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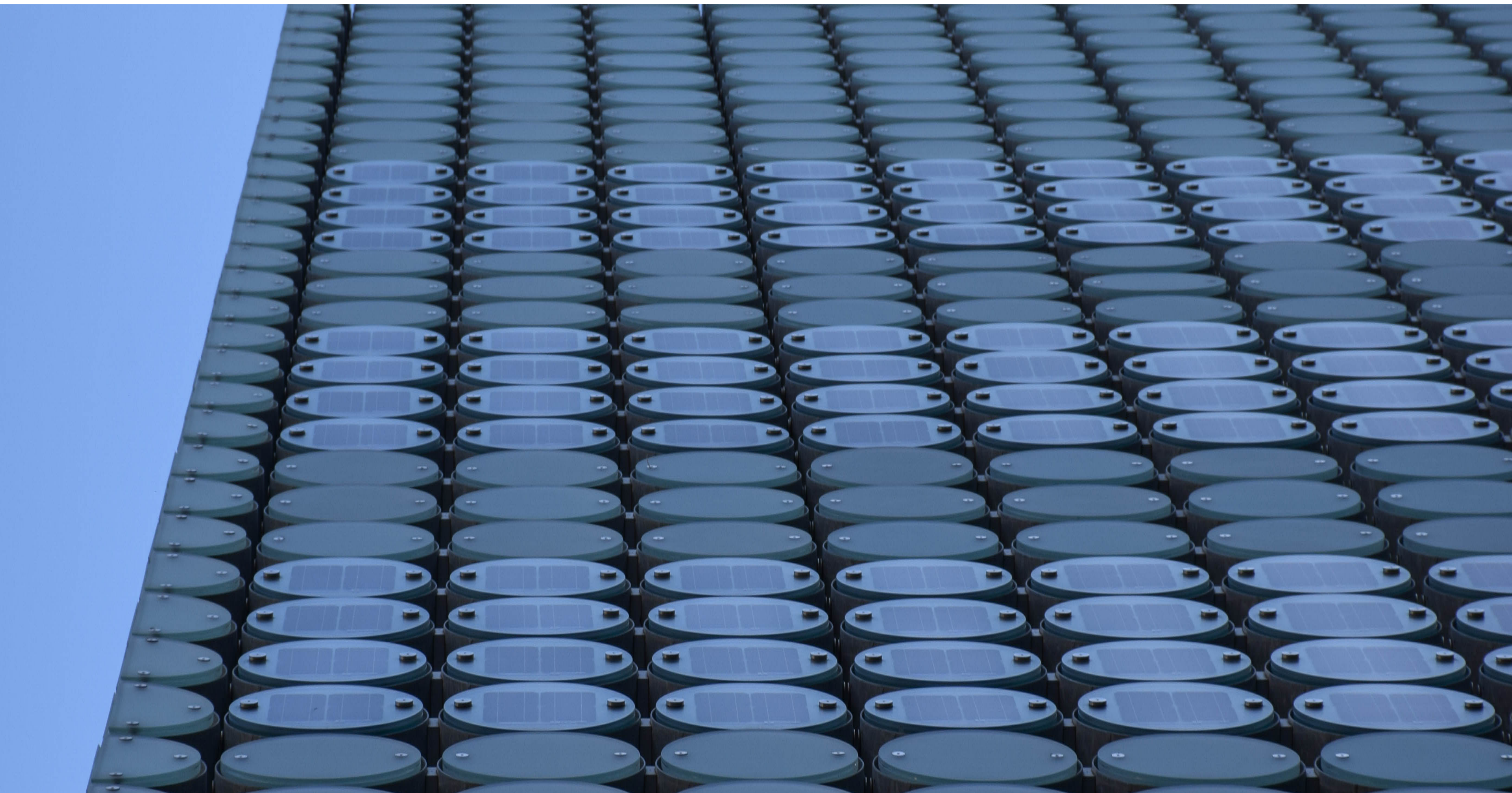

Task 15 Enabling Framework for the Development of BIPV

PVPS

Analysis of the Technological Innovation System for BIPV in Australia
2024

Report IEA-PVPS T15-19:2024

What is IEA PVPS TCP?

The International Energy Agency (IEA), founded in 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD). The Technology Collaboration Programme (TCP) was created with a belief that the future of energy security and sustainability starts with global collaboration. The programme is made up of 6.000 experts across government, academia, and industry dedicated to advancing common research and the application of specific energy technologies.

The IEA Photovoltaic Power Systems Programme (IEA PVPS) is one of the TCP's within the IEA and was established in 1993. The mission of the programme is to "enhance the international collaborative efforts which facilitate the role of photovoltaic solar energy as a cornerstone in the transition to sustainable energy systems." In order to achieve this, the Programme's participants have undertaken a variety of joint research projects in PV power systems applications. The overall programme is headed by an Executive Committee, comprised of one delegate from each country or organisation member, which designates distinct 'Tasks,' that may be research projects or activity areas.

The 25 IEA PVPS participating countries are Australia, Austria, Belgium, Canada, China, Denmark, Finland, France, Germany, Israel, Italy, Japan, Korea, Malaysia, Morocco, the Netherlands, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, and the United States of America. The European Commission, Solar Power Europe, the Smart Electric Power Alliance, the Solar Energy Industries Association, the Solar Energy Research Institute of Singapore and Enercity SA are also members.

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What is IEA PVPS Task 15?

The objective of Task 15 of the IEA Photovoltaic Power Systems Programme is to create an enabling framework to accelerate the penetration of BIPV products in the global market of renewables, resulting in an equal playing field for BIPV products, BAPV products and regular building envelope components, respecting mandatory issues, aesthetic issues, reliability and financial issues.

Subtask A of Task 15 is focused on the analysis of the Technological Innovation System (TIS) for BIPV on national levels in order to identify systemic problems and recommend actions for industry and/or policymakers that want to support the development of the BIPV market and innovation system. This document is one of the national TIS-analysis reports. A synthesis of national TIS-analyses will be made based on this and other national reports.

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COVER PICTURE

Image is the RMIT design hub building, Melbourne, Australia .

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INTERNATIONAL ENERGY AGENCY
PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

Analysis of the Technological Innovation System for BIPV in Australia

IEA PVPS
Task 15
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List of abbreviations

ABCB	Australian Building Codes Board
ABLIS	Australian Business Licence and Information Service
AC	Alternating Current
AER	Australian Energy Regulator
APVA	Australian PV Association
APVI	Australian PV Institute
ARENA	Australian Renewable Energy Agency
BAPV	Building Applied Photovoltaics
BIPV	Building Integrated Photovoltaics
BOS	Balance of System
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DC	Direct Current
ESD	Environmentally Sustainable Design
FiT	Feed-in-Tariff
IEA	International Energy Agency
IEC	International Electrotechnical Commission
NCC	National Construction Code
PV	Photovoltaics
SME	Small and Medium Enterprises
SPPA	Solar Power Purchase Agreements
SRES	Small-scale Renewable Energy
STCs	Small-scale Technology Certificates
TIS	Technological Innovation System

Executive summary

This report describes the analysis of technological information systems (TIS) conducted for BIPV in the Australian industry. The TIS analysis is conducted to identify the status of Australian BIPV industry in terms of its strengths and weaknesses. The main intent of this report it to understand how BIPV industry has evolved in Australia over the years and the level of development it has achieved. The outcome of this report is beneficial for BIPV suppliers, design consultants, building developers, relevant government authorities and academic institutions to (1) identify the opportunities and limitations and (2) assist decision making in BIPV adoption. The study follows the required research process for TIS as guided by the IEA PVPS Task 15 report 'Guide for Technological Innovation System Analysis for Building-Integrated Photovoltaics 2023'.

BIPV in non-domestic buildings in Australia was first installed around 2000 with the aid of the government's renewable energy programmes. There were a few installations from 2000-2006; however, this trend did not continue as expected in subsequent years. A slight interest in the BIPV from the building sector has been visible since 2016 with the recent installations and approved projects. BIPV installations as roof tiles or roof sheets in domestic buildings are growing gradually, although they are poorly documented. To date, award-winning BIPV applications, such as rainscreen facades, windows, balustrades, roof sheets, tiles and skylights, have been installed in Australia. Most of them are small units. The BIPV integrated roof sheets, tiles, skylights and rainscreens are operated in a niche market, whereas others, such as balustrades, curtain walls and windows, are in the demonstration phases. Several actors such as the building and construction sector, PV sector, utility/energy sector and property sector, exist in the upstream and downstream value chains of the BIPV here. New suppliers and distributors are entering the present Australian market; nevertheless, the uptake of BIPV is still low in Australia due to knowledge gaps. The BIPV market was assessed applying TIS analysis in eight functional areas, and revealed that Australian BIPV is characterised as follows:

- Knowledge development is explored to identify the breadth and depth of current BIPV knowledge and different ways of contributing to knowledge in Australia. Knowledge development is weak. Although research units develop scientific knowledge in collaboration with relevant industries at a satisfactory level, the technical expertise transfer from and to practitioners is limited. A few actors participate in creating a knowledge pool in the industry.
- Knowledge diffusion is explored to identify the ways of theoretical and practical distribution of knowledge among the stakeholders and within the industry. Poor knowledge diffusion is attributed to inaccessible information and limited sharing among a wider community. Knowledge is not distributed equally across the value chain.
- Entrepreneurial experimentation is examined to understand the level of probing into new technologies and applications. Entrepreneurial experimentation is weak because there are limited market entrances, and only a few demands of the adopters are addressed. Entrepreneurs have more opportunities to introduce various BIPV applications for different market segments. Resource mobilisation is investigated to identify important resources, their respective "bottlenecks" and how they evolve over time. BIPV-related resource availability is weak because there are few experts, scarce resources, and fewer funding opportunities for upstream and downstream suppliers.
- Development of social capital is explored to understand how to create and sustain social relations such as trust, common understanding and mutual recognition. Social capital is inadequate due to the discrete nature of the building and PV industries, lack

of demonstration projects, misconceptions and limited awareness, which have hindered the development of trust and confidence in society.

- Legitimacy is examined to understand the social acceptance of BIPV technology and compliance with the institutional frameworks. Legitimation is weak in Australia as positioning BIPV with the institutional framework is not visible. Regulations complying with building codes, especially those addressing fire safety and structural loads, are necessary.
- Guidance is explored to understand the expected business potential, expressed customer demand and policy regulations. Guidance is weak as there is a lack of clear vision on the market. However, the government and relevant authorities aim to positively implement clean energy development and applicable policies and regulations.
- Market formation is examined to understand the actual market development and the driving and restraining forces. Market formation is weak as government, entrepreneurs and lead users do not contribute actively to the development of the BIPV.

This evaluation assists identification of weaknesses and strengths and the recommendation of strategies to expand the current market. Key recommendations are: 1) form a BIPV Alliance to create a common platform to link actors, 2) introduce live lab testing modules and systems, 3) develop building codes, particularly on fire safety, and 4) initiate government intervention to support both upstream and downstream actors.

Despite the weakness of BIPV status in Australia, the authors are delighted to observe a significant increase in interest in the building sector recently. Some of the suggested initiatives have been undertaken since the publication of the report, which will open great opportunities for the Australian BIPV market.

1 INTRODUCTION

With abundant solar resources, Australia is a land where harnessing energy using photovoltaic (PV) sources to meet its demands. The excellent 15.5% contribution of PV systems to Australia's power consumption bolsters the country's development (IEA PVPS, 2022). As a part of the nation's road map of renewable energy targets, solar PV is included in most of the policies and agendas of governmental bodies and relevant authorities. Officials have been actively formulating policies and strategies to facilitate this transition. Amidst this landscape, integrating solar PV into building envelopes, known as building integrated photovoltaics (BIPV), is a remarkable technological approach for the building and construction sector. BIPV embodies a synergy between PV and building envelope materials, wherein solar modules become integral to a building's exterior in achieving architectural aesthetics.

Because the Australian building industry is searching for novel sustainable technologies that can complement the building's architectural appearance and reduce carbon emissions, there is a burgeoning interest in BIPV. BIPV is manufactured with an accepted quality, guaranteed by PV standards and building and construction codes and regulations. BIPV products provide unique benefits, such as acting as a building envelope material, aesthetic enhancement and onsite electricity generation. BIPV offers a great mechanism to utilise this unused façade space, generate more green energy, which can feed back to the grid, save money, provide a building valuation uplift, and improve the whole building lifecycle costs. However, their practical applications to the Australian building industry are challenging, complicated, value sensitive and require their bespoke nature. It has not yet become a well-known building envelope system in the industry.

