited load bearing capacities for example. Both rigid and flexible products exist. Examples include membranes and rolls, using crystalline silicon or thin-film technology. They can be placed on surfaces without any mounting system, most of the time by simply sticking them onto the roof. In some cases, the addition of the PV layer can be done at the manufacturing level of the roof, making it a "true" BIPV product.

Figure 3.1. In-roof mounting BIPV system (top)



0: criteria evaluated as low / 3: criteria evaluated as high (evaluation is relative to the other BIPV use cases)

Strengths: Mature technologies. Can accommodate different roof configurations. In-roof mounting systems can use conventional mainstream PV modules.

Weaknesses: Lack of integration (aesthetic or functional) as building component.

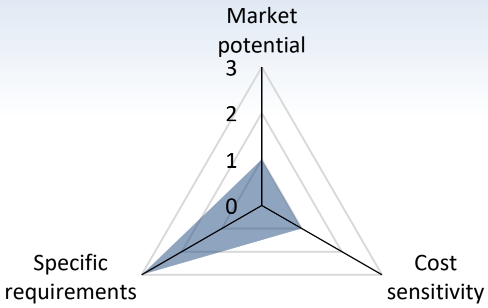
Opportunities: These solutions stand a good chance of remaining on the market due to their light weight and cost-effectiveness for building structures of commercial, industrial and agricultural applications.

Threats: These partially integrated solutions might not be considered as BIPV in the eyes of some policies or support schemes.

3.1.2 Discontinuous BIPV roofing (including roof tilting solutions, shingles, etc)

This category includes all integrated roofing solutions, which can be seen as an evolution of in-roof mounting systems. In those solutions, the roofing is made of specifically designed roof components which include PV characteristics.
Those components are designed to be integrated both aesthetically and in terms of functionality, including thermal insulation for example. They can resemble traditional modules but with better functional and aesthetic integration through colours notably, or mimic usual building elements such as tiles, shingles or seamed metal sheets, but integrating PV capabilities. Roof solutions are usually aimed at the residential market.

Figure 3.2. Different examples of BIPV tiles



0: criteria evaluated as low / 3: criteria evaluated as high (evaluation is relative to the other BIPV use cases)

Strengths: Full integration leading to lower cost sensitivity and higher acceptance of the technology. Drives the demand for customized manufacturing.
Weaknesses: More expensive than in-roof mounting BIPV
Opportunities: Near zero energy building policies and other policies encourage development of all BIPV products. These technologies are expected to gain maturity over the coming years.
Threats: Very large and diversified products exist, with no real benchmark which complicates standardization.

3.1.3 Skylights

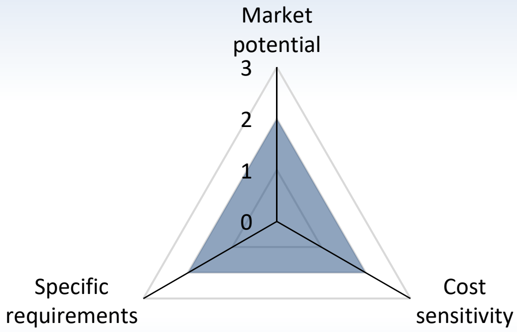
Also called glazed roofing or glazing, they bring very different benefits, challenges and requirements compared to opaque roofing solutions mentioned earlier.

A photovoltaic skylight generates clean and free energy at the same time that it provides bioclimatic properties of thermal comfort. It has an optimized solar filter, which absorbs almost all of the ultraviolet and infrared rays, which are harmful to the occupants of the building.

Transparency is key to allowing light to enter, but in some cases, shading can be desired as well. A tradeoff between lighting and PV output is necessary.

Figure 3.3. Different examples of BIPV skylights

These solutions are often used in parts of the buildings that require less strict performances in terms of thermal insulation for example. They are usually aimed at the non-residential market, for larger buildings.



0: criteria evaluated as low / 3: criteria evaluated as high (evaluation is relative to the other BIPV use cases)

Strengths: Full integration leading to lower cost sensitivity and higher acceptance of the technology. Drives the demand for customized manufacturing.

Weaknesses: Relatively costly technology.

Opportunities: Near zero energy building policies and other policies encourage development of all BIPV products. These technologies are expected to gain maturity over the coming years. Solar carports are becoming an obligation for new large parking lots in a series of countries.

Threats: Very large and diversified products exist, with no real benchmark which complicates standardization.

3.1.4 Curtain wall façade elements

Also called non-ventilated or "warm" façade elements, curtain wall façade elements are expected to boast thermal insulation capacities, and are often (semi-)transparent, acting as cladding, outside layer of the building, and light source simultaneously.

Compared to rainscreen façade elements (see next Section), curtain wall façade elements combine more functionalities, but have a higher cost sensitivity due to these additional requirements.

They are usually aimed at the non-residential market, for high buildings such as skyscrapers.

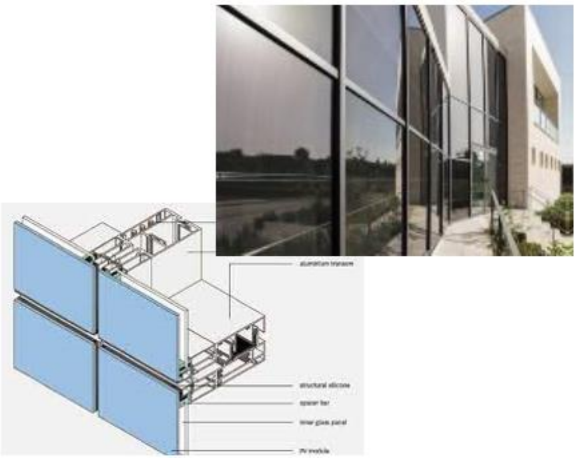
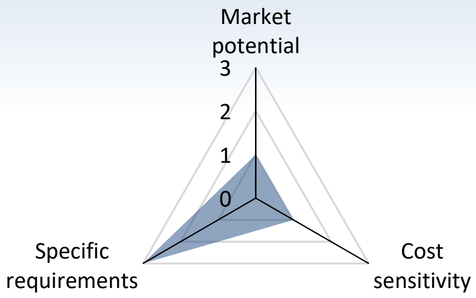


Figure 3.4. Examples and illustration of a BIPV curtain wall



0: criteria evaluated as low / 3: criteria evaluated as high (evaluation is relative to the other BIPV use cases)

Strengths: Full PV integration is necessary for this configuration. Transparency and coloring needs drive the demand for specific modules. Highly customizable.

Weaknesses: Current elevated costs (compared to in-roof mounting BIPV) can prove prohibitive. Integration of PV into warm facade elements or replacement of PV module in case of maintenance is not trivial.

Opportunities: Near zero energy building policies and other policies encourage development of all BIPV products. Customization possibilities enable the acceptance of this type of product.

Threats: Acceptance and inclusion into conventional architecture and construction processes are progressing slowly.

3.1.5 Rainscreen façade elements

Rainscreen are also called "cold" or ventilated façade elements as there is a ventilation space between the façade cladding and the second layer of façade elements, creating a capillary break to allow drainage and evaporation, making the water/air barrier more effective. BIPV rainscreen elements can replace traditional rainscreen elements, fulfilling its base functions as well as electricity generation. As there is a second layer assuming thermal insulation duties, the rainscreen itself is not meant to provide thermal insulation (although it can in some cases), therefore having less requirements and a lower cost sensitivity compared to curtain wall BIPV elements.

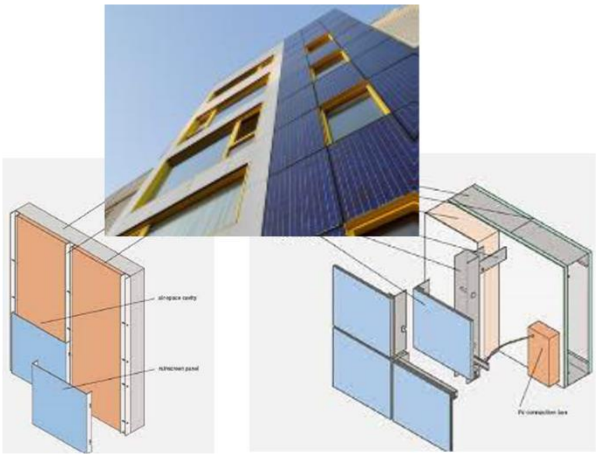
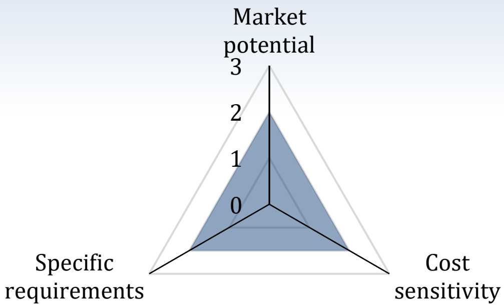


Figure 3.5. Examples and illustration of a BIPV ventilated facade

They are also mostly aimed at the non-residential market but are also relevant for multifamily apartment buildings.



0: criteria evaluated as low / 3: criteria evaluated as high (evaluation is relative to the other BIPV use cases)

Strengths: Full PV integration is necessary in this configuration. Transparency and coloring needs drive the demand for specific modules. Highly customizable.

Weaknesses: Current elevated costs (compared to in-roof mounting BIPV) can prove prohibitive.

Opportunities: Near zero energy building policies and other policies encourage development of all BIPV products. Customization possibilities enable the acceptance for this type of products. Renovations of high-rise buildings with no transparency needs constitute an important market potential.

Threats: Acceptance and inclusion into conventional architecture and construction processes are progressing

3.1.6 Insulating façade cladding system

Insulating façade cladding is a really common system used in the last years to improve the thermal requirement of the building. The work is mainly done with insulating panels fixed on the wall and plastering the external surface.

The system shown in this chapter has the same concept but it is made with a dry façade system: prefabricated panels fixed on metal supports. The panels are composed by a coupling of colour fibre reinforced mortar layer and insulating panel. The panels can be integrated with a third layer: the PV one.

The system suit for all types of building: hospitality, housing, commercial, public buildings.