This study conducts a technological innovation system (TIS) analysis for BIPV in Australia. It explores the structural characteristics and functional fulfilment of BIPV technologies and stakeholders in Australia. The purpose of this report is to understand the prevailing condition of BIPV industry and highlight its strengths and weaknesses. The analysis considers the whole BIPV system, such as BIPV modules, inverters, mounting equipment, cabling and balance of system (BOS) components. The research also considers the entire project lifecycle of BIPV while conducting the analysis. This study has two primary analyses: (1) structural analysis and (2) functional analysis. The structural analysis concerns the technology, actors, networks and institutions related to BIPV and development in Australia. The functional analysis examines the critical processes associated with BIPV and development and their status under eight key themes. It investigates the history and prospects of BIPV adoption. The analysis assists in the identification of current conditions and proposes recommendations in Australia. The outcome of this report will be beneficial for different stakeholder groups such as PV industry, building industry, government authorities and the academia. PV industry stakeholders such as BIPV suppliers can use the report outcomes to understand the technological demands, current interests and investment opportunities. The building industry stakeholders such as architects, developers and design consultants can use this report to understand the opportunities and limitations of using BIPV in their developments. The government authorities can use this report to understand the institutional challenges and decide how they can be effectively engaged in BIPV uptake. The academia can understand the demanding areas which require further research and development.

Information for this analysis is gathered from 1) publications, 2) authors experiences 3) interviews and 4) workshops. With respect to publications, this study reviews articles, books, official websites, newspapers, magazines and national reports that have cited the BIPV contexts in Australia. The search for publications is conducted under two selection criteria: (1)

publications should contain the Australian context, and (2) publishers should be reliable, and the websites should be official and recognised for BIPV information dissemination. The primary purpose is to maintain highly accurate data. Furthermore, the study has used the findings of 50 semi-structured interviews in the last 3-4 years. Interview/Workshop participants were building and PV stakeholders who have been involved and are interested in BIPV technologies. The authors of this report possess extensive experience conducting research activities focused on advancing this technology and actively engaging with diverse stakeholders within the field. The authors insights and opinions significantly enrich the report The purpose of using interview findings is to understand the current experience and opinion of BIPV technology. Two workshops were conducted in Melbourne, Australia, to discuss BIPV adoption and its technical, economic and social parameters. Stakeholders from the building industry, PV industry, academics, regulatory bodies, renewable energy authorities and fire departments were invited to attend the workshops to discuss BIPV adoption, safety, benefits, drawbacks and requirements for future uptake. The data were analysed according to the principles of TIS analysis.

2 DEFINITION OF THE TECHNOLOGICAL INNOVATION SYSTEM FOR BUILDING INTEGRATED PHOTOVOLTAICS

2.1 Scope of this analysis

The scope of the analysis is BIPV modules and systems, along with PV modules and systems for purely aesthetic integration.

- A BIPV module is a PV module and a construction product designed to be a building component. A BIPV product is the smallest (electrically and mechanically) non-divisible PV unit in a BIPV system that retains building-related functionality. If the BIPV product is dismounted, it must be replaced by an appropriate construction product (IEA PVPS, 2023).
- A BIPV system is a PV system in which the PV modules fulfil the above definition for BIPV products. It includes the electrical components that connect the PV modules to external AC or DC circuits and the mechanical mounting systems required to integrate the BIPV products into the building (IEA PVPS 2023).

In this TIS analysis, no limitation is made with respect to BIPV application categories. However, the different types of BIPV solutions are focussed on BIPV façade systems (rainscreens, curtain walls/double glassing wall, windows, balustrades, shading devices) and roof integrated systems (continuous roof, discontinuous roofs and skylights. This report focussed on the current situation of the BIPV market in Australia. A well-established TIS framework is employed for structured and functional analyses. The study follows the required research process for TIS as guided by the IEA PVPS Task 15 report 'Guide for Technological Innovation System Analysis for Building-Integrated Photovoltaics 2023'.

2.2 Technological development

The technological development of BIPV is a slow-paced process in Australia. Table 1 shows that less than 1 MW capacity of BIPV projects has been installed in Australia from 2015 to 2021.

Table 1: Australian BIPV Status

Source: (APVI, 2016–2021)

Application		**2015 (MW)**	**2016 (MW)**	**2017 (MW)**	**2018 (MW)**	**2019 (MW)**	**2020 (MW)**	**2021 (MW)**
BAPV	Residential	540	544	778	1068	1504	1882	1737
	Commercial	168	208	331	510	628	1029	1355
	Industrial	14	28	75	117	91	145	109
BIPV		<1	<1	-	-	-		
Ground-mounted		60	60	123	2359	2510	1422	1713
Total		783	841	1307	4054	4733	4478	4914

These data include only several BIPV projects that were developed for demonstration purposes. Few BIPV product choices are present in the Australian context. BIPV products integrated into roofing elements, such as roof tiles or sheets, are available for residential and commercial applications in the Australian market. However, BIPV integrated façade elements are limited because of high costs and fire safety concerns. Limited distinction is made between Building Attached Photovoltaics (BAPV) and BIPV regarding product certification and installation.

2.3 Historical development of the innovation system

Australia has a vast opportunity to install solar applications due to its location: a climate zone with optimum solar radiation. Therefore, the fast growth of BAPV and solar thermal applications has been experienced primarily in residential properties for decades across all states in Australia. Besides, the installation of large-scale BAPVs in commercial and industrial facilities and solar farms has increased. This expansion has assisted the country in achieving a remarkable position in the global PV market and has served the nation in progressing toward its Net Zero targets of 2050. The contribution of BIPV to the countries' total solar PV generation is insignificant; however, Australia has a long history of BIPV. The implementation of BIPV in Australia has been witnessed since 2000. The first commercial BIPV project was designed in 2000, a façade application in an educational building. Since 2000, a few BIPV projects have been implemented in the Australian building sector. The major projects in non-domestic buildings are listed as follows (Prasad and Snow, 2004; Solarch, 2005).

- 2000: Sydney Olympic Solar Village, 700 kWp roofing laminates, mono-c-Si modules
- 2002: University of Melbourne, 40 kWp of façade system, semi-transparent poly-c-Si
- 2002: High-rise building in Brisbane 28 kW contains roof and overhangs, a-Si modules
- 2004: Kogarah Town Square, 164 kW integrated into the roof system, a-Si modules
- 2004: CSIRO Energy Center, 90 kW, roof/wall system, dye-sensitised modules
- 2006: Ballarat University, 8.4 kWp of double-glazed façade, semi-transparent a-Si
- 2006: Szencorp building, 1 kW of a pergola, semi-transparent a-Si modules
- 2007: Australia's first BIPV Noise Barrier (Tullamarine) a-Si double-glazed modules

From 2000 to 2006, BIPV applications have slightly grown in non-domestic buildings. Financial support of the government has majorly reinforced these developments. The government fundings associated with renewable energy programmes and state and local government support schemes in initiating innovative technologies have successfully aided the installations. For example, BIPV was installed in the Sydney Olympic Village as an iconic and innovative technology in 2000 with assistance from government support schemes.

Older BIPV projects were installed as double-glazed facades, roof-integrated systems and pergolas. Most of them are equipped with c-Si and a-Si technology with frameless modules; for instance, modules in the Sydney Olympic Solar Village have high efficiency and frameless roofing. Some projects, such as those in Melbourne University and Ballarat University, have used semi-transparent modules (10% transparency), allowing visibility and sunlight inside the building. Most BIPV panels were imported from a foreign country, such as Germany. Almost all the projects are demonstration cases. These projects comprise a capacity of less than 100 kWp and contribute significantly to the building's energy needs. The BIPV system in the Kogarah suburb provided nearly 15–20% of the building's electricity load. Moreover, projects such as Ballarat University, Tullamarine-Calder Interchange and Szencorp buildings were award-winning projects for excellence in Designing and Installing a Grid-Connected Photovoltaic Energy System. BIPV distributors and accredited installers were actively involved in the installation and construction of the projects. The installations and constructions comply with AS/NZS 5033: Installation and safety requirements for photovoltaic (PV) array and AS 4777: Inverter requirement standards. These standards were primarily applicable to PV applications. During this period, universities and other institutes conduct research in technical and economic aspects. A few publications have intended to disseminate the knowledge.

However, the trend of BIPV implementations did not continue as expected. From 2006 to 2016, not many BIPV installations have been identified. The systems were unpopular and not fully acknowledged by the building sector. BIPV suppliers have left the market, and most of them have shifted to operating as BAPV entities. The manufacturing plants were also closed. One of the leading causes would be the low demand for BIPV from the building sector. The energy market and low fossil fuel prices have also affected the BIPV demand (Prasad and Snow, 2004). Furthermore, government support was primarily focussed on residential solar PV applications, disregarding BIPV, which has discouraged significant deployment.

Historically, BIPV roof tiles and roof sheet systems are ad-hoc among residential properties. These are most popular among luxury properties. A few companies whose primary business is BAPV distribute roof tiles as an additional market segment. These systems were still popular among residential properties but not well publicised or documented.

From 2016 to the present, interest in the building sector has increased steadily, with a slow growth in BIPV among residential and commercial properties. Table 2 listed most of the BIPV projects in non-domestic buildings from 2016. 1). Several small-scale BIPV systems have been commissioned. New suppliers and distributors are entering the present Australian market. However, the uptake of BIPV is still low compared to other regions, such as some European and Asian countries, such as China, Singapore and Germany.

Table 2: BIPV projects in non-domestic buildings from 2016

(source: (Onyx Solar, 2016); (Hanergy Thin Film Power, 2021); (PV Magazine, 2021(Vasiliev et al., 2019); Avancis,2023))

Building Name	Year	Application	Technology	Capacity	Surface
Scotch College	2016	Pergola	a-si	4.32 kW	113m^2
Latrobe University	2016	Roof	c-si	28 KW	
General Apartment	2016	Balcony	a-si	5 KW	120 m^2
Melbourne Grammar	2017	Skylight	a-si	1 kW	29m^2
Warwick Shopping Centre	2019	Window	c-si	1 kW	23.3m2
Murdoch University	2021	Glazing	c-si		1.2m2
St Andrew's Cathedral	2021	Canopy	a-si	2.3 kW	70m2
Paragon Tower	2021	Cladding	c-si	42 kW	158 m^2
Como Railway Station	2022	Rainscreen	c-si		87m2
Spencer st	Ongoing				
Cbus properties	Approved				

3 STRUCTURAL ANALYSIS

The structural analysis is the first step of the TIS analysis, which includes identifying the crucial elements of the innovation systems, such as actors and networks, technology and institutions.

3.1 Technology

The technologies and areas of knowledge in the BIPV innovation system in Australia are:

Research, development and innovation of BIPV products (material and cells): Several institutions, such as universities and research institutes, and a few companies facilitate research and innovation in BIPV products, materials and cell technologies. Their research investigates BIPV cell technologies, such as flexible thin films and semi-transparent electrodes and device development.

BIPV product manufacturing: Currently, there are no local manufacturing plants for BIPV in Australia. However, a few companies supply solar glass windows, roofs and façade products.

BIPV architectural integration and building performance: BIPV modules must align with the building design and its aesthetic appearance. The modules are also integrated into a support structure depending on the position of the building envelope to which it is attached. The system and its functions shall comply with building codes and requirement on conventional building elements.

Fire Regulations: BIPV applications shall comply with the fire regulations in Australia. BIPV facades should be tested for external wall performance in accordance with AS 5113: classification of external walls of buildings based on reaction-to-fire performance. Meeting fire standards has been critical for BIPV installations in Australia, particularly for the vertical BIPV. Necessary guidelines must be developed to improve the fire performance of the modules.

Thermal insulation: BIPV system components must comply with the thermal insulation-related standards (U-value and R-value) under the Building Codes of Australia (BCA). There are few attempts to enhance the thermal properties of BIPV in Australia. Several institutions are conducting studies on the impact of BIPV on the building's thermal environment.

Structural factors: The loads on a BIPV envelope include dead load, wind load, earthquake load, live load, rain load and snow loads imposed on the building structure. Not much research has been dedicated to the structural impact of BIPV products. The wind load on the BIPV design can be estimated manually by referring to the AS/NZS 1170.2:2021: Structural design action standard, which sets out the procedure for assessing wind actions on structural designs.

Civil engineering and building construction: Australia has limited standard procedures for assembling or constructing BIPV envelopes. Most BIPV projects are unique, and integration methods may vary based on the project. Research studies have explored the potential benefits of considering BIPV in prefabricated units.

Building energy needs and production: Current BIPV systems meet a small portion of total building energy needs. Several publications have investigated how BIPV energy production would help fulfil Australia's building energy needs.

Economic and environmental life cycle assessment of BIPV projects: Research institutes are conducting studies on the economic life cycle assessment and environmental life cycle analysis. The BIPV enabler tool developed by the Solar Energy Application Lab at RMIT

University can estimate the financial life cycle assessment of BIPV projects in Australia. However, there is not enough information related to the BIPV product supply chain in Australia to perform an environmental life cycle analysis for BIPV projects.

Glass construction: A few projects used glazing BIPV applications. One glass manufacturer in Australia has used BIPV (mono-c-Si modules) to create glazing with a low-emissivity coating.

Operation and maintenance of BIPV projects: There is a few BIPV maintenance companies in Australia. In most cases, the BIPV product supplier or installer would provide the after-sales services such as replacement or repair.