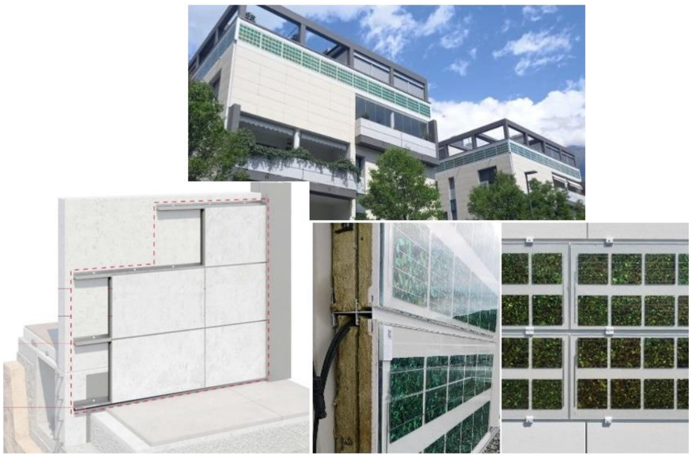
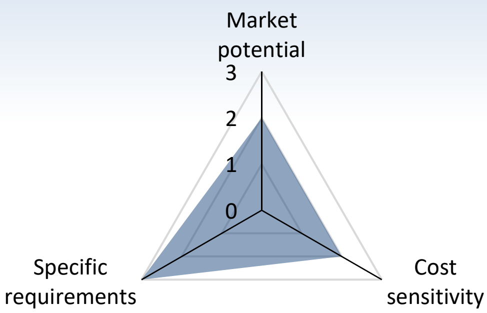


Figure 3.6. Examples of a BIPV insulating façade cladding system (Source: BIPVBOOST)



0: criteria evaluated as low / 3: criteria evaluated as high (evaluation is relative to the other BIPV use cases)

Strengths: Full PV integration is necessary in this configuration. Transparency and coloring needs drive the demand for specific modules.

Weaknesses: Current elevated costs (compared to in-roof mounting BIPV) can prove prohibitive.

Opportunities: Near zero energy building policies and other policies encourage development of all BIPV products. Customization possibilities enable the acceptance for this type of products. Renovations of high-rise buildings with no transparency needs constitute an important market potential.

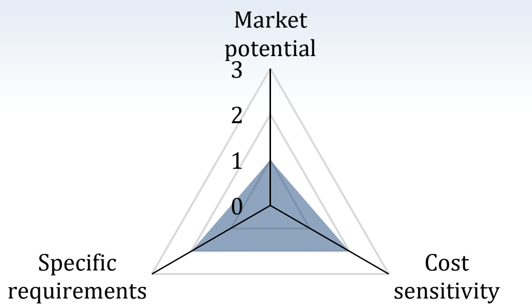
Threats: Acceptance and inclusion into conventional architecture and construction processes are progressing slowly.

3.1.7 External integrated devices (balustrades, balconies and other accessories)

This category includes all building elements that can be considered non-essential to the building, but which allow for BIPV products that combine electricity generation with another function useful to the building such as shading or fall protection.

While balustrades and balconies are the most common, shading elements (e.g. solar cells integrated on blinds), louvers or solar cells integrated to safety glass are other examples of such "accessories" to the building.

Figure 3.7. Example of a IPV shadings (top left)



0: criteria evaluated as low / 3: criteria evaluated as high (evaluation is relative to the other BIPV use cases)

Strengths: Those products are easier to place than roof or façade elements. Transparency and colouring needs drive the demand for specific modules.

Weaknesses: As they are of secondary importance, the market and acceptance for such products is limited.

Opportunities: Near zero energy building policies and other policies encourage development of all BIPV products. Buildings with difficult surfaces to integrate other solutions are an opportunity to improve the acceptance and the integration.

Threats: A variety of products exist, with no real benchmark or definition, preventing swift.

3.1.8 Summary

Table 3.1. Overview of BIPV use cases

	Market potential	*Specific requirements*	*Cost sensitivity*	*Final Appreciation for SEAMLESS-PV*
Discontinuous BIPV roofing (simplified BIPV)	**3**	**1**	**3**	**Not relevant**
Discontinuous BIPV roofing (roof tiling solutions)	**1**	**3**	**1**	**Strongly relevant**
Skylights	**2**	**2**	**2**	**Relevant**
Curtain wall façade	**1**	**3**	**1**	**Relevant**
Rainscreen façade	**2**	**2**	**2**	**Strongly Relevant**
Insulating façade cladding	**2**	**3**	**2**	**Relevant**
***Balustrades & balconies* and other accessories**	**1**	**2**	**2**	**Relevant**

Taking into account the aforementioned criteria, only subsegments relevant to SEAMLESS-PV (i.e., where SEAMLESS-PV can contribute to reduce the technical gap) will be further studied. In other words, subsegments who require specific manufacturing, whose cost sensitivity is acceptable, and technology mature enough to have realistic market potential.

The selected subsegments are:

- **Discontinuous BIPV roofing (roof tiling solutions)**
- **Skylights**
- **Curtain wall façade**
- **Rainscreen façade**
- **Insulating façade cladding**
- **Balustrades, balconies and other accessories**

3.2 BIPV stakeholders

3.2.1 BIPV value chain

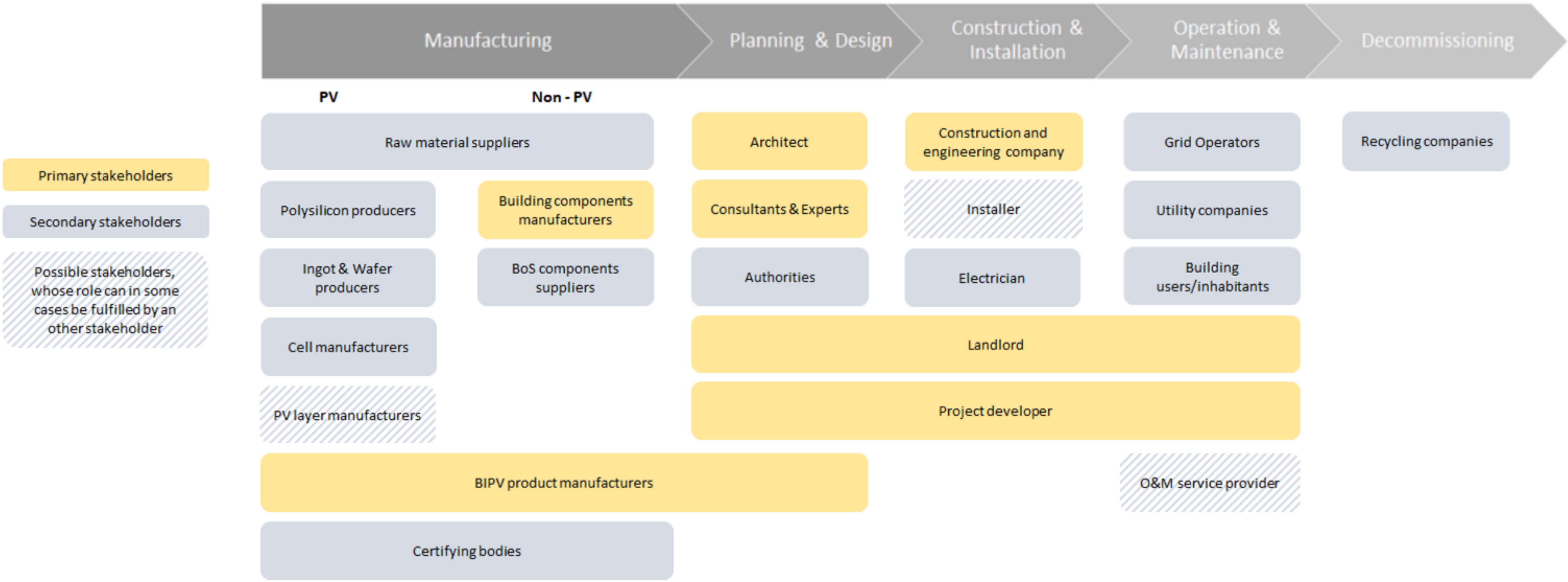


Figure 3.8. Overview of BIPV value chain

3.2.2 BIPV stakeholders' roles

Table 3.2 BIPV stakeholders' roles

	Steps in the value chain			
Stakeholders	**Manufacturing**	**Planning & Design**	**Construction & Installation**	**Operation & Maintenance**
Construction product manufacturer	Produces generic building components, both those potentially replaced by BIPV products and others.	May be involved in the development of tailor-made solutions to accommodate BIPV products into the building.	/	/
BIPV product manufacturer	Produces specific BIPV modules for building integration with special module requirements.	BIPV product manufacturers should be involved in the development of tailor-made solutions to analyse whether the customer's requirements are feasible for the manufacturing process and help designers choose the best solution in terms of manufacturing.	BIPV product manufacturers usually provide an installation guide or a product manual to avoid possible issues.	The manufacturer usually provides some recommendations to the clients in the product manual for operation & maintenance.
PV layer manufacturer	Produces specific PV layers for BIPV products.	PV layer manufacturers may be involved in the development of tailor-made solutions.	/	/
Consultant/BIPV expert	Bridge between the manufacturing and planning stages. Supports The architects, the electricians, and the project developer to identify the optimal strategies at the preliminary stage, which is key for BIPV projects.		/	/
Architect	Architect can sometimes be relevant in the manufacturing process when customization is an important factor.	Responsible for the delivery of the conceptual project and evaluation of design alternatives. Defines construction guidelines and special module requirements.	Directs construction and installation works. Ensures the project is being implemented as expected.	/
Construction and engineering company	/	Responsible for feasibility studies and preliminary civil and electrical engineering work, e.g. fulfil requirements for fire prevention.	Construction of the project in accordance with the project conceptualization. Responsible for IPV solution installation.	/
Authorities	/	Approve concept for compliance with building regulations.	/	/
Landlord	/	If the landlord is a significant shareholder of the PV system, they will have a role in the development of a project.	The landlord can have their say on the system installation.	Responsible for safeguarding the PV system's integrity.
Project developer	Orders specific product manufacturing for a project.	Selection of design and development of technical model of the BIPV system, including energy yield and self-sufficiency aspects.	Engineering and technical drawing, construction work planning, permitting and management of construction and installation works.	Can be responsible for O&M.