Business development and innovation support: Government and non-government institutes fund business development and innovation in BIPV projects (e.g., Australian Renewable Energy Agency [ARENA] and Australia Photovoltaic Institutes [APVI]).

User behaviour and acceptance: Few stakeholders know the application of BIPV, available BIPV products and their potential benefits. Many perceive BIPV as an application of high investment. Therefore, they are reluctant to use it in building applications.

Project development and financing: Australia has limited BIPV-related government incentive schemes other than the feed-in tariffs introduced for renewable energy technologies. Purchasing power agreements are rapidly used in rooftop PV while ignored for these systems. However, the support programmes presented in Table 3 can be considered for BIPV projects.

3.2 Actors and networks

Actors and networks are the critical agents in the innovation system. Actors represent individuals or organisations directly and indirectly involved in the BIPV value chain. Networks represent national and international groups working together for the deployment. Many actors and networks are present in the BIPV value chain in Australia. They are categorised as follows:

Industry: The industry represents actors involved in the upstream supply chain of the BIPV system. In the present context, a few BIPV-specific upstream actors (ten or fewer in each category) are identified as follows:

- BIPV suppliers/distributors
- BIPV manufacturers
- BIPV consultancy firms
- BOS manufacturers
- Construction companies/façade builders/roofers
- Installers/electricians/electrical engineers
- Civil and structural engineers
- Maintenance companies

BIPV suppliers/distributors or BIPV consultancy firms are supplying BIPV-related elements such as modules, inverters and integrated systems. They amalgamated with BIPV manufacturers to sell their products. Previously, there is no BIPV module manufacturing plant, including assembling in Australia; therefore, all modules are imported from various countries. However, a few local BIPV companies have obtained or are in the process of obtaining government support in establishing local manufacturing process. BIPV consultancy firms collaborate with builders or designers, delivering sustainable design and installation. In the present market, around ten local and international entities distribute modules. They import diversified modules, such as c-Si and CIGS, with different transparency levels, etc., from various countries. Furthermore, a few construction and PV consultancy firms work independently and collaboratively on implementation and installations. Electrical installers, roofers, glazers, façade installers, builders and engineers are other actors in the upstream value chain of the BIPV. A single entity providing a complete service of design to installation of systems is absent. Here, many parties worked collaboratively to deliver a service.

Market: The market represents actors who create demand for BIPV directly or indirectly or support downstream activities.

- Architects
- Property owners
- Consultants/planners/designers
- Builders/developers
- End-users
- Facility managers

Various property owners and facilities managers request BIPV installations. Current projects are distributed mainly in residential, apartment, commercial and educational buildings. Residential dwellings have BIPV roof tiles or roof sheets. A wide range of BIPV applications such as rainscreens, skylights, windows and balustrades has been installed in different states. Moreover, the BIPV market is established in new and retrofitted buildings. Architects/designers and environmentally sustainable design (ESD) consultants, some builders, construction companies and developers inquire about the BIPV installations, creating a demand in the market. However, also some practitioners recommend this system to their clients: property owners and developers.

Research: Research represents actors involved in developing knowledge. The following actors conduct research and disseminate knowledge on multiple aspects of BIPV (technical, social, economic, and environmental): CSIRO, Monash University, RMIT University, University of New South Wales, Melbourne University, and University of Newcastle conduct research into BIPV/printed PV.

Education: Education implies the actors' involvement in disseminating knowledge through education and training, both academic and vocational. Very limited number of courses or modules teach or train BIPV system design and installations in Australia. However, many universities discuss BIPV as a sustainable technology attached to the buildings.

Politics and policymakers: Politics and policymakers represent actors initiating, defining and/or deciding on institutions (legislation, regulations, etc.). Federal, State and Local governments mainly maintain and endorse regulations. The Federal government implements decarbonisation strategies to reach 100% renewable energy by 2050. State governments also initiate procedures to promote renewable energy. However, processes directly focussing on BIPV have not been initiated so far by any parties.

Funding organisations: Several government and non-government institutes provide funds for BIPV projects, such as

- Public funding by Federal, State and local governments
- Financial institutes such as banks
- Clean Energy Finance Corporation (CEFC)
- Cooperative Research Centres Projects
- ARENA
- Department of climate change, energy, the environment and water (DCCEEW)

Utility companies: Utility companies are electricity suppliers in Australia. Based on Australia's current electricity distribution network, many electricity retailers are interested in BIPV and have the potential to support BIPV installations. They generally provide services, such as grid connection, enabling access to the electricity network grid and FiT for the BIPV owners.

Intermediaries and supporting organisations: Intermediaries and supporting organisations represent actors that try to engage in collaboration between different partners or act to support and facilitate the development of technology. The institutes act individually and collectively to develop BIPV in Australia. Some examples of institutes, which can potentially contribute to BIPV deployment, are as follows:

- Australia Photovoltaic Institutes (APVI)
- Clean Energy Council
- Engineers Australia
- Green Building Council Australia
- Master Builders Australia
- Property Council Australia
- Australian Institute of Architects
- Australian Institute of Building
- Master Builders Association of Victoria

Networks: The network represents the international networks and collaborations in the value chain of BIPV technology. Several actors work together internationally and locally in Australia to install and deploy this technology in the Australian market. For example, some architects and ESD consultants' partner with foreign suppliers to import modules and related products to install systems. Such networks are visible in the market. Apart from that, several networks emerged through the academics working with the manufacturers and/or distributors to test new modules and applications and deploy the technology across the country. Furthermore, these collaborative groups appeared because of the government (ARENA) and non-government (APVI) entities who assist in financial and non-financial support to encourage research and development (R&D). Moreover, APVI has initiated a 'BIPV alliance (BIPVA)'that aims to enable collaborations within the entire stakeholder ecosystem across different industry sectors in addressing design, technical, practical, policy and standard-related issues in BIPV adoption, highlighting good practices, filling in industry knowledge gaps, and providing training opportunities. This alliance highlights the development of technology. Figure 1 illustrates the potential participants in the BIPVA.

Figure 1: Potential participants in BIPV

Figure 2 summarises the present value chain in BIPV market in Australia. Actors and networks were mainly defined based on their roles and responsibilities.

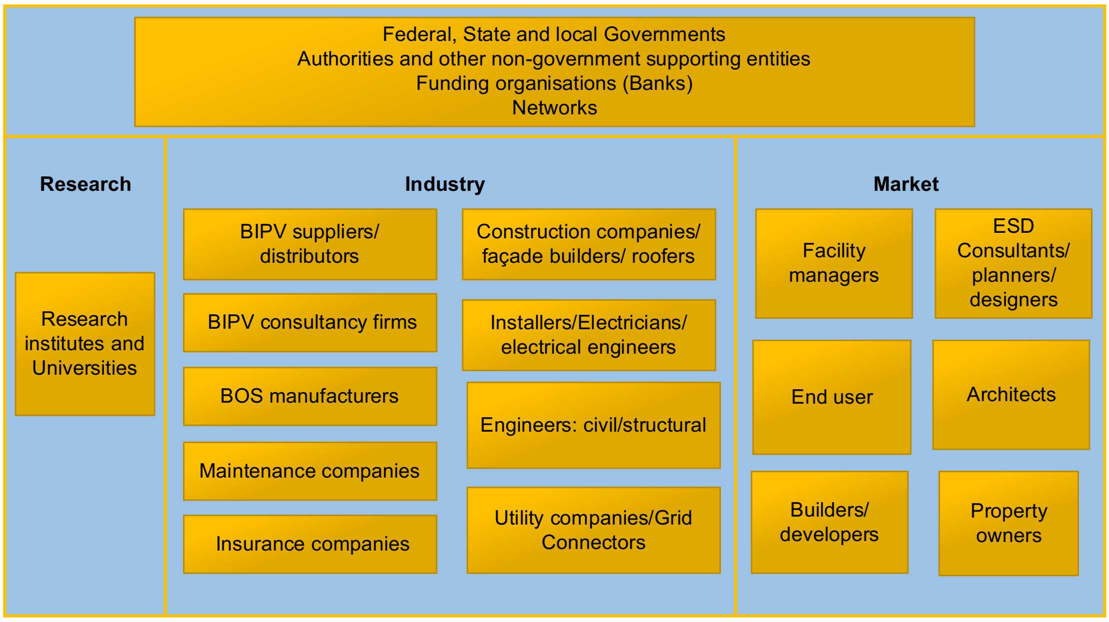

Figure 2: Value chain of BIPV in Australia

3.3 Institutions

Institution can be defined as the social systems or structures that arrange the primary social practices, roles and relationships (Martín-Chivelet et al., 2022). Institutions are divided into two main sections: soft institutions and hard institutions. Soft institutions describe the social norms and cultural aspects of the society whereas the hard institutions describe the regulatory framework. Following sections explain the soft and hard institutions of Australian BIPV industry.

3.3.1 Soft Institutions

Soft institutions in Australia can be discussed under five areas: (1) acceptance, (2) awareness, (3) aesthetic requirements, (4) public procurement practices and (5) stakeholders' conduct/ practice. All these soft institutions are based on the social norms, beliefs and values of the stakeholders.

Stakeholder acceptance: The acceptance of BIPV technologies and applications by the stakeholders, such as property owners, project developers and end-users, is crucial for the technology uptake. Nevertheless, it is challenging to witness an encouraging acceptance from the above stakeholders in Australia. The approval generally comes with trust in the technology. Trust is developed by the legitimacy of the technology, its better performance and proven benefits. The stakeholders can be convinced about the technology's legitimacy if there are specific regulations and standards. Stakeholders can be appropriately informed about the performance level and benefits of the technology via proper advertising and promotions. Unfortunately, Australia currently lacks all these aspects. Another main reason for the lack of acceptance is the limited cost information of the BIPV technology compared to conventional building construction. Professionals, such as architects and consultants in Australia, often complain that convincing their clients to select BIPV options is arduous due to the lack of understanding of product options. Limited number of BIPV-specific policy incentives or mortgage schemes are available to reduce the financial risks and encourage Australian developers. The professionals prefer conventional building construction and rooftop PV due to their lack of professional skills, education, and experience. Decisions of system adopters are primarily focussed on BIPV performance, such as energy, carbon footprint, financial and architectural substitutability.

Stakeholder awareness

Awareness of technology: In general, the stakeholders such as architects, ESD consultants and engineers from the construction sector and PV suppliers, designers and installers from the PV industry in Australia have little awareness of BIPV technologies and applications. The necessary skills, experience and knowledge to use the technology are often scarce. Currently, in Australia, there are hardly any courses or educational programmes specific to BIPV construction except some general teaching in undergraduate courses and in-depth research in postgraduate programmes. The stakeholders, such as property owners, project developers and end-users, are very poorly aware of the technology. The lack of awareness among the public is one of the primary reasons for the slow uptake of BIPV in Australia. However, a few stakeholders, such as the BIPV-related R&D sector, construction companies with a BIPV speciality, and BIPV material suppliers and installers with adequate knowledge, skills and awareness, are available nationwide. They are working round the clock to accelerate the technology uptake.

Awareness of the impact of climate change: The Australian government, public and private sector entities, and the public have a substantial understanding of climate change and the impact that it can create on the country. The government encourages sustainable building construction and renewable energy adoption. Several energy-relevant and sustainability-related regulations, policies and standards have been introduced to the construction sector. According to a survey conducted by the Australian Institute about the public perception of climate change, 81% of Australians have significant concerns about natural disasters such as floods and droughts that climate change can occur (Merzian et al., 2019). In total, 64% of Australians prefer a national target for net-zero emissions by 2050, and 69% support state governments introducing incentives for renewable energy. Besides, 76% of Australians choose solar power as one of the top three preferred energy sources, making it the most popular. Therefore, Australians have acknowledged climate change and are committed to environmental protection.

Aesthetic requirements: Many architects in Australia prefer conventional construction as it can deliver better aesthetic outcomes. According to the architects, traditional construction facilitates design flexibility and complex designs. The critical aesthetic requirements preferred by the industry include (1) the availability of a wide range of design options with different colours, sizes, and textures, (2) compatibility with existing building components and construction processes, (3) the possibility of colour and size adjustments (customisation), and (4) affordability of diverse design options.

Australia's property and real estate market is booming daily; thus, improving the building's marketing value by any means possible is highly recommended. Aesthetic value is one of the key factors increasing the building's marketing value. When it is combined with sustainability and green concepts, the outcome is more favoured. However, this combination should be affordable and provide real money value. PV modules can be integrated into buildings by making them explicitly visible or not recognisable (IEA, 2020). Both BIPV application methods are essential; for example, explicitly visible BIPV facades can encourage the technology and build a reputation. BIPV buildings that can promote themselves are more suitable for the current Australian niche market.