3.2.3 BIPV stakeholders' needs

Table 3.3 BIPV stakeholders' needs

	Steps in the value chain				
Stakeholders	**Manufacturing**	**Strategy (pre-design)**	**Planning & Design**	**Construction & Installation**	**Operation & Maintenance**
Building components manufacturers	Clear client specifications for tailor-made products	/	Clear communication with designers and project developers for custom-made products	/	/
BIPV product manufacturers	Tailor-made products require clear client specifications and technical information about the installation surface/space.	/	Clear communication with designers and project developers is imperative for custom product development. Technical data from the client and final project design confirmation are required before commencing production.	Communication with installers to receive updates on installation completion and identifying any damaged units requiring replacement.	/
PV BoS manufacturers (inc. electric and electronics)	Clear client specifications, particularly for tailor-made products	/	Clear communication with designers and project developers for custom product development	/	/
Architect	/	Considering BIPV early on in the design stage	Building design and plans. Communication with BIPV development stakeholders for IPV product integration	Maintaining a clear view of construction progress and providing regular consultation to offer guidance.	/
Construction and engineering company	/	/	Effective communication with developers and access to plans and specifications for IPV and non-IPV components for construction planning	Communication with subcontractors (façade/roof builders, electricians, PV installers)	/
Authorities	/	/	Communication with the construction/engineering company is necessary for approval.	/	/
Landlord	/	/	Understanding of the limitations, responsibilities, and benefits of the system. Consultation regarding PV implications is required.	Ensuring communication on the construction and installation timeline	May need training in PV system maintenance if responsibility falls on them
Project developer	Information about availability and manufacturing time of desired products	Considering BIPV early on in the design stage	A clear understanding of the status, progress, and needs of other involved stakeholders	Maintaining a clear understanding of the status, progress, and needs of all involved stakeholders. Facilitating communication among various stakeholders to ensure a seamless connection.	Establishing contact with a third-party operation and maintenance (O&M) company if one is needed

4 IIPV

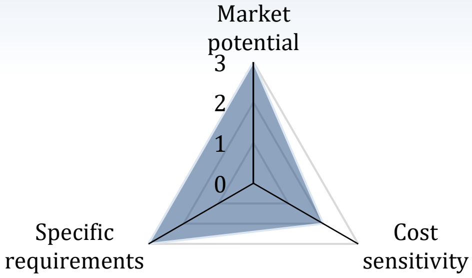
4.1 IIPV use cases

4.1.1 PV Noise barriers

The inaugural Photovoltaic Noise Barrier (PVNB) was showcased in 1989 adjacent to the A13 motorway in Switzerland, featuring a 100-kilowatt (kW) system constructed using conventional modules affixed to pre-existing noise barrier structures (retrofit installation). The adoption of PVNB technology subsequently expanded to various European nations, notably Germany and the Netherlands. Presently, the industry witnesses the development of multi-megawatt (MW) scale installations.

Figure 4.1. Cassettes PVNB along railway (top) Bifacial vertical PVNB along highway (bottom)

Numerous configurations are available, allowing modules to be either top-mounted (or berm-mounted) or seamlessly integrated into the noise barrier. The latter approach seeks to amalgamate acoustic efficacy with energy generation, thus necessitating the utilization of specialized integrated PV modules. The market potential for Photovoltaic Noise Barriers (PVNB) is substantial, given the extensive available spaces alongside highways and railways. Additionally, vertical bifacial configurations enable the harnessing of energy from both North-South oriented roads and East-West roads, which traditionally employ South-oriented modules. Beyond the imperative noise abatement performance criteria, the customization of modules becomes significant, as these modules must seamlessly integrate into diverse designs and withstand external factors, including dust and varying weather conditions, to optimize power output.



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Strengths: Relatively mature technology, with proven examples and a large untapped potential area, combining into a significant market potential. Integrated solutions exist and should continue to develop.

Weaknesses: In some situations, simple mounting of traditional modules may be more advantageous, especially considering acoustic performance requirements.

Opportunities: Road and rail authorities, as well as related companies, may find the incentive to incorporate PV technology as an energy-generating solution, driven by policies that urge them to curtail their environmental footprint.

Threats: To date, there has been a dearth of adequate integration between PV projects and their non-PV function, namely noise abatement. Anticipated stricter requirements are poised to facilitate the attainment of a harmonious fusion of these functionalities, thereby accentuating the merits of integrated solutions.

4.1.2 PV road roofing

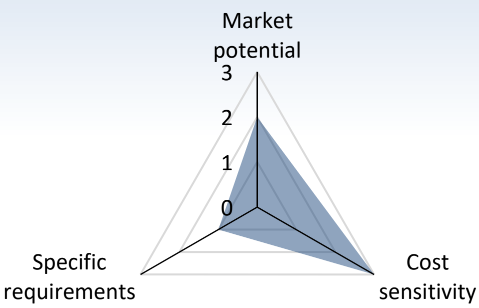
Figure 4.2. Highway road roofing (source: Fraunhofer)

Road roofing is another technology looking to exploit road and rail potential. The main currently active development is a German-Austrian-Swiss research project called PV-SÜD, led by a consortium including Fraunhofer ISE, Forster FF and the Austrian Institute of Technology.

As for PVNB, the potential is large considering the available roadway and railway areas. However, whether this potential will turn into a market remains to be seen, as PV on rooftops, grounds, and other areas around road and rail remains much more competitive at present.

Many challenges remain, especially around the mounting structure, which must withstand strong mechanical constraints to comply with safety regulations. Above a certain length, such structures could be considered as tunnels, which would add further constraints. Regulatory and technical requirements are the biggest obstacles to wide road roofing development.

As the objective is to create an elevated ground for PV deployment, there are not many specific requirements in terms of module manufacturing, except if transparency needs are considered. Indeed, one could see such projects developed using traditional modules, without actual integration.



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Strengths: Large theoretical potential in terms of available area.

Weaknesses: Unproven technology, with strong doubts over regulatory and economic feasibility (due to very demanding constraints). Although technical and regulatory requirements are high, the need for integrated solutions is not certain. Furthermore, such projects would often be built especially for PV-mounting (without the need for road covering), resulting in a high cost sensitivity.

Opportunities: Road/rail authorities and companies might be prompted to integrate PV as an energy generating mean through policies encouraging them to reduce their environmental impact.

Threats: There is a long way to go before road roofing becomes as advantageous a PV-mounting area as rooftops and grounds. Even if it develops, chances are that it would be mainly using traditional PV modules.

4.1.3 PV road, pavement and railway crossties

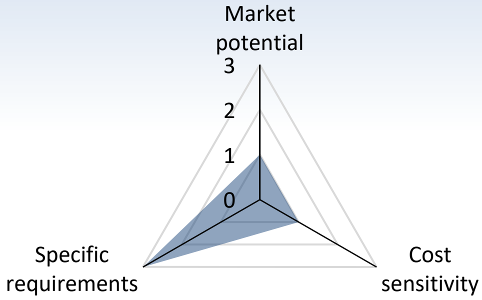
The perspective of solar roadways and pavements has made a lot of noise since the mid-2010's, but has since faced a reality check and lost momentum. Yet some examples exist (e.g., pavement-integrated PV in Zadar, Croatia with ertex solar modules). Feasibility remains very uncertain, but some researchers and companies have continued to explore its possibility. However, despite large potential considering the available roadway areas, PV on rooftops, grounds, and other areas around road and rail remains much more competitive at present.

The main obstacle for feasibility of solar pavement is its cost, due to strong mechanical constraints necessary to withstand traffic weight. Most full-scale tests have yielded disappointed results until now.

Similarly to road or pavement integrated PV, PV integrated to the path of railways has been investigated. Few projects exist, namely one involving PV manufacturing company Bankset and the Deutsche Bahn. It consists of traditional panels, albeit narrower, clipped on railway crossties. Here again, railway areas are large and the potential is theoretically big, but feasibility is very uncertain, as concerns over performance, maintenance and cost remain.

Figure 4.3. Solar roadway trial (top) Solar railway crossties (middle) Solar pavement (bottom)

In terms of modules, the need for specific manufacturing is significant as solar pavements would have very specific designs.



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Strengths: Large theoretical potential and a very strong need for integrated PV modules, as it is impossible to use traditional modules, except for railway crossties.

Weaknesses: Unproven technology, with very strong doubts over feasibility and competitiveness. Extremely challenging technical constraints lead to very specific requirements. The cost sensitivity is equally important due to the cost of integrating such technology to roads.

Opportunities: Road/rail authorities and companies might be prompted to integrate PV as an energy generating mean through policies encouraging them to reduce their environmental impact.

Threats: There is a long way to go before solar pavement becomes a realistic option, let alone as advantageous as rooftops and grounds.

4.1.4 Commercial carports

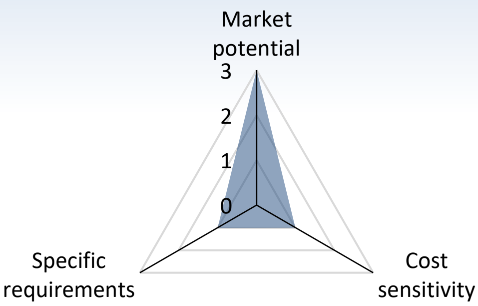
Large non-building roof areas such as parking lots, bus or train stations and carports are increasingly looked at from an integrated PV perspective. By integrating PV, such roof could combine shading or rain/snow sheltering with energy generation.

While traditional PV can be mounted on such roofs, integration can improve performance, aesthetics and cost-effectiveness. Synergy with EV charging is also increasingly coming to the fore.

Figure 4.4. Solar carports on parking lots

Many projects resembling commercial PV-integrating carports are in use. The technology is therefore mature and still has a massive room to grow. Commercial carports have even more potential than residential carports as areas are much larger.

The need for specific manufacturing of modules is limited, although various aesthetic considerations might require some customization. The added value of integrated PV means that there is a demand for such modules.



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Strengths: Significant potential. Low-risk, proven technology. Growing demand for integrated PV modules.

Weaknesses: The specific requirements for this application are limited, and the need for customized module manufacturing is mainly driven by aesthetic considerations.

Opportunities: Companies using large parking or stationary areas might be prompted to integrate PV as an energy generating mean for profit, to boost their image or through policies encouraging them to reduce their environmental impact. Wider utilization of EV can drive such installations. In some countries, obligations of solar carports for new large parking lots are being introduced or have already entered into force.

Threats: Regulation change in the future can alter the ease of building such structures compared to PV on buildings.

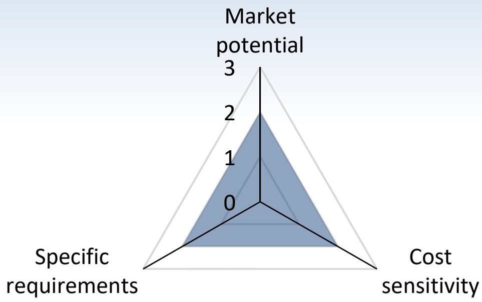
4.1.5 Residential carports/solar canopies

Smaller in scale than its commercial counterpart, residential carports nonetheless have a fairly large potential, and depending on legislation and incentives, can be profitable for both prosumers and the grid. "Canopies" encompasses all outdoor roofing structures providing shade, rain or snow protection for other uses than car parking (e.g. patios, pergolas, gazebos, etc). They represent an opportunity for prosumers as they offer additional area for PV besides rooftops, especially when rooftops are not ideal for PV installation. In some cases, they can also have the advantage of less restrictive regulations as buildings.

Figure 4.5. Solar carport (top) Solar canopy (bottom)

Aesthetic considerations and cost-effectiveness are pushing towards integration of PV modules as opposed to simple mounting. Such demand can drive the need for integrated module manufacturing.

As for commercial carports, synergy with EV-charging is a driver for residential carports.



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Strengths: Proven technology, decent potential. Customization potential.

Weaknesses: As for commercial carports, the specific requirements for this application are limited, and the need for customized module manufacturing is mainly driven by aesthetic considerations.

Opportunities: Ideal for residential buildings where PV cannot be placed on rooftops. Wider utilization of EV can drive such installations.

Threats: Regulation change in the future can alter the ease of building such structures compared to PV on buildings.

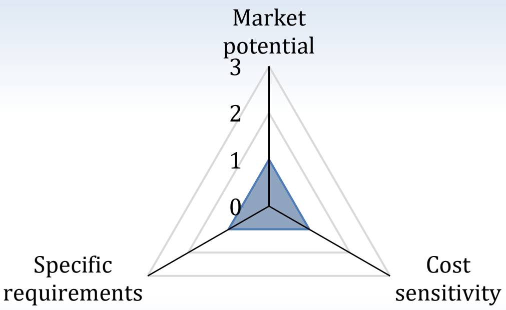
4.1.6 Urban-integrated canopies (e.g., bus shelters)

Figure 4.6. Example of IPV bus shelters

The application of PV technology on bus shelters has been the subject of experimentation in numerous cities worldwide. These systems can either be grid-connected or operate as stand-alone units. Modules employed in these installations may encompass both mounting and integration methods, occasionally featuring transparency or colouring. The advantages associated with this approach encompass electricity generation, illumination, and the provision of power for visual displays and audio equipment.

Presently, the diverse array of applications appears to reflect more of an ambiguity surrounding economic models rather than representing a varied market. While the cumulative area of bus shelter installations holds significant potential for PV integration, the practicality of connecting a PV system to the grid is often hindered by the limited available space at individual bus stops. This circumstance has led to the exploration of stand-alone alternatives, often including storage systems. In such scenarios, one can question the utility of such a system beyond providing lighting. Indeed, other mentioned benefits like display screens, primarily utilized for advertising, may hold limited appeal to the general public.

In instances of grid-connected bus shelter PV systems, advantages may be realized in specific scenarios where the shelter areas are larger (bus stations), and enjoy optimal sun exposure. Nonetheless, this niche market for tailored IPV solutions may be modest, as aesthetic enhancements can be prioritized.



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Strengths: Potential for customizable integrated PV solutions, primarily motivated by aesthetic and visibility considerations aimed at increasing public acceptance of PV technology.

Weaknesses: Can be achieved with conventional modules, reducing the need for special manufacturing

Opportunities: Cities and/or transportation companies could be prompted to integrate PV to reduce their environmental impact and/or bolster their public image.

Threats: Limited combined benefits of such installations may lead to a waning of interest in this trend.

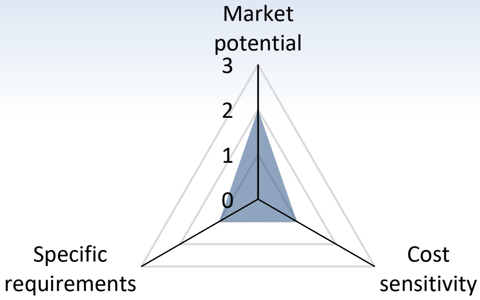
4.1.7 Public lighting

Like bus shelters, public lighting infrastructure is characterized by a segment with substantial aggregated area and potential, but each individual unit offers limited exploitable space, rendering profitability less straightforward.

The concept is not new, but recent advancements in LED lighting and battery technology are making such infrastructure increasingly feasible. In the case of small bus stops, linking the PV system to the grid provides minimal advantages. However, when employed as stand-alone systems, PV lighting can function autonomously and alleviate the grid's load during the evening, especially when deployed on a large scale.

Figure 4.7. An example of PV street lighting

In terms of technology, this application requires very little specific or customized manufacturing, and most current examples utilize traditional modules, albeit sometimes in smaller sizes, with the addition of specific mounting structures.



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Strengths: Relatively important potential

Weaknesses: Does not require integrated PV.

Opportunities: Cities and/or road authorities could be prompted to invest in PV to reduce their environmental impact.

Threats: The market for integrated PV within this segment appears to have limited prospects

4.1.8 Summary

Table 4.1. Overview of IIPV use cases

	Market potential	Specific requirements	Cost sensitivity	Final Appreciation for SEAMLESS-PV
PV noise barriers	3	3	2	Very relevant
PV road roofing	2	1	3	Not relevant
PV road, pavement and railway crossties	1	3	1	Not relevant
Commercial carports	3	1	3	Very relevant
Residential carports and canopies	2	2	2	Very relevant
Urban-integrated canopies (e.g., bus shelters)	1	1	1	Not relevant
Public lighting	1	1	1	Not relevant

Taking into account the aforementioned criteria, only subsegments relevant to SEAMLESS-PV (i.e., where SEAMLESS-PV can contribute to reduce the technical gap) will be further studied. In other words, subsegments who require specific manufacturing, whose cost sensitivity is acceptable, and technology mature enough to have realistic market potential.

The selected subsegments are:

- **PV noise barriers**
- **Commercial carports**
- **Residential carports**

4.2 IIPV stakeholders

4.2.1 IIPV value chain

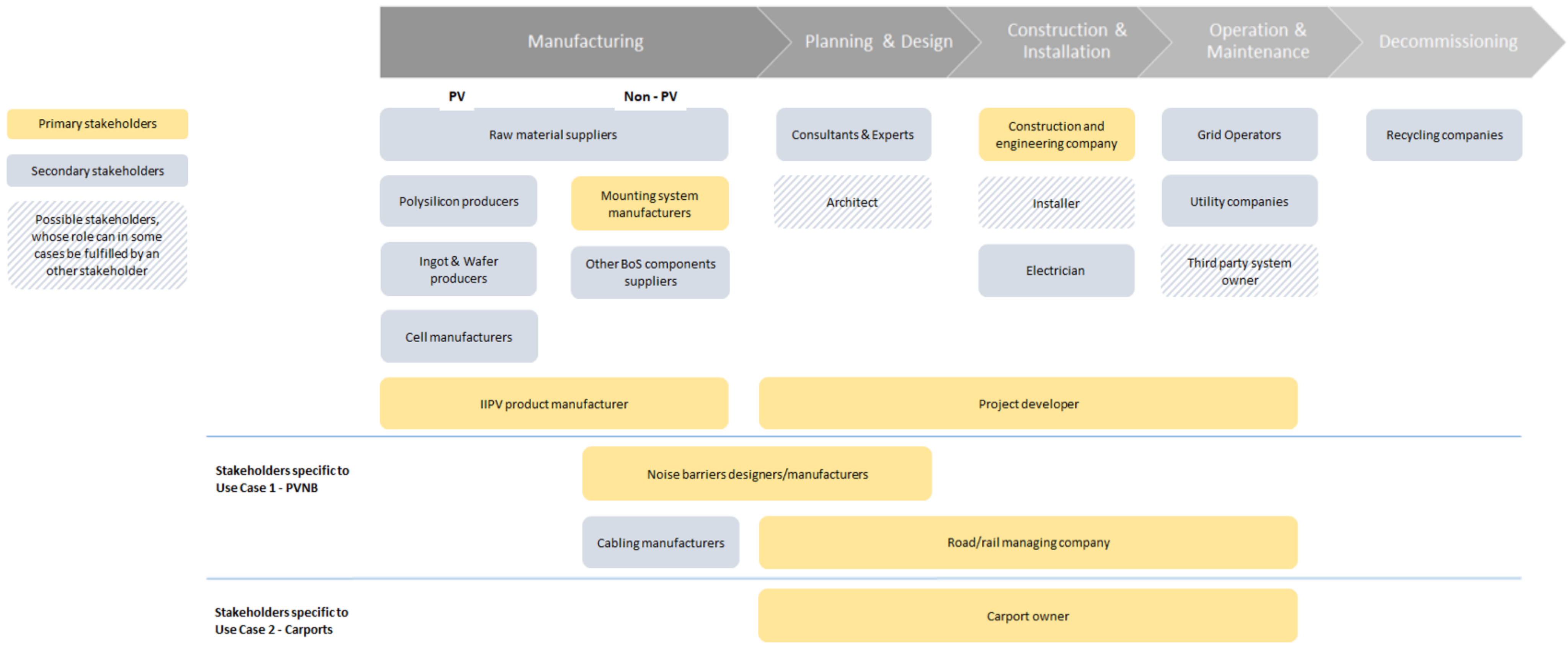


Figure 4.8. Overview of IIPV value chain

4.2.2 IIPV stakeholders' roles

Stakeholders		Steps in the value chain: Manufacturing	Planning & Design	Construction & Installation	Operation & Maintenance
General Stakeholders	Mounting system manufacturers	Producing mounting structures adapted to IIPV as simple and efficient as possible	May be involved in the development of tailor-made solutions coordinating with the other stakeholders to accommodate (I)PV products into infrastructures	/	/
General Stakeholders	IIPV product manufacturer	Producing specific IPV modules for infrastructure integration with special module requirements	Participating in the development of tailor-made solutions to assess the feasibility of customer requirements within the manufacturing process and assist designers in selecting the most optimal manufacturing solution	Offering installation guides or product manuals to prevent potential issues. Offering consulting services to provide data on tailor-made IIPV modules and offering recommendations to assist stakeholders in making informed decisions in IIPV design	Offering recommendations in the product manual for clients regarding operations and management
General Stakeholders	Construction and engineering company	/	Conducting feasibility studies and initial civil and electrical engineering work	Responsible for the construction of the project in alignment with the project conceptualization, including the installation of IPV solutions	/
General Stakeholders	Project developer	Placing orders for the production of specific products required for a project	Engaging in the design and creation of a technical model for the IIPV system, including preliminary studies on energy gains and cost considerations	Handling engineering and technical drawing, construction work planning, permitting, and overseeing the management of construction and installation activities	May assume responsibility for operations and maintenance
Stakeholders specific to PVNB	Noise barriers designers / manufacturers	Manufacture standard noise barriers that can be retrofitted with PV or transform into IIPV product manufacturers by producing PVNBs (refer to the "IIPV product manufacturer")	Participating in the planning and design of PVNB projects, whether they are new or involving existing noise barriers	Serve as consultants to provide data on existing noise barriers	/
Stakeholders specific to PVNB	Road / rail managing company	/	Contributing to the conceptualization and development of a project as the owner of the noise barriers	Actively participating in the construction and installation process as the owner of the noise barriers, taking responsibility for traffic management during works and ensuring security in and around the construction site	May be accountable for maintenance and ensuring the integrity of the PV system