Public procurement practices: Public procurement practices for BIPV are not well recognised as a practice in Australia. The government has financially supported a few BIPV projects primarily attached to state-owned buildings. Commercial buildings are funded through grants allocated for renewable energy applications. However, there is no specific public procurement practice for BIPV-generated electricity in Australia other than the general power purchase agreements (PPA) and power leasing agreements (PLA) (Australian Competition & Consumer Commission, 2022). A solar power purchasing agreement is a contract between a solar provider and a purchaser. The solar provider installs and maintains the system in exchange for the purchaser agreeing to buy the produced energy for a specified price and time. A solar leasing agreement is a contract between the solar provider and a client. The solar provider installs the system in exchange for the client's regular repayments for an agreed time. However, these agreements are common to all renewable energy sources. Another common public procurement practice is tendering between approved solar retailers and the government (Clean Energy Council, 2018). This provision is also not specific to BIPV.

Stakeholders' conduct/ practice: Every stakeholder group (i.e., architects, ESD consultants, BIPV builders and project developers, among others) has a set of rules outlining the standards, roles and responsibilities of their company. Furthermore, there are proper practices to be followed while executing a project. All building stakeholders in Australia follow complex institutions like the minimum energy performance and Green Star requirements. Moreover, they acknowledge the sustainability requirements while developing a project. Other than these basic requirements, some stakeholders focus on delivering more eco-friendly buildings to society. Solar energy is highly recognised in Australia and is often installed in building projects. However, most solar systems installed in Australian buildings are BAPV due to their affordability, technical advancement and favourable policies.

The most common best practice among BIPV suppliers, distributors and installers in Australia is ensuring product quality and customizability. They focus on importing trusted brands and building strong relationships with manufacturers and customers. Some other practices that are preferred by the BIPV building industry in Australia are: (1) BIPV suppliers' involvement in the early stages of the construction project (i.e., design stage), (2) effective cross-sector stakeholder collaboration and communication, (3) BIM-enabled BIPV designing and optimisation, and (5) safety and quality assurance. The socio-economic research on BIPV adoption and application in Australia highly focusses on the above areas.

3.3.2 Hard Institutions

Hard institutions in Australia can be discussed under three areas: (1) rules, codes, and standards, (2) government support programmes, and (3) public procurement regulations. The rules, codes and standards can be national or/and international, whereas government support programmes and public procurement regulations are mostly at the national and/or state level.

Rules, codes and standards: The Australian building industry does not have BIPV-specific rules, codes and standards. Nevertheless, several rules, codes, and standards are relevant to implementing BIPV building construction and systems. The Renewable Energy (Electricity) Act 2000 and Renewable Energy (Electricity) Regulations 2001 are the two central Acts and regulations applicable to BIPV building construction (Clean Energy Regulator, 2021). BIPV projects should also follow the relevant codes and standards imposed by the Australian Building Codes Board (ABCB) and Standards Australia. The ABCB provides the National Construction Code (NCC), which sets the minimum required level for the safety, health, amenity, accessibility, and sustainability of certain buildings (ABCB, 2019). Standards Australia provides the Australian standards and Australian/New Zealand standards related to technical and commercial aspects (Standards Australia, 2021). Furthermore, the Australian

BIPV sector follows the relevant international standards for all electrical, electronic and related technologies introduced by the International Electrotechnical Commission (IEC) (APVA, 2009).

The Australian standards authorities are currently looking into the BIPV-specific international standards enforced globally to develop local BIPV standards; however, this is still at the conceptual and academic levels. These international standards provide a proper framework to commence the work; however, they should be evaluated before being applied in Australia.

Government support programmes: The Australian government strongly supports renewable energy adoption and thus provides many support programmes. Most of these programmes are common to all renewable energy sources; however, some are specific to rooftop solar PV and battery systems. Many of these support programmes are conducted by the State governments; therefore, they differ slightly from one state to another. Federal government also undertakes a few national-level support schemes. Furthermore, a low-cost loan for the transitions to energy efficiency homes for technologies such as solar panels and double glazing is allocated (Green Building Council, 2023). However, there are limited government support programmes to commit to BIPV technologies and applications directly. Table 3 lists support programmes available for solar PV applications, thus applicable to BIPV applications.

Table 3: Government support programmes for solar PV adoption

Sources: Clean Energy Council (2018), Department of Industry, Science, Energy and Resources (2022), Solar Victoria (2021)

Support Programme	National/ State	Explanation
Small-scale Renewable Energy Scheme (SRES)	National	Offers a financial incentive for households and businesses to install small-scale renewable energy systems. This incentive is provided as small-scale technology certificates (STCs). They are issued upfront, considering the system's anticipated power generation based on the installation date and geographical location until the SRES expires in 2030.
Solar homes programme – Victoria	State	**Solar panel rebates for homeowners and rental properties:** A rebate of up to AUD 1,400 is offered to homeowners and rental properties for any solar system installation. Households can also apply for an interest-free loan equivalent to the rebate amount. This loan can be repaid over four years or as a single repayment before the completion of four years. **Solar battery rebate:** Victorian households can receive up to a maximum of AUD 3,500 point-of-sale discount to install a solar battery. **Solar for businesses:** This rebate allows small businesses to install a solar system. It will cover up

		to 50% of the rooftop solar system cost with a maximum rebate of AUD 3,500. **Solar PV panel assistance for landlords and renters:** A rebate of up to AUD 1,400 for solar system installation is given to landlords and renters. Landlords and renters can also apply for an interest-free loan equivalent to the rebate.
Next-Generation Energy Storage Grants – Australian Capital Territory	State	Rebate is given to households and businesses to install a battery storage unit coupled with a new or existing solar PV system.
Smart Distributed Batteries project – New South Wales	State	Provides a point-of-sale discount to residential and small businesses to install battery storage.
Home and Business Battery Scheme – Northern Territory	State	Provides AUD 6,000 grant to homeowners, businesses, not-for-profit and community organisations to purchase and install solar PV systems, eligible batteries, and inverters. Owners can apply for this grant for the current PV system to purchase and install a battery and inverter.
Home Battery Scheme – South Australia	State	Provides subsidies and loans up to AUD 3000 to install home battery systems.
Feed-in-Tariff (All states)	State	Provides payment for the surplus solar energy feeding to the grid. The FiT rates differ from state to state and retailer to retailer. In some states, the government regulates the minimum tariffs; however, retailers mostly decide these rates.

Public procurement regulations: Public procurement is not well discussed or explained with respect to BIPV technologies and applications. However, independently distributed energy generators, such as PV system owners, are supervised by the Australian Energy Regulator (AER) if they are engaged in solar power purchase agreements (SPPA) (Australian Energy Regulator, 2014). Further, solar energy suppliers via SPPA should have an exemption under the National Energy Retail Law (Australian Competition and Consumer Commission, 2022).

4 PHASE OF DEVELOPMENT AND TARGET DEFINITION

As a building material element and a renewable energy source, BIPV is acknowledged gradually by Australian building practitioners and property owners. Only a few BIPV applications and a few actors exist in the market. Most BIPV installations are apparently demonstration projects. Currently, various types of BIPV applications are available, and they can be characterised as continuous roofs, discontinuous roofs, skylights, balustrades, curtain walls, rainscreens, double-skin façades, shading devices and windows. BIPV application development phases are segmented by the applications (Figure 3).

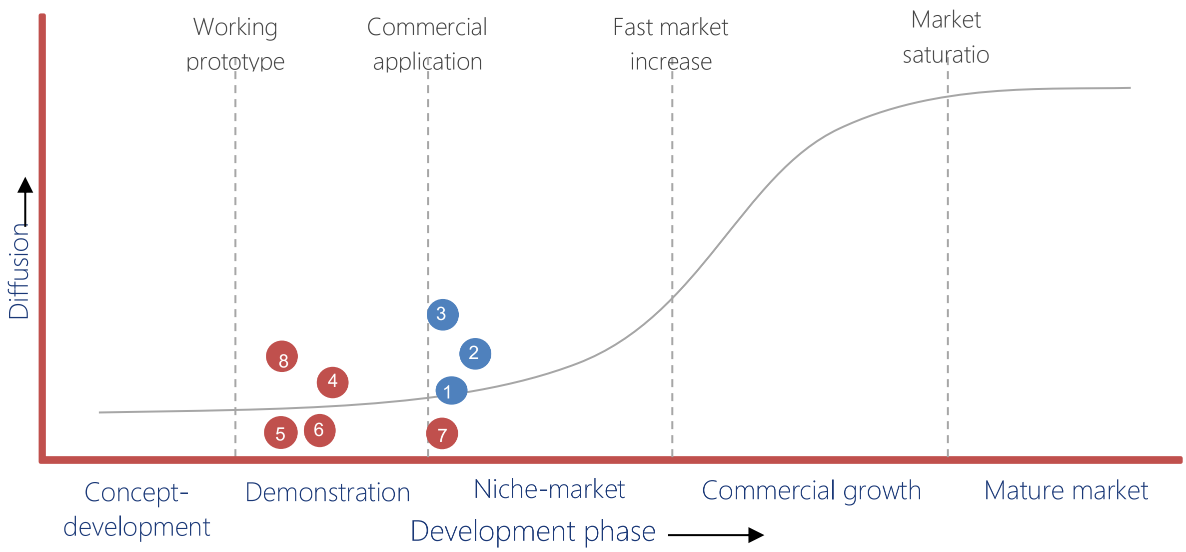

Figure 3. Development phases for BIPV in Australia.

(Blue circles indicate roof-integrated solutions and orange circles indicate façade-integrated or externally integrated solutions. Numbers in the circles indicate the sub-division: continuous roofs (1), discontinuous roofs (2), skylights (3), balustrades (4), curtain walls/double skin facades (5), windows (6), rainscreens (7) and shading devices (8))

Concept development implies that new concepts, prototypes and models are developed and tested on a limited or small scale. Demonstration means that prototypes and concepts are further developed into functional units and systems that illustrate the technology's functionality in environments that enable feedback from potential customers and society. A niche market implies technology is launched in naturally occurring or politically constructed niche markets. In these markets, the technology is not fully exposed to competition from other mature technologies and can still receive valuable feedback from customers and users. Commercial growth implies the technology becomes competitive with established alternatives and is starting to spread in mass markets. A mature market suggests that technology replaces existing technologies to a significant degree, thereby causing a restructuring of society's production and consumption systems.

Roof applications representing continuous roofs (1), discontinuous roofs (2) and skylights (3) have been installed in many buildings. These applications can be emphasised in niche markets as there are several projects, most of them applying commercialised units. In recent years, like in 2016, roof sheets with c-Si technology and skylights with a-Si technology with different transparency levels have been installed in several buildings. A few buildings have installed BIPV as pergolas or canopies. However, these projects represent a small capacity and are installed in both new and retrofitted phases of the buildings. A few BIPV suppliers/distributors in the market provide these devices. They are also in the early stage of their business operations in Australia. With the current installations, it is noticed that the adoption is slow.

BIPV roof tile/roof sheet applications have been installed mainly in residential buildings. There is a significant demand for roof-integrated systems amongst residential property owners, particularly high-end customers. However, BIPV is not the building practitioners' first choice for the green concept, nor do the property owners request it. They often prefer BAPV applications due to availability, flexibility costs and higher offers in the market. Yet, the residential property owners who dislike the appearance of integrating BAPV panels on their roof seek alternative solar options. A few entities whose primary business is solar applications offer roof tile systems to property owners in Australia. They supply a range of roof tiles and sheets costing 8,000–18,000 AUD for a 4-kW system (Choice, 2017). Noticeable applications exist in this roofing category, implying a niche market.

A few BIPV façade systems have been installed in non-domestic buildings since 2000. Semi-transparent façades represented the first attempt at BIPV in high-rise buildings. Recently, an apartment building had BIPV modules as balcony glass balustrades and educational buildings have incorporated BIPV curtain walls. BIPV has also been installed as a window or in an arcade in several properties. Rainscreen façades have garnered much attention recently. Commercial buildings in Melbourne have obtained approval to commission rainscreen BIPV facades, such as the Cbus property and Spencer St in Melbourne City (Riches, 2021; Miletic, 2022). BIPV as a shading device has rarely been seen in the Australian built environment. Façade-integrated systems have been activated across states. However, only a few systems exist from each type. Most of these projects were demonstration projects as one of their kind, of small capacity. They feed a significant amount of energy to the building's energy needs. These products can be classified as demonstrations due to the small number of installations. However, similar modules are commercially available for new installations. A significant demand for BIPV installations in non-domestic buildings has been identified as an innovative technology (Appendix: Major BIPV projects in Australia). The number of BIPV suppliers/distributors has increased today, and they sell various modules. Also, the number of property owners interested in BIPV has grown recently. The market has expanded to new and retrofitted and even historic buildings.

R&D institutes and universities have installed several BIPV roof and façade applications in Australia as prototypes or testing facilities. The intention is to develop a high-efficiency module with alternative materials. However, most of them were not promoted as commercial installations. Therefore, some products were in the concept development phase.

Currently, the market is driven by a small number of small and medium-scale enterprises (SMEs). They are locally operated businesses with various partnerships with foreign entities. A variety of BIPV modules, such as different technologies (c-Si, a-Si and CIGS), transparency levels and application types, are viewed in the industry as commercial products. However, annual sales are meagre; less than one MW of units are installed annually (APVI, 2019).