Stakeholders specific to carports	**Carport owner**	/	Participating in the selection, design, and conceptualization of the project.	Playing a role in the planning and installation of carports	Assumes responsibility for safeguarding the integrity of the PV system

4.2.3 IIPV stakeholders' needs

Stakeholders		Steps in the value chain: Manufacturing	Planning & Design	Construction & Installation	Operation & Maintenance
General Stakeholders	Mounting system manufacturers	For tailor-made products, clear client specifications are necessary	Clear communication with designers and project developers in order to develop tailor-made products adapted to their needs	/	/
General Stakeholders	IIPV product manufacturer	Clear and comprehensive client specifications, particularly for tailor-made products, including technical information about the installation surface/space	Clear communication with designers and project developers for the development of tailor-made products. Clear technical data from the client and final confirmation of the project design before initiating the production process	Sustained communication with installers to receive updates on installation completion and any need for manufacturing replacements due to unit damage.	/
General Stakeholders	Construction and engineering company	/	Communication with developers and access to IPV and non-IPV components' plans and specifications to plan construction	Communication with subcontractors (façade/roof builders, electricians, PV installers)	/
General Stakeholders	Project developer	Information about the availability and manufacturing lead time for the desired products	A comprehensive understanding of the status, progress, and needs of other involved stakeholders	Clear view of other involved stakeholders' status, progress and needs. Communication from the different stakeholders involved in the construction and installation to ensure the link between them	Contact with third party operation and maintenance, if one is involved
Stakeholders specific to PVNB (Use Case 1)	Noise barriers designers / manufacturers	Clear client specifications are crucial, especially for tailor-made products	Be consulted by project developers for designing adapted solutions, especially in the case of retrofit	Communication with installers to ensure correct and optimal installation	/
Stakeholders specific to PVNB (Use Case 1)	Road / rail managing company	/	Understanding of the system's limitations, responsibilities, and benefits. Need to be consulted regarding the PV implications	Communication on the construction and installation timeline, with clarity on work progress and traffic impact estimation	May need training in maintenance of the PV system if responsibility falls on them
Stakeholders specific to carports (Use Case 2)	Carport owner	/	Understanding of the system's limitations, responsibilities, and benefits. Need to be consulted regarding the PV implications	Communication on the construction and installation timeline	May need training in maintenance of the PV system if responsibility falls on them

5 AGRIPV

5.1 AGRIPV use cases

5.1.1 Ground-mounted PV with grazing

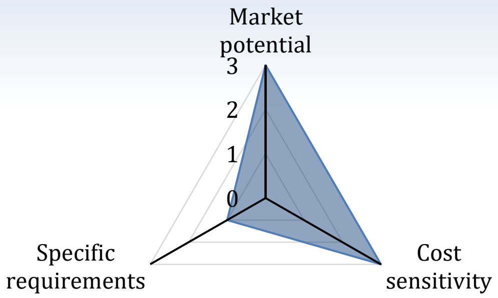
Ground-mounted PV with grazing (Source: Baywa)

Ground-mounted power plants situated on agricultural land typically follow a conventional setup. These solar installations consist of structures and photovoltaic modules, with a maximum height ranging from 1 to 3 meters at their highest point, oriented towards the south for optimal solar exposure. A special emphasis is placed on designing foundations that minimize any adverse effects on the soil. Similarly, careful consideration is given to the layout of cabling and structures to ensure the well-being of local fauna and wildlife.

The PV technology utilized is well-established and cost-effective, resulting in a mature and cost-optimized PV system. The PV yield and PV density, with an approximate rate of 1 MWp per hectare, are optimized for efficient energy generation. Moreover, the spacing between rows can be tailored to suit agricultural requirements, thereby impacting the overall energy density and agricultural utility.

The term "AgriPV" has stirred some debate regarding its definition and the corresponding legal framework in various countries. In certain regions, AgriPV systems are defined as solutions that are integrated into existing agricultural activities or where agriculture serves as the primary focus. In such cases, ground-mounted PV systems with grazing often fail to meet these criteria. This is typically due to the fact that PV electricity production becomes the primary activity, and grazing may not occur before the installation of PV systems. Additionally, the areas designated for agricultural production are often separated from those dedicated to PV, further complicating the classification.

Furthermore, ground-mounted PV systems with grazing often exhibit minimal distinctions from conventional ground-mounted PV power plants (the main difference being related to the height of the structure and the PV modules above ground), which has added to the complexity of categorizing them as AgriPV installations.



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Strengths: Most Mature PV use, as it is technologically equivalent to conventional ground-mounted PV.

Weaknesses: Permitting of construction of PV plants on agricultural land in some countries is restricted. The potential damage of the PV plant and its components by animals, especially with large or climbing species. Less financial support is provided for this use of AgriPV, when compared to other uses.

Opportunities: All grazing land worldwide is suitable. Around 25% of the global land surface.

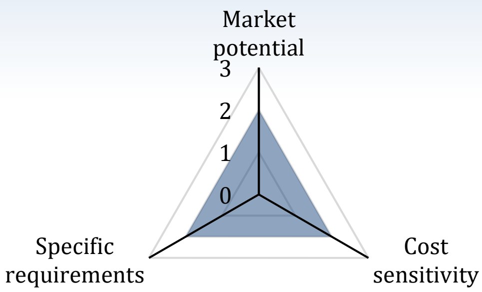
Threats: Stricter requirements for PV plant construction on agricultural land. Food security concerns.

5.1.2 Vertical PV

In this setup, the PV modules are positioned vertically, harnessing solar radiation from both sides. The spacing between rows is maintained at a minimum of 8 meters to facilitate the use of standard agricultural equipment and to minimize shading effects on crops. This configuration has a smaller footprint, resulting in a lower PV density, which is directly related to the row spacing.

Deviation from the optimal PV yield is estimated to be around 10%, based on initial field feedback in North Europe. In instances where an East-West orientation is employed, the shift of energy production toward the morning and evening hours can be economically advantageous, especially when considering factors like self-consumption or capitalizing on temporal variations in electricity prices.

Figure 5.1. Vertical PV (Source: Next2Sun)



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Strengths: Large theoretical potential in terms of available area. No soiling due to snow.

Weaknesses: Susceptible to wind-related damage. Reduced PV production during peak hours of sunlight throughout the day and changing seasons. Limited implementation has the potential to result in higher LCOE unless cost-effective construction methods are identified. Limited synergy with agricultural crops, as its vertical configuration does not provide shading during the hottest hours or IR heat loss protection during nighttime. Highly susceptible to damage from gravel projection and soiling.

Opportunities: Applicable to all available cropland, particularly in regions at higher latitudes.

Threats: Increasingly stringent criteria for PV plant construction on agricultural land, driven by concerns about food security.

5.1.3 Elevated PV – No tracking

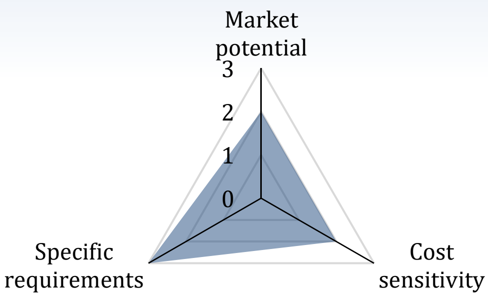
PV shading systems involve elevating PV modules above ground-mounted plants by employing various structures, typically positioning them at a height of approximately 4 to 5 meters above the crops. This elevation allows for the unimpeded movement of agricultural machinery and facilitates planting of shrubs beneath the PV modules.

Figure 5.2. Elevated PV without tracking (source: Baywa)

Project designs for PV shading systems exhibit a wide range of variations, including factors such as height and row spacing. These systems offer flexibility and can be tailored to meet the specific requirements of individual farmers. The PV density can vary, with some systems achieving nearly the same density as a conventional ground-mounted PV plant, while others may opt for a lower density using semi-transparent modules, for instance.

However, it's important to note that the understanding of compatible crop varieties in different geographical locations is still limited and in the process of development.

Elevated PV systems without tracking mechanisms are installed above agricultural activities, and the design is customized to align with the specific agricultural project. In the absence of tracking, the use of semi-transparent PV modules becomes a more favourable choice. This design approach leads to cost savings since it eliminates the need for tracking infrastructure and the associated additional investment and operational and maintenance (O&M) expenses.



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Strengths: Offers a wide range of design possibilities and deployment configurations. Lower CAPEX and OPEX compared to similar systems equipped with tracking mechanisms. Provides a level of crop protection against extreme weather events.

Weaknesses: Lack of control over sunlight exposure to crops (in the absence of a dynamic light control system). Limited knowledge regarding which crops are best suited for this type of agrivoltaic setup. When using semi-transparent modules, it may result in a higher LCOE. Controlling sunlight exposure might require unconventional methods (currently non-commercial).

Opportunities: Theoretically applicable to all available cropland. Possibility of incorporating protective nets on structures without dedicated supports.

Threats: Higher PV density can have a negative impact on crops. Increasingly strict requirements for PV plant construction on agricultural land. Concerns about food security. The risk of farmers favouring PV production to the detriment agricultural production due to the potentially greater profitability of PV production

5.1.4 Elevated PV – Tracking

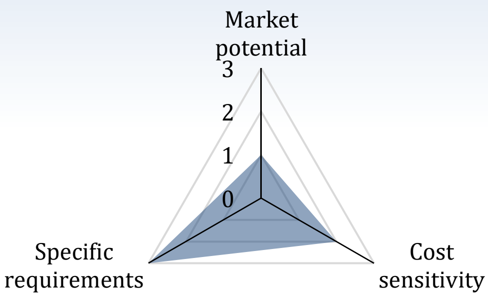
The PV system is positioned above the crops, typically at a height ranging from 2 to 6 meters above the ground. This elevation is designed to accommodate the passage of agricultural machinery and minimize the shading impact on the ground. These systems are equipped with trackers, which can operate along one or two axes, with their configuration tailored to the specific requirements of the agricultural activity while optimizing electricity generation. This approach is sometimes referred to as dynamic agrivoltaics or advanced agrivoltaics.

Figure 5.3. Elevated PV with tracking (Source: Sun'agri, REMTEC)

Initial investments for this AgriPV application tend to be higher when compared to other AgriPV uses. However, it stands out as the only approach that allows for precise control to ensure a harmonious balance between agricultural and PV production, ultimately optimizing the profitability of the AgriPV project. This optimization is achieved through the implementation of crop-specific algorithms that govern the tracking system. It is important to note that the control of the tracking system and the development of these algorithms will impact the system's operational costs.