The different applications of BIPV are mainly found in the demonstration and niche markets. However, none of the products and actors are in the commercial growth market where mature markets or competition exist. It also welcomes innovative modules, actors, and relevant policies in the market to move forwards. Although recent experience provides evidence for a slow growth of BIPV in each category, there is a potential for transition to the commercial development of BIPV in Australia. The intension of the stakeholders is to develop a mature market for BIPV in providing sustainable built environment.

5 FUNCTIONAL ANALYSIS

The functional analysis represents the primary analysis of the TIS analysis. Eight functions (Hellsmark et al., 2014, p. 20–22) are analysed for the functional analysis as follows:

- Knowledge development
- Knowledge dissemination
- Entrepreneurial experimentation
- Resource mobilisation
- Development of social capital
- Legitimation
- Guidance of the search
- Market formation

5.1 Knowledge development

Knowledge development embraces the current knowledge spread across the value chain. Knowledge required for this technology has been developed over the years via multiple aspects across the value chain in Australia. The scientific knowledge has been developed by various research institutes in Australia, such as CSIRO, Monash University, RMIT University, University of New South Wales and the University of Newcastle. They research multiple factors, such as socio-technical deployment, module technologies, and building and designing software applications. BIPV-related prototypes, cells and panels are developed and experimented with in their laboratories to deliver systems catering to the current requirements. Technical knowledge is shared among a few professionals or groups in the building, construction and PV sectors. Some building professionals are unaware of the technology and possess less technical knowledge to perform their specific tasks. A handful of professionals, such as architects, engineers, BIPV designers, façade installers and electricians, provide expert technical knowledge. Lack of technical knowledge, skills and competencies brings various challenges in designing and installing the system. Limited specific tools or software are available for developing BIPV applications, although many software programmes are available for creating and monitoring rooftop solar PV applications. Such design complexities have become a prevailing barrier to technology deployment. Funded by ARENA, the 'BIPV Enabler' becomes a tool that facilitates designing BIPV applications in Australia, which is at the industry pilot stage. It would be a valuable addition for many stakeholders in designing and promoting the systems. The technical knowledge generated by the stakeholders is limited and not shared across the BIPV value chain; some universities introduced coloured BIPV modules and printed modules, whereas some have tested on different energy storage systems. Various pilot installations have been identified in universities like RMIT and the University of Melbourne. However, most of these products are customised. The knowledge currently developed by the academic and scientific sectors seems sufficient.

A few leading researchers and experts have primarily contributed to developing BIPV knowledge in Australia via academic papers, industry reports and IEA PVPS reports. The PV and building and construction professionals contribute to knowledge development despite the academic leadership. Scientists and researchers have published their knowledge via various sources such as publications, books, reports and newspapers. Around 50 publications in scientific journals have been included in the Web of Science database over the past years. These articles focussed on multiple aspects of BIPV, such as testing technology and applications, social and economic aspects and deployment, and demonstration cases. In addition, a few books covering design principles/methods and installations have been published: *Designing with Solar Power: A Source Book for Building Integrated Photovoltaics (BIPV)* (Prasad and Snow, 2005). Furthermore, the Centre for a Sustainable Built Environment in the University of New South Wales introduced best practice guidelines for solar power building projects in Australia in 2005, providing a reliable guide on developing and implementing solar PV buildings from feasibility to decommissioning (UNSW, 2005). The guideline highlights the above practices and the importance of evaluating (1) building performance against the client-imposed targets, (2) architectural quality, (3) structural stability, (4) multiple design options for selecting the best option, (5) BIPV technology specifics, (6) planning approval, (7) skilled labour availability, (8) project scheduling, (9) safety and compliance with the standards, codes and regulations, (10) system monitoring, and (11) appropriate recycling/decommissioning. These guidelines were published in 2005 and require an updated version. Nevertheless, scientific knowledge development in Australia is rapidly increasing, and numerous relevant publications and research are good sources of knowledge.

It is also noticed that only a handful of patents are registered in Australia. According to the WIPO IP Portal search using terms such as ‘BIPV’ and ‘solar sheet’, a few patents exist for Australia. The patents are for BIPV modules and other integrated systems. Some of the patents were published years ago.

Knowledge and awareness of BIPV among the building and PV sector professionals and end users, such as property owners and developers, are minimal. The idea of BIPV is not identified among most architects, designers, builders, engineers and even within PV sectors, particularly with small and medium-scale constructions. A few professionals are practising and recommending this technology, which is still considered to be a luxury technology in the Australian Built environment. The actors in knowledge creation are limited, although they work individually and collaboratively to develop knowledge. The initiation of a BIPV alliance (BIPVA), government support schemes to promote BIPV developments, etc., could expand knowledge development in Australia.

Summary: Although research units and educational institutes develop scientific and academic knowledge in collaboration with the industry at a satisfactory level, the technical knowledge passed by the experts to practitioners is minimal. Necessary resources such as software applications, product specifications, guides and workshops are limited and not shared among a wide market. Due to the lack of expertise in the market, several knowledge gaps, such as fire safety design criteria, among others, have been identified. More importantly, an insignificant amount of knowledge about BIPV products, installations and design and its functionality is delivered to the public or potential adopters, creating fewer appetites for the technology. A slight knowledge pool is developed from the industry because of the smaller number of players in this sector. Also, this knowledge is not distributed across the BIPV value chain equally. Therefore, this function is weak in Australia.

5.2 Knowledge dissemination

A successful implementation, along with the rapid deployment of technology itself, requires knowledge dissemination from multiple sources. Knowledge dissemination embraces how developed knowledge is diffused across the supply chain. Various information distribution and diffusion methods have been adopted in the current industry. A few parties are involved in spreading the knowledge across the supply chain.

BIPV manufacturers, suppliers, and several building professionals such as architects, builders and ESD consultants maintain project-related information on their websites. The information, including basic characteristics, is made available on their online platforms. More importantly, details on their completed BIPV projects, including key characteristics, capacities and lessons learned, were included. Such information from the demonstration cases helps build confidence among stakeholders to uptake BIPV. However, their data are scattered, and no single platform or database can provide the access to all – information.

BIPV knowledge has been disseminated via workshops, conferences and exhibitions in Australia. Industry partners and academics individually and collaboratively coordinate various private workshops disseminating information. Recently, a limited number of workshops, such as those conducted by RMIT University and Engineers Australia, were held. These workshops facilitate an increase in publicity, particularly among the building professionals. BIPV suppliers/distributors use workshops for building professionals and potential adapters to inform about their products and disseminate knowledge on BIPV.

BIPV is also significantly acknowledged in PV-related exhibitions. For example, in the annual Australian renewable energy exhibition, BIPV manufacturers and distributors display their products, whereas others, such as architects, builders, and potential adopters, acquire knowledge. Unfortunately, many participants are from the energy sector rather than the building sector, in which more workshops will be organised for the building professionals. The workshops and exhibitions provide universities or research institutes opportunities to deliver their knowledge to the industry and academic platforms.

Publications such as newspaper articles, magazines, blogs and publications distribute information on BIPV. Of them, the news articles, such as ‘PVmagazine’, ‘realcommercial’ and CoINVEST, generally publish the status of BIPV in Australia.

Knowledge diffusion by the upstream actors is limited; a few suppliers are in the market. With less product availability, comparisons and choices for diverse panels are limited for potential adopters and other interested parties. The information has been shared weakly among the small and medium-scale entities, particularly in the building sector. Most downstream actors are also unaware of the current possibilities for BIPV in Australia. Information shared by the current BIPV owners and relevant experienced parties is only within a niche market where their presence is crucial. Information is not served equally and adequately across value chain.

Further, authorities' involvement in disseminating knowledge has been observed occasionally in Australia. Although there are many programmes/initiatives for deploying renewable energy applications, explicitly aiming for BIPV is not supported by the authorities. Relevant authorities could publish guidelines and reports to regulate this technology. Knowledge diffusion by the various apprenticeship programmes and technical workshops or appropriate programmes is unseen as there are no such BIPV-specific programmes. It is apparent that with the guidance and target initiatives by the regulators/authorities, many more educational programmes could emerge and lead to specific skilled knowledge across the value chain.

Technical knowledge is shared among a few professionals or groups in the building, construction and PV sectors. Some building professionals are unaware of the technology and possess less technical knowledge to perform their specific tasks. There is little understanding of the range of technologies and designs available in the market due to the limited number of suppliers/distributors and lack of information-sharing platforms. The building industry has not concerned itself with detailed knowledge of the installation in both new and retrofitted building phases. Moreover, most BIPV installations are tested on educational buildings, whereas projects should be tested on other building categories to establish trust and confidence among the potential adopters. More awareness and knowledge distribution programmes are essential for BIPV development in Australia.

Summary: Technical knowledge is not adequately disseminated. Building professionals, including architects and engineers, face difficulties while designing and installing BIPV systems due to a lack of information on installations and design tools. Also, their inactive collaborations. Further, there is a scarcity of apprentice programs or training programs for BIPV. Knowledge diffusion is essential to eliminate the current myths of BIPV, such as not being suitable for investment and technical complexities. The social acceptance of technology can be increased when knowledge is well circulated. Although knowledge dissemination exists, it is weak in Australia.

5.3 Entrepreneurship

Entrepreneurship is uncertainty-inherent, with opportunities for both upstream and downstream business and innovation. Entrepreneurial experimentation in the Australian BIPV sector can be discussed from multiple perspectives along the value chain. Local and foreign firms have been entering the market since the 2000s. These firms operate in different forms to conduct business. Only a few local companies own the technological IP; most manufacturing plants are overseas. Several local companies ally with foreign BIPV manufacturers or suppliers to operate the business locally. Multinational companies have entered the Australian BIPV market independently or with a partnership. In addition, some entities, such as ESD consultants, import BIPV modules in collaboration with foreign entities. Moreover, some institutes collaborate with universities to test versatile BIPV products. In contrast, some spin-off companies emerged because of innovative research outcomes, such as printed modules, high-performance modules and applications. Overall, around ten BIPV module manufacturers and distributors/suppliers currently operate in Australia, supplying international & local brands.

However, at this stage, not all businesses have succeeded in Australia. BIPV manufacturers and suppliers who operated during the early 2000s have left the market due to fewer demands from the building sector. Some local entities are now doing business overseas rather than in Australia. A high capital cost, particularly the cost of manufacturing and transportation (i.e., when they are exported), was one of the barriers in the Australian market. More importantly, the cost comparison of substitutes, such as façade materials, or competing products, such as PV modules, should be considered in the lifecycle cost benefit assessment of BIPV projects. There is limited integration and collaboration between the PV and building industries for successfully deploying BIPV. BIPV maintenance is not significantly considered in the industry and lacks related knowledge.

Apart from business opportunities, it is crucial to invent innovative modules and features of BOS. An aesthetically appealing module is vital to attract building sectors. The critical aesthetic requirements preferred by the industry include (1) the availability of a broad range of design options with different colours, sizes and textures, (2) compatibility with existing building components and construction processes, (3) the possibility of colour and size adjustments (customisation), and (4) the affordability of diverse design options. It is highly unlikely that BIPV manufacturer within Australia can fulfil all the above requirements; however, many suppliers can supply aesthetically enhanced BIPV products to Australia. The stakeholders involved in residential building construction (i.e., volume builders and design consultants) are primarily interested in BIPV roof tiles because other types cannot be effectively used in single-storey houses. Recent systems are mostly roof-integrated systems such as skylights, pergolas, roofing sheets and roof tiles. The BIPV roof tile market is continuously growing among residential properties. In general, BIPV façade types are popular among high-rise buildings. A few suppliers provide modules such as cladding materials, balconies and windows. These systems have been installed in a few buildings (more than 20) during the new and refurbishment construction stages, which is not widely open to potential adopters. Apart from considering energy and aesthetics, they accept modules that comply with Australian building codes, especially concerning fire safety. There is a growing concern among mid-rise and high-rise building owners for systems that potentially pass the building tests, such as for fire safety, wind load and water resistance. BIPV is gradually becoming popular in the building industry, especially in commercial mid to high-rise building construction, when BIPV could satisfy the above features when competing against conventional building construction. It is encouraging to see several universities and research institutes experimenting on BIPV. The value chain of the BIPV can be expanded for prefabricated modules to be easily integrated into the buildings. Innovations are crucial for harnessing electricity at an attractive cost on a large scale, which is to be solved by research.

Summary: Entrepreneurial experimentation in Australia is weak because there is a limited market entrance, and it addresses few demands/requirements of the adopters. However, entrepreneurs have more opportunities to implement various BIPV applications for different market segments. Innovative and aesthetic modules that comply with the building codes are always welcomed in the industry. A large-scale BIPV module that can cater to a substantial amount of building energy is still absent; however, it is much needed in Australia. Such projects can be noticeable examples of promoting and making potential buyers confident.