While the market predominantly offers 1-axial tracking solutions for elevated PV systems, a limited number of manufacturers already provide 2-axial tracking systems. However, these 2-axial systems are associated with higher costs and increased operational complexity. The tracking system has the potential to act as a protective measure for crops against environmental hazards when necessary.

In addition to tracking systems as used in conventional ground-mounted PV applications, dynamic shading management systems also exist.



0: criteria evaluated as low / 3: criteria evaluated as high (evaluation is relative to the other APV use cases)

Strengths: Enhanced adaptability to a variety of crop types. Ability to prioritize either PV or agricultural production, allowing for optimized PV production outside the growing season. Provides protection against extreme meteorological events, such as heatwaves, hail, and storms. Contributes to the reduction of plants' evapotranspiration, which leads to lower irrigation costs and its associated costs.

Weaknesses: High costs, therefore sensitive to cost fluctuations. This AgriPV use is still in its early stages, leading to limited knowledge regarding the actual impact of PV production on crops. Potential conflicts may arise between the farmer and the electricity producer concerning the allocation of sunlight for agricultural and PV purposes.

Opportunities: In theory, it could be implemented on all available cropland, offering widespread potential for AgriPV integration.

Threats: Potential for increasingly stringent requirements for PV plant construction on agricultural land. Concerns regarding food security. The risk of farmers favouring PV production to the detriment agricultural production due to the potentially greater profitability of PV production.

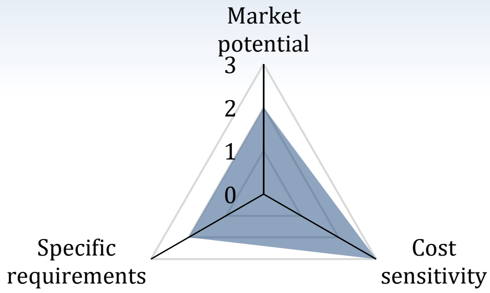
5.1.5 PV Greenhouse

PV greenhouses are conventional greenhouse whose roof partially integrates PV modules. Greenhouse roofs can have one or two different symmetric or asymmetric slopes. Semi-transparent PV modules are typically relevant for this application. Moreover, PV modules may need to fit the dimensions of standard glass used in greenhouses.

In this application the PV modules avoid the need for greenhouse whitening (i.e., applying a layer of lime paint to create a light filter).

It is a mature technology which has been largely deployed. Yet, there are perspectives to improve the synergies between the agricultural and the photovoltaic activities as research is being conducted to determine the most suited crops for PV greenhouses.

Figure 5.4. PV greenhouse (Source: Akuo)



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Strengths: Mature technology

Weaknesses: Knowledge regarding the actual impact of PV production on crops and most suitable crops is still limited. Potential conflicts may arise between the farmer and the electricity producer concerning the allocation of sunlight for agricultural and PV purposes.

Opportunities: Electricity consumption of greenhouses is important so self-consumption based business models are possible.

Threats: The risk of farmers favouring PV production to the detriment agricultural production due to the potentially greater profitability of PV production.

5.1.6 Summary

Table 5.1. Overview of APV use cases

	Market potential	Specific requirements	Cost sensitivity	Final Appreciation for SEAMLESS-PV
Ground-mounted PV with grazing	3	1	3	Not relevant
Vertical PV	2	2	2	Very relevant
Elevated PV (without tracking)	2	3	2	Very relevant
Elevated PV (with tracking)	1	3	2	Very relevant
PV greenhouses	2	3	1	Very relevant

Taking into account the aforementioned criteria, only subsegments relevant to SEAMLESS-PV (i.e., where SEAMLESS-PV can contribute to reduce the technical gap) will be further studied. In other words, subsegments who require specific manufacturing, whose cost sensitivity is acceptable, and technology mature enough to have realistic market potential.

The selected subsegments are:

- **Vertical PV**
- **Elevated PV (no tracking)**
- **Elevated PV (with tracking)**
- **PV Greenhouses**

5.2 AGRIPV stakeholders

5.2.1 AGRIPV value chain

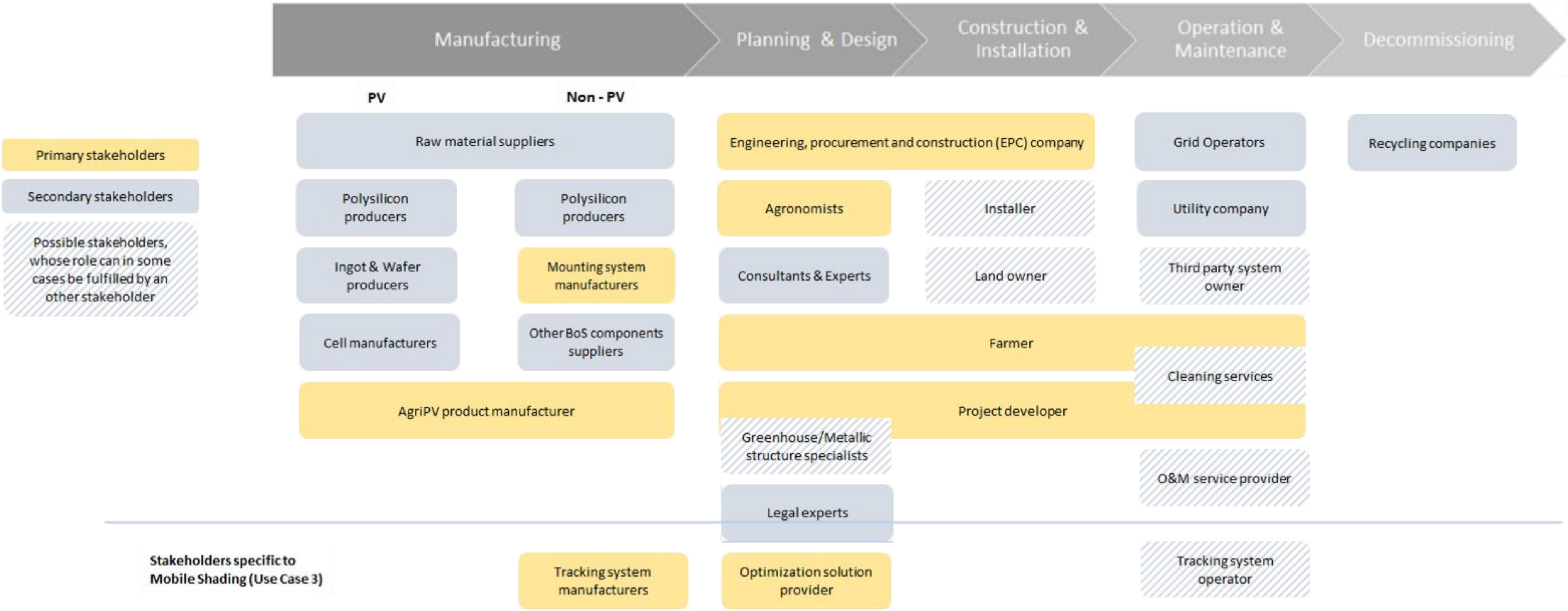


Figure 5.5. Overview of AgriPV value chain

5.2.2 AGRIPV stakeholders' roles

Stakeholders		Steps in the value chain: Manufacturing	Planning & Design	Construction & Installation	Operation & Maintenance
General stakeholders	Mounting system manufacturers	Producing generic mounting structure solutions	Participation in the development of tailor-made solutions	May be involved in the construction and installation of customized solutions	/
	AgriPV product manufacturer	Manufacturing specific IPV modules for AgriPV projects with project-specific requirements	Engaging in the development of tailor-made solutions to assess the feasibility of a customer requirements within the manufacturing process and assist designers in selecting the best manufacturing solution	Providing installation guides or product manuals to prevent potential issues	Providing client recommendations in the product manual for operation and maintenance
	Agronomist	/	Conducting initial agricultural impact assessments for PV solutions, establishing construction guidelines to mitigate agricultural disruption, and ensuring adequate irradiation for chosen crops with compatible structures	Ensure adherence to project expectations and preventing alterations that could jeopardize agricultural production	Providing operation guidelines for the AgriPV system to safeguard agricultural production
	EPC	Taking responsibility for procuring system components, including tracking equipment, from manufacturers	Contribute to project conceptualization and preliminary civil engineering and electrical work	Overseeing project construction in alignment with the project concept, including responsibility for IPV solution installation	/
	Farmer	/	Playing a role in the conceptualization and development of projects that align with their work	Must be consulted during system installation to accommodate their and their crops' requirements	Take responsibility for preserving the integrity of the PV system
	Project developer	Placing orders for the production of specific products required for a project	Developing the conceptual project and conducting feasibility studies	Engaging from design, engineering, technical modelling, and drawing to construction planning, permitting and management	May assume responsibility for O&M
Stakeholders specific to dynamic shading management	Dynamic shading management system manufacturer	Manufacturing dynamic shading management systems of various configurations	May participate in the design of tailor-made AgriPV solutions	Possibly participating in system installation to ensure it meets dynamic shading management requirements	Participate in the production of replacement parts for elevated mobile systems maintenance, as model system components are more susceptible to damage
	Optimization solution provider	Establishing a close partnership with dynamic shading management system manufacturers to develop optimization algorithms tailored to each tracking solution for different crop types	Developing an optimization solution algorithm	/	Possible engaging in mobile system operation to optimize either agricultural or PV production; the optimization algorithm may undergo continuous modifications