5.4 Resources mobilisation

Resources mobilisation denotes the resources, such as competencies, financial capital and complementary assets, needed to mobilise this innovation system. According to the National Survey Report of PV Applications in Australia 2020 (APVI, 2021), a very slow uptake can be observed in adopting BIPV applications. Therefore, a significant increase in local BIPV-related materials, human resources, financial aids and technological advances cannot be seen.

There is no evidence that Australia uses its raw materials for BIPV manufacturing. Only one PV manufacturer is available in Australia (Energy Matters, 2021); however, multiple suppliers and distributors exist. Local manufacturing is not cost-effective at this stage due to the material shortage, high capital costs and lack of government support. Compared to local manufacturing, the BIPV module import offers the better option. Therefore, the country imports PV modules from regions such as Europe and China. Scarcity is visible in availability of diverse materials in Australian market, and there are not enough suppliers to accelerate BIPV uptake.

A lack of expertise can be observed in BIPV design and installation; nevertheless, a booming interest in using BIPV is visible in the Australian market. A ray of hope is shining in BIPV-related R&D, as several leading institutes and universities are researching technical, economic, social and environmental aspects of BIPV adoption with promising outcomes. BIPV-related academic and industry training is hardly available in Australia. The current academic approach is to teach BIPV as a part of construction and building - related modules.

BIPV-specific financial schemes, loans/mortgage schemes, policies or incentives are limited in Australia. Most of the current policies and incentives are common for PV and renewable applications. Moreover, entrepreneurs can apply for funding from authorities such as ARENA, CEFC, Victorian Building Authority and CRC-P to conduct BIPV R&D research. These authorities funded a few projects, such as developing a prototype, new module, and software, among others, as development and encouragement for the sector. Moreover, the Western Australian Government assists a local BIPV company in manufacturing their core components onshore (Roberts, 2023). Such government encouragement with respect to BIPV-related R&D and significant funding could be positive for the market.

Technical advancement of BIPV can only be seen at the R&D level. Several R&D projects that examine cell efficiency, BIPV design and management, and BIPV materials are present. Australia prepares for infrastructure developments for renewable energy applications. The grid-related issues specific to BIPV systems are not identified at this stage. Traditional standalone PV systems have intermittent output, typically starting to ramp up in the morning, peaking at noon, and reducing near twilight. By contrast, BIPV modules with a vertical plane of array usually ramp up their output earlier and reduce output later, as the vertical surface receives more direct irradiance during dawn and/or twilight, depending on orientation. Hence, there is a potential to fully utilise the PV energy by the building throughout the day. Infrastructure development is primarily considered for rooftop PVs because of the massive demand. Australia currently maintains a stable grid-connected PV system without any interruptions. However, research is conducted at academic and industrial levels to identify solutions for increasing solar feed to the grid, and South Australia is already introducing such solutions on a widespread commercial scale.

Summary. BIPV modules are not manufactured in Australia; therefore, the associated materials, financial aid, technologies and human resources are not currently used. Importing BIPV modules is the primary method of material acquisition. Scarcity can be witnessed in skilled labour and expert knowledge. R&D on BIPV is encouraging and demonstrates a promising future. Overall, BIPV-related resource availability in Australia is weak now.

5.5 Development of social capital

The development of social capital implies creating and sustaining social relationships. A significant social relationship among actors cannot be observed in the Australian BIPV industry. In general, the clients, building owners, building developers, investors and building occupiers prefer BIPV adoption if it primarily balances the economic, environmental and aesthetic values. The lack of awareness is a prominent issue. Most clients and building industry professionals are unaware of BIPV products, prices, benefits and technology. Very few building professionals have the skillset to adopt BIPV in their projects. In addition, most are not confident to propose this system as a sustainable application. Such confidence can be built via social capital or interpersonal trust.

The limited integration and collaboration between the PV and building industries have created distrust in BIPV adoption. BIPV requires the early consideration of the PV component during the project's design stage; therefore, an appropriate collaboration is needed. Nevertheless, the Australian building industry is highly segregated when considering the relationships between building professionals throughout the building life cycle and the relationship between the building industry and other related industries. Integration and collaboration can build mutual trust between the building and PV industries. One of the success factors for the rapid growth of PV would be word of mouth or existing project owners. It is also evident from the industry that having a successful project could create a trend to implement similar projects. However, only a few projects exist here to retain trust and build social assurance. Moreover, word-of-mouth publicity is not strongly evident in the Australian BIPV market.

Knowledge dissemination on BIPV is the correct pathway for BIPV academia; however, knowledge dissemination to the public is insufficient in Australia. The research institutes and universities studying BIPV are keen to publish their findings; however, the knowledge of product details, varieties, and how BIPV can deliver economic and environmental benefits is not widespread. Although PV is a prevalent topic among Australians, few Australians know about BIPV. A limited number of actors in the segments upstream and downstream of the supply chain also presents a shortcoming for social capital.

BIPV projects are widely spread across states in Australia. However, a BIPV community hardly exists. Although several professionals are working together to deliver a complete design service to installations, there is no transparent nationwide platform to share the information, even among the project owners and professionals. A BIPV alliance, which is being developed, would be one approach to build trust. Sharing and informing on lessons learned from experience could be a beneficial factor in building stakeholder trust.

Summary. The building and PV industries' segregated nature and lack of collaboration and communications have hindered the development of trust and confidence in BIPV adoption in the Australian BIPV industry. Public awareness by the researchers and demonstration cases can build up substantial social capital in the market. The development of social capital is weak.

5.6 Legitimation

Legitimation implies social acceptance and compliance with an institutional framework. BIPV is not adequately articulated in the PV market in Australia. BIPV is recognised as an effective green building construction method in Australia. Some adopt BIPV to preserve a sustainable image or reputation. However, the social acceptance of BIPV is still inadequate for it to go beyond the niche market. The public acceptance of BIPV as an architectural outlook and energy efficiency is still experimental. Nevertheless, the building industry cannot see solid resistance to BIPV adoption.

Moreover, the high costs of BIPV cause less legitimacy in the market. A lack of understanding of the total costs and economic contributions and the lack of valuing aesthetic and other added values of BIPV would further stress the high costs. Attractive costs and economic benefits could better position the BIPV. Furthermore, some project owners do not recommend this due to low energy generation and high costs. BIPV systems can be less efficient than rooftop PV due to the architectural constraints and the commonly lower efficiency of BIPV modules than their equivalent standard ones. In contrast, BIPV always offsets the building material costs and adds aesthetic appeal, which cannot be obtained through rooftop PV. Some professionals are still reluctant to admit BIPV as a building envelope option similar to facades. Accordingly, there are several myths about BIPV in society, which can be removed via trust and confidence.

Australia has very limited BIPV-specific rules, regulations or policies; however, policy-related research is available for recommendations. BIPV products are treated as conventional PV products and are being registered with the Clean Energy Council. However, there are limited procedures to certify BIPV products as a building material. It is essential to pass the different kinds of testing (i.e., fire safety, structural stability) before installing BIPV or any building façade material; however, Australian building codes do not provide specific rules for BIPV testing. These products are indeed tested abroad by the manufacturer and their building sectors; nevertheless, there is no guarantee that they comply with Australian standards. The current institutional frameworks are developed for renewable energy or specifically for PV. However, a booming interest in enhancing rules in the existing institutional framework, conformance to existing institutional frameworks such as standardisation, and the creation of a new institutional framework can be evidenced in Australian BIPV-related R&D. BIPV must follow two sets of regulation schemes: (1) building codes and regulations and (2) electrical codes and regulations. For current BIPV developments, these codes and other related regulations must be followed. Table 4 documents several codes and regulations applicable to BIPV.

Table 3: Codes and Standards applicable to BIPV

Source: APVA (2009), Australian Business Licence and Information Service (ABLIS) (2022), ABCB (2019), Standards Australia (2021)

Code/ Standard	National/International	Applicability to BIPV
		Codes (NCC)
B1	National	Structural provisions: performance requirements and verification methods
C1.9	National	Requirements on non-combustible building elements
C1.10	National	Requirements on fire hazard properties
C1.11	National	Performance requirements on external walls in fire
C1.14	National	Requirements on ancillary elements (non-combustibility)
C2.5	National	Protection of the residents in Class 9a and 9c buildings from the spread of fire and smoke (class 9a buildings – health care buildings, class 9c buildings – aged care buildings)
C2.6	National	Vertical separation of openings in external walls (Minimising the fire spread from one floor to another)
C3.2	National	Protection requirements of openings in external walls
C3.3	National	Separation of external walls and associated openings in different fire compartments (to limit the spread of fire)
C3.4	National	Acceptable methods of protection are required for different types of openings in a building
C3.8	National	Protection requirements on openings in fire-isolated exits
C3.11	National	Bounding construction: Class 2 and 3 buildings and Class 4 parts
National and international standards		
AS/NZS 3000	National	Provides standards for electrical installations to buildings, structures and premises and SAA wiring rules. Applicable to BIPV in terms of installation requirements, protection against overcurrent, protection against the spread of fire, protection against overvoltage, protection against arcing fault, cabling, selection of PV system and installation
AS/NZS 5033	National	Provides standards for the installation of PV arrays. Applicable to BIPV in terms of protection against electrical shock, overcurrent, earth fault, lightning and overvoltage, PV component requirement, PV

		installation, PV isolation methods, installation of disconnection devices and fire tests
AS 1530	National	Provides the methods for fire tests on building materials, components and structures. Subsections AS 1530.1 are about combustibility, AS1530.3 is about evacuation and smoke development, AS1530.4 is about the fire-resistance level
AS/NZS 1170	National	Provides standards about minimum design loads on structures. Subsection AS/NZS 1170.2 is about the wind load
AS/NZS 1768	National	Explains lightning protection
AS 1931.1	National	Explains about high voltage test requirements
AS 3008	National	Provides standards for cable selection
AS 3100	National	Explains about the approval and test specification of electrical equipment
AS 3595	National	Provides standards on energy management programmes
AS/NZS 3131	National	Explains the approval and test specification of plugs and socket outlets for use in the installation wirings
AS / NZS 4509.1	National	Provides standards about stand-alone power systems: safety and installation (Part 1)
AS / NZS 4777.1	National	Provides standards about the grid connection of energy systems via inverters: installation requirements
AS 4086.2	National	Provides standards about the secondary batteries for use with standalone power systems: installation and maintenance
IEC 61215	International	Explains the design qualification and type approval of crystalline silicon terrestrial PV modules
IEC 61730-1	International	Explains the requirements for construction, particularly PV module safety qualification (Part 1)
IEC 61730-2	International	Explains the requirements for testing, particularly about PV module safety qualification (Part 2)
IEC 62109	International	Provides PV module safety qualification Series

The lack of BIPV-specific product and process standards has become an issue for the Australian BIPV industry. It can cause many expensive issues, such as confusion, project delays, getting approval and assuring safety. Therefore, the need for creating a new BIPV-specific policy framework has increased over the past decade.

The federal government and other relevant authorities could reinforce the legitimacy of such innovative technology. Their actions enhance social acceptance and encouragement. For instance, the National Construction Code (NCC) has updated its energy-efficient home initiatives, primarily focussing on solar PV applications. Although it is not about BIPV, such attention would also increase the growth of vertical solar PV. Furthermore, the Victoria Building Authority and other institutes are interested in BIPV. Therefore, the responsibility of BIPV legitimation could also lie with the government and authorities in Australia. While the universities and research institutes provide academic recommendations, the government must establish an appropriate framework for BIPV adoption. It is recommended that BIPV standards should be imposed internationally under three categories: 'internationally mandatory', 'useful to design BIPV' and 'useful to characterise BIPV'; however, the specific characteristics, such as fire safety, seismic resistance, air permeability, water tightness and wind resistance, should have national standards (Yang et al., 2019).

Summary. Positioning the BIPV technologies in the market within the institutional framework is still hidden; however, the regulatory authorities and research institutes have positively discussed about on the impacts of BIPV. Their actions could legitimise and promote social acceptance of BIPV in the Australian market. Currently, BIPV legitimation is weak.

5.7 Guidance of the search

Guidance of the search implies guidance about the innovation system towards the actors. Currently, there is a lack of visions and expectations on the growth and technological design of BIPV technologies with respect to the Australian BIPV industry. The awareness of BIPV technologies among the actors within the building industry is minimal. There are national policies to promote the application of renewable energy in buildings, but there are limited specific requirements for BIPV. Several authorities have taken initiatives to increase renewables in the built environment. For example, CEFC provides low-cost loans for double glazing, solar panels and other improvements (GBCA, 2023). Furthermore, some recognised authorities recommend this technology as a sustainable application in their reports; however, it is not regulated. Australia is now on the road map of reaching renewable energy targets, and many strategies are being initiated in political agendas. However, much of the guidance is directed towards BAPV rather than BIPV. Most of the incentives aim to expand BAPV and utility-scale PV. None of them has addressed the BIPV applications.

Furthermore, the BIPV application in buildings must comply with the building codes and regulations and electrical codes and regulations in Australia. Currently, there are very limited specific requirements related to BIPV envelope designs in the national construction codes in Australia. However, there should be improvements with respect to product information, training and education in Australia's building and construction sector. Also, there should be improvements in projects to promote and compare the benefits of BIPV to BAPV systems.