5.2.3 AGRIPV stakeholders' needs

Stakeholders		Steps in the value chain			
		Manufacturing	Planning & Design	Construction & Installation	Operation & Maintenance
General Stakeholders	Mounting system manufacturers	In the case of tailor-made products, need for clear specifications of the desires of the client	Clear communication with designers and project developers in order to develop tailor-made products	Communication with installers to ensure correct and optimal installation	/
	AgriPV product manufacturer	In the case of tailor-made products, need for clear specifications of the desires of the client and technical information about the surface/space were it will be installed	Clear communication with designers and project developers in order to develop tailor-made products. Clear technical data from the client and final confirmation of the project design in order to start with the production process	Communication with installers to be informed when the installation has been completed or whether some unit has been damaged and we have to manufacture a replacement	/
	Agronomist	/	Communication with the farmer and the PV development stakeholders, to be able to support the PV system stakeholders on understanding the guidelines to allow finding a balance between PV and agricultural productions. Analysis of the daily irradiance received by the crops, for every moment of the year.	Clear view and updates on the project installation	Be consulted to provide operation guidelines
	EPC	Information about availability and manufacturing time of desired products	Communication with developers and access to IPV and non-IPV components' plans and specifications to plan construction	Communication with subcontractors and electricians	/
	Farmer	/	Understanding the limitations, responsibilities and benefits of such a system. Need to be consulted regarding the limitations a PV system integrated into agricultural production may bring	Communication on the construction and installation timeline	Training to operate the agricultural production, not to damage the systems. May need some training in maintenance of the PV system if they are responsible for it, namely in coping with soiling
	Project developer	Information about availability and manufacturing time of desired products	Clear view of other involved stakeholders' status, progress and needs. Being aware of the limitations an AgriPV system could bring to the farmer and collaborate to minimize them	Clear view of involved stakeholders' status, progress and needs. Communication between the different stakeholders involved in the construction and installation	Contact with third party operation and maintenance company if there is one
Stakeholders specific to dynamic shading management	Tracking system manufacturers	Information about availability and manufacturing time of desired products	Clear communication with designers and project developers in order to develop tailor-made products. Agronomic inputs (light transmission to crops should be favoured over PV production)	Communication with installers to ensure correct and optimal installation	Receive feedback from the O&M managers to provide adequate repair or replacement
	Optimization solution provider	Collaboration with dynamic shading management system manufacturers to adapt the optimization solutions offered to different types of configuration and crops	Understand the client's and project's needs to develop the most suitable algorithm. Agronomic inputs about crops (light transmission to crops should be favoured over electricity production)	/	Receive feedback from the operator for the continuous optimization of the algorithm, modification of needs during operation

6 VIPV

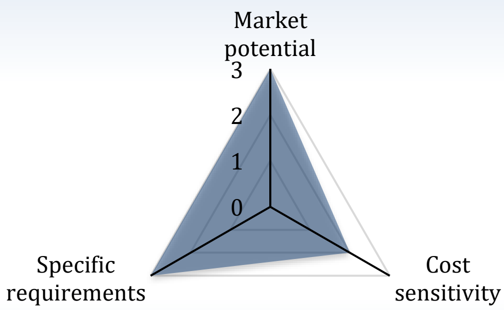
6.1 VIPV use cases

6.1.1 Passenger cars

PV integration in light passenger cars was originally conceived as an auxiliary system designed to provide support for lighting and air-conditioning. However, as PV technology has advanced significantly over the years and the cost of PV systems has notably decreased, the market for VIPV in light vehicles has become commercially viable. VIPV technology is primarily employed in hybrid and electric vehicles, which are substantial consumers of electricity. Nevertheless, it is important to note that VIPV integration in battery-powered light vehicles is the specific focus in this subchapter.

PV integration in light passenger vehicles is primarily concentrated on the mostly flat rooftop, with some instances extending to the sides and front of the vehicle. The integration of PV technology in curved areas of the car and windows has posed challenges, yet the emergence of flexible PV and PV incorporated into windows holds the potential to transform this into a standard practice. Additionally, the ongoing advancements in coloured PV technology are anticipated to make PV integration in vehicles more appealing and readily accepted by the general public.

Figure 6.1. LEV with PV rooftop from Lightyear (top) LEV with PV rooftop and body from Sono (bottom)



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Strengths: Passenger cars are ubiquitous; PV integration alleviates the battery and contributes to mitigating electricity grid consumption. EV car range is significantly increased.
Weaknesses: Higher costs added to EVs; Low area available for integration.
Opportunities: Ultimately all passenger car vehicles could have some degree of PV integration. Opportunity in the luxury car segment.
Threats: The benefits of VIPV are highly dependent on the driver profile. Passenger cars in dense urban environment typically drive in surroundings with important shading (from other cars, from buildings, …) and park in underground or covered parking lots.

6.1.2 Commercial Vehicles

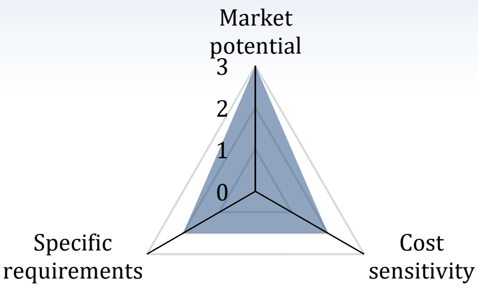
Integrating PV technology in commercial vehicles presents fewer challenges when compared to passenger cars, owing to the presence of more horizontal and flat surfaces on commercial vehicles. Some commercial vehicles also exhibit increased electricity consumption when used for refrigerating purposes, creating an opportunity to incorporate PV systems aimed at mitigating the electricity demand on the vehicle's battery or the diesel consumption in the case of an ICE vehicle.

Numerous companies have successfully launched commercial electric vehicles (CEV) in the market. In Europe, the research institute Fraunhofer ISE has been actively investigating the potential of VIPV for commercial vehicles and refrigerated trucks in Germany, evaluating their applicability for various routes. In the same country, DHL is conducting research aimed at integrating PV systems onto some of its own CEV fleet.

The configuration of VIPV in CEVs closely resembles that of VIPV in LEVs. The primary challenge remains the integration of PV technology into curved surfaces and windows. However, given the larger flat surfaces available in CEVs, it is anticipated that these vehicles will achieve higher installed PV capacities, both on the rooftop and sides.

Figure 6.2. Commercial vehicle with PV modules attached by DHL (top) Commercial vehicle with rooftop-integrated PV by Fraunhofer ISE (bottom)

In this case of PV integration, the importance of aesthetics is expected to be relatively lower in CEVs than in LEVs. Moreover, unlike LEVs, where solar cells may need to be discreetly incorporated, PV installations on CEVs can serve as a means to promote a company's commitment to sustainability.



0: criteria evaluated as low / 3: criteria evaluated as high (evaluation is relative to the other VIPV use cases)

Strengths: LCEV demand is set to explode in the next decades; PV integration alleviates the battery and contributes to mitigating electricity grid consumption. LCEV range is significantly increased, so less frequent battery charging stops. More flat surfaces than LEVs. Support to auxiliary utility services in LCEVs (e.g. cooling).

Weaknesses: Higher costs added to EVs; A consumer for large energy yield is required. This could increase the cost for battery capacity or go unused.

Opportunities: Ultimately all LCEVs could have some degree of PV integration. Large surface areas are available and easy accessible since they are not curved thus high electrical outputs and yield can be achieved. Perfect in combination with cooling units for refrigerated vehicles. Driving profile is probably less of an issue compared to LEVs since CEVs are driving a lot on highways and are driving almost every day

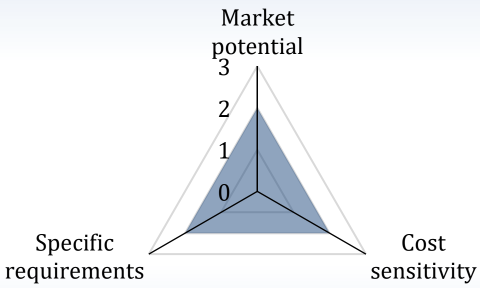
Threats: The benefits of VIPV are dependent on the driving profile. Solar modules can become a safety problem in case of an accident: therefore, low voltage systems preferred (<=60 V).

6.1.3 Buses

The integration of Photovoltaics in buses, based on real-world applications, appears to be a feasible option for implementation on both existing electric and non-electric buses. Notably, in the case of conventional diesel buses, which exhibit additional fuel consumption for air conditioning, ventilation, and onboard appliances, the potential integration of PV technology is of considerable interest. Such integration has the potential to significantly increase the overall installed PV capacity in this context and pave the way for the adoption of integrated PV mobility, even before transitioning the fleet to electric alternatives.

Buses, particularly those designed for long-distance travel, typically host a multitude of electrical equipment operating at a low voltage level. This setup reduces the complexity of power electronics needed to feed energy into a high voltage battery and, instead, allows for the direct supply of onboard consumers. The addition of PV systems, in general, empowers (local) buses to discontinue running their engines upon reaching their final destinations, eliminating the need to keep them operational solely for the purpose of supplying cooling and other onboard systems.

Figure 6.3. Flixbus diesel bus with PV modules on rooftop (top) Munich Transport Company's diesel bus with PV modules on the rooftop (bottom)



0: criteria evaluated as low / 3: criteria evaluated as high (evaluation is relative to the other VIPV use cases)

Strengths: Easily integrated on existing buses (both EV and Diesel) to supply auxiliary electricity needs. Buses have mostly flat surfaces, PV integrations will not face many challenges, except for windows.

Weaknesses: The PV element is a cost adder with benefits only observable in the medium-term.

Opportunities: All buses could ultimately have some degree of PV integration. Manufacturers may find themselves compelled by legislation to enhance their sustainability efforts by accelerating IPV adoption.

Threats: The benefits of VIPV are dependent on the driving profile.

6.1.4 Other VIPV use cases

The integration of photovoltaic (PV) technology is viable for virtually all existing modes of transportation. Among non-land-road vehicles, boats are the most popular choice for PV integration. Boats present a significant opportunity for solar PV adoption because they operate independently of the grid once they depart from the dock or port. However, it's important to note that the majority of PV installations on boats may fall under the category of BAPV variety. In the case of boats, the potential cost associated with Integrated PV is often mitigated due to the luxury nature of these vessels. Customers are generally more inclined to invest in PV for the sake of prestige. While some pilot projects have been undertaken for aircraft, the use of commercial PV integration in this sector remains limited. The same observation applies to trains, where BAPV is the prevailing choice for PV installations.




Figure 6.4. Boat with solar PV integrated (top left), Aircraft with integrated solar PV (top right) Cargo Bikes & Tuk Tuks (bottom left) Train with solar PV modules attached (bottom right)

Considering the limited prevalence of genuine PV integration in the aforementioned applications, along with the limited commercial potential for the development of these use cases, they will be excluded from the analysis within the scope of SEAMLESS-PV.
In contrast, significant market potential is presented by cargo bikes and electric Tuk Tuks. These modes of transportation are widely adopted in major cities worldwide for both passenger and goods transport. Particularly in the case of cargo bikes, the incorporation of a PV system has the potential to supply a substantial portion of the energy needed for operation, reducing or eliminating the reliance on grid charging.

6.1.5 Summary

Table 6.1. Overview of VIPV use cases

	Market potential	*Specific requirements*	*Cost sensitivity*	*Final Appreciation for SEAMLESS-PV*
Passenger cars	**3**	**3**	**2**	**Very relevant**
Commercial vehicles	**3**	**2**	**2**	**Very relevant**
Buses	**2**	**2**	**2**	**Very relevant**
Other VIPV use cases	**1**	**3**	**1**	**Not relevant**

Taking into account the aforementioned criteria, only subsegments relevant to SEAMLESS-PV (i.e., where SEAMLESS-PV can contribute to reduce the technical gap) will be further studied. In other words, subsegments who require specific manufacturing, whose cost sensitivity is acceptable, and technology mature enough to have realistic market potential.