Summary. Overall, there is a lack of clear vision of how the BIPV market should develop and the policies and regulations related to BIPV in Australia. Therefore, the fulfilment score for the search guidance is weak in Australia.

5.8 Market formation

Market formation implies the current and expected future market size of the technology. BIPV is still a niche market in Australia. Table 1 shows that BIPV applications are minimal compared to PV installation in general. The usual argument is that there is not much competition for land use for the installation of utility-scale PV in Australia. However, this overlooked the great potential benefits of BIPV for stabilising energy supply and enriching energy flexibility in the building sector. The market formation of BIPV in Australia largely depends on technical confidence, available products, financial support schemes and public awareness. Government, entrepreneurs and lead users make various activities to expand the market.

The government or the relevant authorities are inactive on the development and growth of BIPV in Australia. Strong support from the federal, state, and local governments has promoted the rapid growth of standard PV. However, such motivation has not been recognised for the BIPV. The government's intent of delivering flexible, affordable and convenient renewable energy sources for the public is not achieved via BIPV due to its complex technologies and high costs. The involvement of the government could legitimise BIPV in the market.

Currently, there are a few entrepreneurs in the market. The market size could be increased if BIPV is promoted as a building envelope element with higher energy generation capabilities. Known actors typically connect on different platforms; however, stakeholders do not collaborate strongly to expand the market. The market size could be increased with the direct support of the leading players.

Any leading players with high market demand in Australia do not recognise it. The BIPV applications are used chiefly for higher-end projects and demonstrations. Luxury building categories in residential and commercial building sectors mainly accept technology. However, medium-height to high-rise apartments and commercial buildings could be a potential target for expanding Australia's façade-integrated BIPV market. Residential buildings can also be considered for roof-integrated applications. Lack of awareness of the BIPV products, lack of BIPV-related standards and regulations, higher investment costs, and lack of incentives and funding mechanisms are the barriers limiting the expansion of the BIPV market.

Summary. A well-developed BIPV market is essential to improve the application of BIPV technology in Australia. However, as discussed above, several barriers must be overcome to stimulate the growth of the BIPV market. The current market development for BIPV in Australia can be defined as weak.

5.9 Summary of the Functional Analysis

An overall assessment is given for each functional element considering the current context in Australia (Figure 4). The status of eight functions is assessed as 'Weak'. Table 4 summarises the functional analysis, highlighting the strengths and weaknesses.

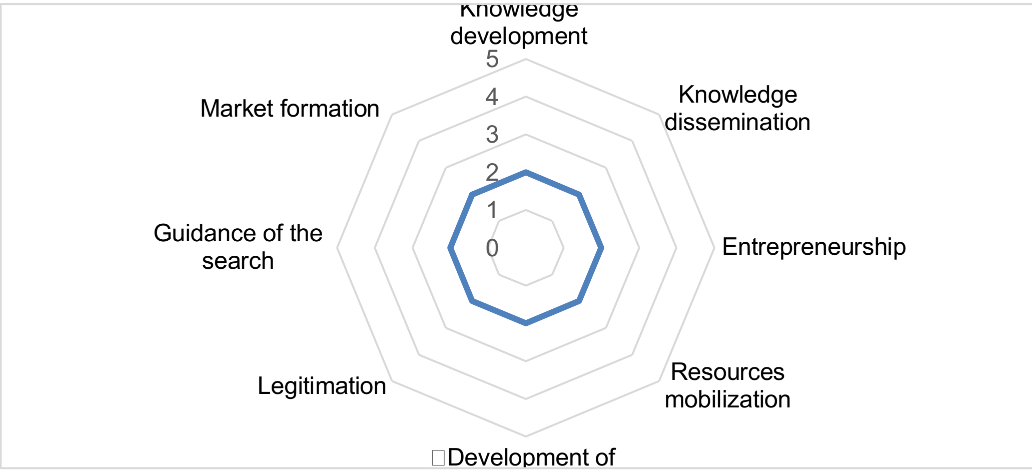

Figure 4: Summary of functional analysis

Table 4: Summary of the functional analysis

Functions	Strengths/Opportunities	Weaknesses	Assessment

Knowledge development	Scientific/academic knowledge generate by a few groups of practitioners Several research projects are continuing and addressing multiple aspects of BIPV Around 40 publications A few specialised academic and industry professionals	Essential knowledge needs to be developed particularly concerning fire safety, designing and installation criteria A small number of patents Insufficient knowledge development for and from technical staff	Weak
Knowledge diffusion	Knowledge of products and actors in the market is slowly increasing BIPV database and tool for designing are available Details of the existing projects are available online Small groups (industry and academics) are promoting and referencing the technology Several exhibitions and workshops, etc., exist PV is recommended by various technical reports, guides and experts	Disinterest from the authorities Limited apprentice/training programme Not the first choice for sustainability due to other alternatives and unawareness Knowledge pool has little access to stakeholders Lack of collaboration among stakeholders across the value chain	Weak
Entrepreneur ship	Increasing interest by international BIPV manufacturers BIPV suppliers/distributors exist (limited) Multinational and local companies enter the market with different partnerships A few new products are emerging with new application types The current requirement is to certify the modules by the Clean Energy Council	Limited products and availability The survival rate of previous companies is meagre Limited large-scale development with architectural design High cost for manufacturing and transportation Modules are not satisfying the customer's requirements Lack of entrepreneurship	Weak
Resources	Booming interest and focus for renewable energy research Increasing R&D on BIPV products and applications Active academic and institutional involvement	Lack of skilled labour and professional expertise Limited educational opportunities Limited BIPV-specific government funding Lack of product availability in the market	Weak
Development of social capital	Initiation of cross-sector collaboration via BIPVA Small group collaborations across states	Segregation between building and PV industries Limited BIPV communities	Weak

		Distrust among supply chain actors	
Legitimation	Recognition as an effective green technology No substantial social resistance High interest in the BIPV-specific policy framework Experts/authorities' recommendations Proper attention is given to building codes, especially related to fire safety	BIPV is often wrongly compared to BAPV with respect to costs, energy, complexity and value addition Issues related to compatibility between imported products and local standards Lack of guidance for the design, installation and operation and certification Limited official recognition	Weak
Guidance of the search	Climate action and policies that encourage the use of renewable energy Recognised as an innovative solution	Lack of vision for BIPV development Lack of BIPV-specific roadmaps and strategies from the government Lack of specific building standards Many substitutes for BIPV, such as façade materials and BAPV modules	Weak
Formation of markets	Market is slowly growing Increasing BIPV façade applications in medium-height to high-rise buildings BIPV rooftiles popular among luxury residential properties Potential for application in new and retrofit projects	Limited stakeholder awareness Lack of incentives and support schemes Insufficient public awareness A niche market Lack of BIPV-specific certificates	Weak

6 IDENTIFYING SYSTEM WEAKNESSES AND STRENGTHS

The functional analysis of TIS identified the weaknesses and strengths of the current BIPV system in Australia. The systemic problems and opportunities were categorised according to Wieczorek and Hekkert (2012) as:

- Actors' problems
- Institutional problems (hard and soft)
- Interaction problems
- Infrastructural problems

6.1 Actors' problems and opportunities

Various actors play in the upstream and downstream value chain of the BIPV in Australia. They represent several industries: the building and construction sector; the PV sector; the utility/energy sector; the property sector; policymakers and perform diverse roles and responsibilities. Several problems and opportunities are:

- There are very few actors specialising in BIPV technology, such as BIPV consultants, manufacturers and engineers. More options should be provided to the local expertise The government and relevant authorities can initiate an accreditation or training/apprentice programme to gain the skills of stakeholders.
- The majority of the stakeholders from the building and construction sector has very limited engagement and are unaware of the technology or unable to quantify the real benefits in terms of economic, environmental and social aspects of BIPV, as most of the information is not accessible to the broader market. Also, industry should be able to communicate a clear vision for the market. A proper communication channels or common platforms for sharing knowledge and proper tools is necessary.
- Most actors concern new technologies/methods as they are more comfortable with traditional technology. Some actors propose rooftop PV as a sustainable option but are reluctant to shift to alternative renewable energy sources. Further, a lack of holistic facade and roof solutions have restrained the demand.
- There is low demand from property owners, which leads to frustration with the current suppliers or distributors. However, a few buildings now accept this technology, creating a positive demand. More demands can be seen when systems are attractive in terms of cost, aesthetic appeal, and compliance with building codes.
- Manufacturers and other actors have limited financial capabilities to invest in research where positive intervention from the government is needed for both upstream and downstream actors.

6.2 Institutional problems and opportunities

There are two types of institutional problems: (1) presence-related problems and (2) capacity-related problems. Presence-related problems arise when hard and soft institutions are unavailable (Vroon et al., 2022). Capacity-related problems arise when hard and soft institutions do not meet the required quality.

Soft institutions

- Stakeholder acceptance is limited mainly because of limited understanding of the technology and comparatively expensive cost. Government intervention could provide opportunities to position this technology in the market.
- Insufficient aesthetic expectations have been identified due to the niche and expenses.
- lack of BIPV-specific public procurement practices

Hard institutions

- There are lack of properly articulated BIPV-specific rules, codes and standards. BIPV shall comply with building codes such as fire safety, etc.
- Government support programmes are not directly associated with BIPV, although there are initiatives for renewable energy. At this stage, the government has not identified the direct benefit of BIPV over other renewable energy applications, mainly because of high costs and booming growth of other PV applications.

6.3 Interaction problems and opportunities

The interaction of the BIPV sector refers to the networks and individual contacts in the industry. Deployment and implementation of BIPV require close collaboration of multiple sectors including the building and construction sector and PV sector in Australia. A few weak networks and interactions are present among the BIPV actors in the Australian industry.

- Lack of collaboration between PV, building, construction and utility sectors. The PV sector is dominated by residential solar applications, where BIPV is not addressed much. On the other hand, the building and construction sector is a separate sector.
- Few communities and lack of proper communication channels for collaboration. A proper channel is not created due to a lack of participants in this sector and lack of adequate intervention from the relevant authorities. However, a positive outcome can be identified with the BIPVA and some initiatives the authorities took.
- A few BIPV-specific exhibitions and other networking opportunities provide minimal opportunities to communicate among the upstream and downstream actors and build social capital among the actors.

6.4 Infrastructural problems and opportunities

The following can be identified as the BIPV-related infrastructural problems:

- There are limited BIPV-related government incentive schemes besides the general PV FiTs in Australia.
- There is limited standard process for integrating BIPV into the building envelope in Australia. BIPV products are required to meet the AS4777 construction code. Therefore, the BIPV products must be certified per IEC 62125 or 62670 international standards (Sullivan, 2013). However, the above certificate would not be adequate to confirm the safety behaviour of BIPV modules as a building material (Sullivan, 2013). As a result, BIPV modules would not easily comply with the Australian building fire safety-related standards. Initiatives should be implemented to add regulations for BIPV. Currently, the Victorian Building Authority has published a report related to the fire safety of BIPV systems.

- A proper infrastructure has not been developed for local manufacturers/suppliers to operate. It was recognised cost (of manufacturing) resources limit onshore manufacturing.
- A lack of BIPV-specific policymakers or representatives slow the regulation process and implementation of most required standards, such as BIPV-specific building codes.
- Historically, large-scale applications have been initiated because of government support schemes for renewable energy. Similarly, BIPV-specific funding schemes for upstream and downstream stakeholders may increase the deployment and enhance market development.

7 RECOMMENDATIONS

The TIS analysis presents an opportunity to understand the market in multiple aspects. The strengths and weaknesses and the overall assessment of each function in Table 4 lead to following overall recommendations.

Improving knowledge diffusion

One of the critical needs of the BIPV sector is a common platform to collaborate with stakeholders and share their information to address most of the weaknesses identified in each function of TIS. BIPVA is a similar approach that is currently in the development phase. This could be a place to communicate with stakeholders such as property owners, PV/ESD consultants, architects, planners, builders, manufacturers, distributors/suppliers, academia, scientists, and policymakers. Bringing them into a common platform could address many of the knowledge gaps that exist in the current market. This alliance provides a place to share information on BIPV product details, technical benefits, design criteria, etc., opening all value chain actors. Furthermore, the coalition could act as a concrete foundation for BIPV in Australia, which enables legitimising the BIPV in industry. BIPVA, in collaboration with stakeholders or individually, can arrange workshops, training programmes/apprenticeships to increase the number of expertise and distribute the knowledge to a broader community. The alliance could address the social needs of stakeholders. Also, it is wisely to collaborate with the government to find solutions for prevailing challenges. Figure 5 summarises the details of initiating BIPVA in the Australian industry. BIPVA is formed to address several tasks identified for prevailing issues identified in the Australian industry.