The selected subsegments are:

- **Passenger cars**
- **Buses**
- **Commercial Vehicles** *(further differentiation will be made to distinguish between Light Commercial Electric Vehicles and Heavy Commercial Electric Vehicles, recognizing the distinct challenges that each of these subcategories presents).*

6.2 VIPV stakeholders

6.2.1 VIPV value chain

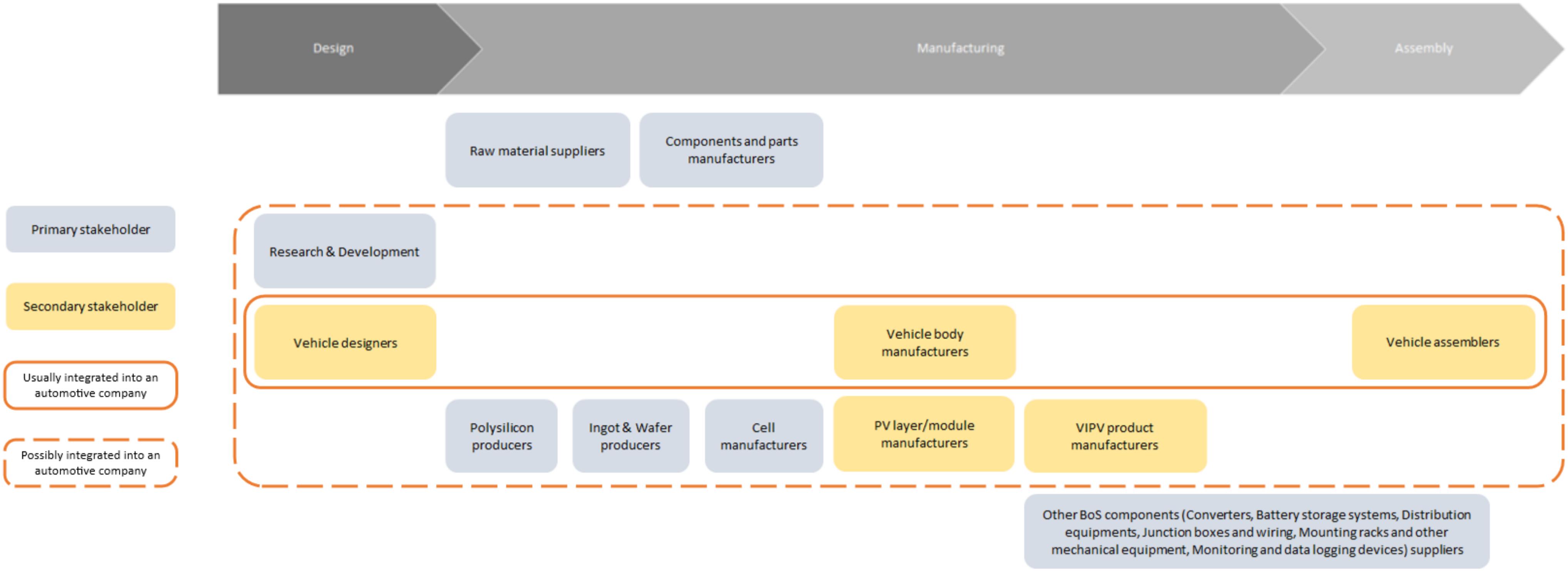


Figure 6.5. Overview of VIPV value chain

6.2.2 VIPV stakeholders' roles

<table>
<tr><th colspan="2"></th><th>Design</th><th>Manufacturing</th><th>Assembly</th></tr>
<tr><td rowspan="5">Stakeholders</td><td>Vehicle designers</td><td>Enabling PV integration into vehicle design. Collaborating with R&D for PV integration in more challenging vehicle parts</td><td>Procuring vehicle parts and components as per the design specifications. When necessary, engaging external VIPV product or glass manufacturers for the production of VIPV elements</td><td>/</td></tr>
<tr><td>Polymer solar panel manufacturers</td><td>May be involved in VIPV product design</td><td>Producing polymer solar panels and potentially integrating PV components</td><td>Providing polymer solar body to vehicle assemblers</td></tr>
<tr><td>Vehicle body manufacturers</td><td>/</td><td>Producing the car bodies. May also integrate PV components</td><td>Providing vehicle body to assemblers</td></tr>
<tr><td>VIPV product manufacturers</td><td>Designing IPV following specifications for automotive industry requirements</td><td>Manufacturing distinct VIPV products to match the brand, model, and car colour. Offering these products for sale to vehicle body manufacturers</td><td>Providing VIPV products to vehicle assemblers</td></tr>
<tr><td>Vehicle assemblers</td><td>/</td><td>Procurement of vehicle parts, including IPV element</td><td>Assembling the vehicle, including IPV parts</td></tr>
</table>

6.2.3 VIPV stakeholders' needs

<table>
<tr><th colspan="2"></th><th>Design</th><th>Manufacturing</th><th>Assembly</th></tr>
<tr><td rowspan="5">Stakeholders</td><td>Vehicle designers</td><td>Investment in R&D for PV integration into complex vehicle body parts, with a thorough grasp of the limitations, responsibilities and advantages of VIPV systems</td><td>Information about availability and manufacturing lead time of desired products. Established collaborations with VIPV product manufacturers</td><td>/</td></tr>
<tr><td>Polymer solar panel manufacturers</td><td>Clear understanding of the specifications and safety standards required for the automotive industry</td><td>Established partnerships with PV component manufacturers, vehicle body manufacturers and/or VIPV product manufacturers</td><td rowspan="3">Precise specifications regarding the requirements and preferences of the vehicle assemblers</td></tr>
<tr><td>Vehicle body manufacturers</td><td>/</td><td>Adapted assembly lines specifically tailored for VIPV integration, distinct from non-VIPV lines.
Readiness for quick adaptation to new trends and VIPV integration levels.
Established partnerships with VIPV manufacturers may also be required</td></tr>
<tr><td>VIPV product manufacturers</td><td>Comprehension of the specific requirements essential for the automotive industry, particularly in the context of customized products</td><td>Maintained awareness of the challenges encountered by vehicle body manufacturers. Effective communication on the optimal approach to enter the vehicle production supply chain and explore partnership opportunities</td></tr>
<tr><td>Vehicle assemblers</td><td>/</td><td>Insights on the prevailing trends within the automotive industry and a comprehensive understanding of the challenges and advantages associated with PV integration</td><td>A comprehensive understanding of the status of other involved stakeholders, including their manufacturing capabilities, product availability, and requirements</td></tr>
</table>

7 CONCLUSION

Four main segments for IPV are listed, described and analysed in this deliverable:

- Building Integrated PV (BIPV),
- Infrastructure Integrated PV (IIPV),
- Agri PV (APV)
- Vehicle Integrated PV (VIPV)

Building Integrated PV (BIPV),

- BIPV can be considered the most mature integrated PV segment.
- Available solutions in this segment showcase a great variety of technical, economic and visual characteristics from in-roof mounting PV systems relying on conventional PV modules through the use of specific mounting structures through building accessories-integrated PV to patterned, coloured and semi-transparent BIPV façades.
- Taking into account the market potential , the cost sensitivity and the need for specific requirements, it is identified that the following BIPV subsegments are the most relevant to SEAMLESS-PV:
  - Discontinuous BIPV roofing (roof tiling solutions)
  - Skylights
  - Curtain wall façade
  - Rainscreen façade
  - Insulating façade cladding
  - Balustrades, balconies and other accessories
- Other analysed BIPV segments included simplified BIPV roofing which do not require any specific requirements and are the most cost sensitive.

Infrastructure Integrated PV (IIPV)

- IIPV leverages surfaces on urban- and transport-related infrastructures (lights, bus shelter, roads, pavement, …)
- On some IIPV segments, MW-scale installations are already being seen, primarily driven by PV noise barriers and commercial carports.
- Taking into account the market potential, the cost sensitivity and the need for specific requirements, it is identified that the following IIPV subsegments are the most relevant to SEAMLESS-PV
  - PV noise barriers
  - Commercial carports
  - Residential carports
- Other analysed IIPV segments included PV road roofing, PV road pavement and rails crossties, bus shelters and public lighting which are considered as little relevant in the frame of the SEAMLESS-PV project because of limited need for specific requirements and limited market potential.

Agri PV (APV)

- Agri PV systems are characterised by the colocation of an agricultural activity and a PV production activity.
- Definition of AgriPV vary from one country to another, but in general technologies which resemble conventional ground-mounted PV can be considered as very mature but often fail to meet the criteria to categorize as AgriPV. On the contrary, spaced and elevated PV systems, which provide clear services to the agricultural activity typically fall under AgriPV definitions (with national specificities).
- The main drivers for APV are land resource optimization, diversification of income streams for farmers and protection of crops from droughts and other climatic event.
- Taking into account the market potential, the cost sensitivity and the need for specific requirements, it is identified that the following APV subsegments are the most relevant to SEAMLESS-PV
    - Vertical PV
    - Elevated PV (no tracking)
    - Elevated PV (with tracking)
    - PV Greenhouses
- Other analysed APV segments included ground-mounted PV with grazing which are considered as little relevant in the frame of the SEAMLESS-PV project because of limited need for specific requirements.

<u>Vehicle Integrated PV (VIPV)</u>

- VIPV still remains limited although numerous established automotive manufacturers, including Nissan, Hyundai, and Fisker, now offer VIPV integration as an optional feature in their vehicles.
- Simultaneously, pioneering and innovative companies like Lightyear and Sono Motors have taken the lead by bringing to market their first vehicles designed with PV integration as a fundamental component.
- Taking into account the market potential, the cost sensitivity and the need for specific requirements, it is identified that the following VIPV subsegments are the most relevant to SEAMLESS-PV
    - Passenger cars
    - Buses
    - Commercial Vehicles
- Other analysed VIPV segments included boat-integrated PV, train-integrated PV, aircraft-integrated PV or cargo bike-integrated PV which are considered as little relevant in the frame of the SEAMLESS-PV project because of their limited commercial potential.

The conducted market and stakeholders analysis allows to present multiple possible applications in each of the integrated PV segments while shortlisting those which can be the focus of SEAMLESS-PV project as they require specific manufacturing, have an acceptable cost sensitivity and a technology mature enough to have realistic market potential.

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Seamless-PV

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