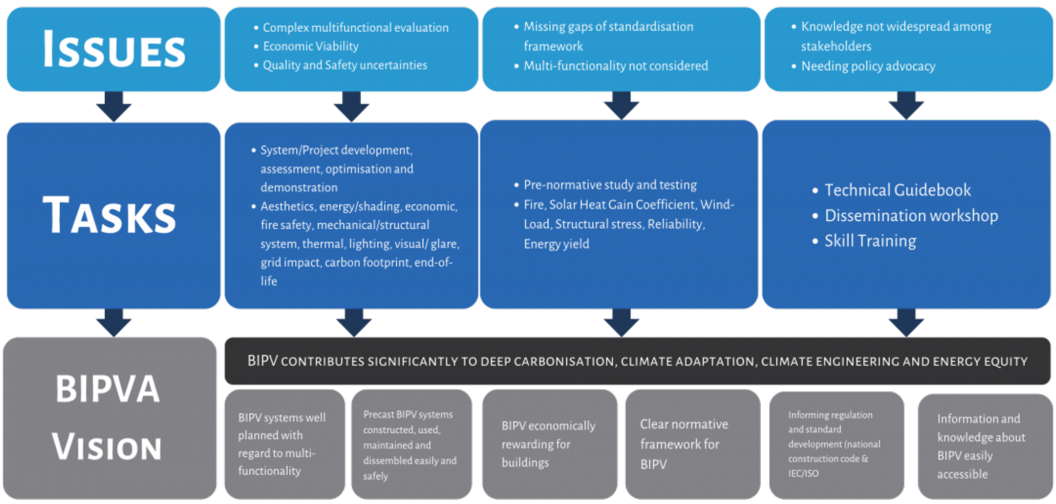

Figure 5: BIPV Alliance (Source APVI)

Improving knowledge development and social capital

As indicated in Table 4, another critical issue is the lack of awareness and less social capital around this technology, which could be eliminated through rich information. Disseminating existing knowledge among stakeholders could increase their trust. Publishing technical guidebooks, industry reports, articles and newsletters by BIPV suppliers and consultants can aid in improving awareness of public as well as the building professionals such as architects, design consultants, building developers and facilities managers. LCA reports and environmental product declarations are some of the publications about BIPV developed by BIPV consultants. Academics can publish BIPV related papers which discusses about current issues and new innovations. Likewise, academic and industry could collectively contribute to the publications. As there is not enough information about BIPV products in the Australian market, an easily accessible BIPV product database would enable all to consider BIPV products for their projects. Promoting more demonstration BIPV systems, especially in public, commercial /mixed-use buildings and a variety of business cases to allow BIPV uptake for a different building group is essential. This approach would aid professionals and property owners in building confidence and motivation to uptake BIPV.

Improving entrepreneurship and Resources

Currently, in Australia, there are very limited pre-normative study and testing facilities. Comprehensive industry consultation regarding the BIPV fire test and the wind load test configuration is critical for façade applications. A live lab that can test and demonstrate all types of BIPV products based on its applications is essential for Australia. Collaboration of industry, academia and government could initiate the lab. This could also link with improving the building codes and standards to provide a complete guide to BIPV design, installation, operation, maintenance, and safety. Further, innovative procurement strategies, BIPV solutions for urban planning, use of digital technologies can be encouraged to enhance the BIPV installations. Local manufacturing of BIPV, esp. starting from system level, can also contribute to cost reduction and increase job opportunities for national economy and supply chain resilience.

Improving Guidance of the search and legitimation

Government authorities can take the lead in disseminating knowledge covering various aspects such as technical, scientific, economic, etc. The government could provide reimbursements for upstream and downstream actors to encourage the development of BIPV such as grant for product verifications, economic incentives for BIPV installations, tax reductions. Furthermore, the government could establish incentive schemes or funding mechanisms while collaborating with the financial incentives for BIPV projects to access this technology for many users.

Given below are some recommendations for BIPV actors:

- Architects, BIPV consultants and developers can reduce the cost of BIPV construction via design optimization and demonstration. This can be initially done in demonstration projects to promote the product.
- BIPV suppliers can ensure the product safety and compliance with building and electrical codes via product performance certificate based on relevant testing. Local manufacturing also provides great opportunities for BIPV products to enhance market confidence and boost local economy.
- Governments can support the initiation of local BIPV product manufacturing and test facilities which are capable of product testing, lamination and prefabrication along with building elements.
- The academics, research institutes and government/ private sector authorities can support research and development on digitalizing BIPV products considering multiple expectations such as aesthetic appearance, energy efficiency, low cost, fire safety, thermal aspects, daylighting, urban and grid impact, and carbon footprint. Further research on new BIPV products can be conducted to minimize the weight, align with mechanical and structural requirement, increase the installation speed, BIPV reuse and recycling, and reduce onsite workers and waste.
- Government and tertiary educational institutes can introduce training schemes to improve the knowledge and skills of building workers and professionals to reduce reworks, occupational risks and unnecessary expenses.

- The government can also focus on developing new policies in relation to BIPV manufacturing, import, BIPV construction, innovative financial mechanisms, incentives and the use of BIPV in urban planning.

Figure 6 summarises the strategic collaboration areas for BIPV future implementation in Australia.

Figure 6: Strategic collaboration areas for BIPV future implementation (Source APVI)

8 REFERENCES

1. Australian PV Association (APVA) (2009). *Best Practice Guidelines for Local Government Approval of (Solar) Photovoltaic Installations*. Available at: https://apvi.org.au/wp-content/uploads/2013/11/APVA-Best-Practice-PV-Guidelines-for-Local-Government.pdf [accessed on 21 April 2022].
2. Australian PV Institute (APVI) (2021). *National Survey Report of PV Power Applications in AUSTRALIA 2020*. Available at: https://apvi.org.au/wp-content/uploads/2021/10/PViA-Report-27.9.21-AUS.pdf [accessed on 21 April 2022].
3. Merzian, R., Quicke, A., Bennett, E., Campbell, R. & Swann, T. (2019). *Climate of the Nation 2019*. The Australia Institute. Available at: https://australiainstitute.org.au/wp-content/uploads/2020/12/Climate-of-the-Nation-2019-WEB.pdf [accessed on 21 April 2022].

4. Australian Competition and Consumer Commission (2022). *Purchasing a solar system*. Available at: https://www.accc.gov.au/consumers/health-home-travel/solar-power/purchasing-a-solar-system [accessed on 21 April 2022].
5. Australian Energy Regulator (2014). *Industry Guidance: solar power purchase agreements.* Available at: https://www.aer.gov.au/site-search/Industry%20Guidance%3A%20solar%20power%20purchase%20agreements [accessed on 21 April 2022].
6. Clean Energy Council (2018). *Government Programs*. Available at: https://www.cleanenergycouncil.org.au/consumers/buying-solar/government-programs [accessed on 21 April 2022].
7. Clean Energy Regulator (2021). *Legislation and regulations.* Available at: http://www.cleanenergyregulator.gov.au/About/Legislation-and-regulations [accessed on 21 April 2022].
8. Department of Industry, Science, Energy and Resources (2022). *Rebates and Assistance*. Available at: https://www.energy.gov.au/rebates [accessed on 21 April 2022].
9. Energy Matters (2021). *Energy Minister Declares Manufacturing Solar in Australia 'Core Focus'*. Available at: https://www.energymatters.com.au/renewable-news/energy-minister-declares-manufacturing-solar-in-australia-core-focus/ [accessed on 21 April 2022].
10. Green Building Council Australia (2023), Billions to build a clean energy economy and a resilient, sustainable nation, Available at https://new.gbca.org.au/news
11. International Energy Agency Photovoltaic Power Systems Programme (2023), Guide for Technological Innovation System Analysis for BuildingIntegrated Photovoltaics, Available at https://iea-pvps.org/wp-content/uploads/2023/08/Report_IEA-PVPS_T15-16-2023-Guide-for-Tech-Innovation-Systems-Analysis-for-Building-Integrated-PV.pdf
12. International Energy Agency Photovoltaic Power Systems Programme (IEA PVPS) Snapshot of Global PV Markets 2022) Available at https://iea-pvps.org/wp-content/uploads/2022/04/IEA_PVPS_Snapshot_2022-vF.pdf
13. International Energy Agency (IEA) (2021). *Categorization of BIPV Applications*. IEA PVPS Task 15. Available at: https://iea-pvps.org/wp-content/uploads/2021/09/IEA-PVPS-T15-12_2021_BIPV-categorization_report.pdf [accessed on 21 April 2022].
14. International Energy Agency (IEA) (2020). *Development of BIPV Business Cases: Guide for Stakeholders*. IEA PVPS Task 15. Available at: https://iea-pvps.org/wp-content/uploads/2020/06/Task-15-STB-B3-Report_Final.pdf [accessed on 21 April 2022].
15. International Energy Agency (IEA) (2018). *International Definitions of "BIPV"*. IEA PVPS Task 15- Subtask C. Available at: https://iea-pvps.org/wp-content/uploads/2020/02/IEA-PVPS_Task_15_Report_C0_International_definitions_of_BIPV_hrw_180823.pdf [accessed on 21 April 2022].
16. Australian Building Codes Board (ABCB) (2019). *National Construction Code: Guide to Volume 1.* Available at: https://neca.asn.au/sites/default/files/NCC2019_BCA_Guide-preview.pdf [accessed on 21 April 2022].
17. Solar Victoria (2021). *Solar Homes Program.* State Government of Victoria. Available at: https://www.solar.vic.gov.au/solar-homes-program [accessed 1 June 2021].
18. Standards Australia (2021). *Australian Solar Standard (AS/NZS 5033) revised to support growing solar industry*. Available at: https://www.standards.org.au/news/australian-solar-

standard-(as-slash-nzs-5033)-revised-to-support-growing-solar-industry [accessed on 21 April 2022].

19. Sustainability Victoria (2022). *Energy ratings, construction codes and standards*. Available at: https://www.sustainability.vic.gov.au/energy-efficiency-and-reducing-emissions/building-or-renovating/energy-ratings-construction-codes-and-standards [accessed on 21 April 2022].
20. University of New South Wales (2005). *Best Practice Guidelines for Solar Power Building Projects in Australia*. The Centre for Sustainable Built Environment, Available at: https://apvi.org.au/wp-content/uploads/2013/11/BiPV-Best-Practice-guidelines.pdf [accessed on 21 April 2022].
21. Vroon, T., Teunissen, E., Drent, M., Negro, S. O., & van Sark, W. G. (2021). Escaping the niche market: An innovation system analysis of the Dutch building integrated photovoltaics (BIPV) sector. Renewable and Sustainable Energy Reviews, 111912.
22. Yang, J., Wakefield, R., Gunarathna, C., & Weerasinghe, N. (2019). Prefabricated building integrated photovoltaics: cost and deployment. London: RICS. Available at: https://www.rics.org/globalassets/rics-website/media/knowledge/research/ research-reports/cost-of-prefabricated-building-integrated-photovoltaics-rics.pdf [Accessed on 21 August 2020].
23. Riches C., (2021), The solar skin on a Melbourne tower could lead the way in sustainability, real commercial. Available at: https://www.realcommercial.com.au/news/the-solar-skin-on-a-melbourne-tower-could-lead-the-way-in-sustainability [Accessed on 21 August 2022]
24. Robert, P. (2023), "ClearVue to Build WA solar PV and nanoparticle manufacturing facility. Available at: https://www.aumanufacturing.com.au/clearvue-to-build-wa-solar-pv-and-nanoparticle-manufacturing-facility[Accessed on 21 June 2023]
25. Miletic B., 2022, Solar facade to generate sustainable energy for Melbourne office building, architecture design Available at: https://www.architectureanddesign.com.au/news/solar-facade-to-generate-sustainable-energy# [Accessed on 21 August 2022]
26. Miller, J (2023), ClearVue Technologies wins $2 million grant to help establish WA manufacturing facility, Proactive. Available at: https://www.proactiveinvestors.com.au/companies/news/1016029/clearvue technologies-wins-2-million-grant-to-help-establish-wa-manufacturing-facility-1016029.html[Accessed on 21 May 2023]
27. HANERGY THIN FILM POWER. 2021. *BIPV Project* [Online]. China: Hanergy Thin Film Power Group Limited. Available: http://en.hanergythinfilmpower.com/index.php?m=content&c=index&a=show&catid=12&id=45#slide=1 [Accessed 27 04 2021].
28. ONYX SOLAR. 2016. *Case Studies* [Online]. Available: https://www.onyxsolar.com/all-you-need [Accessed 12 August 2019].
29. VASILIEV, M., NUR-E-ALAM, M. & ALAMEH, K. 2019. Initial Field Testing Results from Building-Integrated Solar Energy Harvesting Windows Installation in Perth, Australia. *Applied Sciences,* 9**,** 4002.
30. Martín-Chivelet, N., García García, L., & Caamaño Martín, E. (2022). *Analysis of the Technological Innovation System for BIPV in Spain 2022*. Report IEA-PVPS T15-13:2022. Available at: https://www.diva-portal.org/smash/get/diva2:1831617/FULLTEXT01.pdf [Accessed on 03 May 2024].

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