Technology Collaboration Programme
by iea

International Energy Agency
Photovoltaic Power Systems Programme

Task 15 Enabling Framework for the Acceleration of BIPV

PVPS

Analysis of the Technological Innovation System for BIPV in the Netherlands 2024

Report IEA-PVPS T15-22:2024

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 Solar Energy Research Institute of Singapore and Enercity SA are also members.

Visit us at: www.iea-pvps.org

What is IEA PVPS Task 15?

The objective of Task 15 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.

Authors

- **Main Content: O. Bernsen (RVO).**
- **Editors: Evangelos Niforatos (TU Delft) & Otto Bernsen (RVO)**

COVER PICTURE

BIPV Facade, Zig Zag Solar in combination with MetSolar panels, photo Netherlands Enterprise Agency RVO

ISBN 978-3-907281-60-4 Analysis of the Technological Innovation System for BIPV in the Netherlands

INTERNATIONAL ENERGY AGENCY

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

IEA PVPS
Task 15

Analysis of the Technological Innovation System for BIPV in the Netherlands

Report IEA-PVPS T15-22:2024
August - 2024

ISBN 978-3-907281-60-4

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The work presented in this report was performed within IEA PVPS Task 15, with support from the Netherlands Enterprise Agency.

A special thanks is due to the Dutch pioneers still active in the IEA PVPS task 15 among which we count; Tjerk Reijnga from Bear ID Architects, Michiel Ritzen (HogeSchool Zuyd, currently EnergyVille Belgium), Zeger Vroon (Zuyd and TNO) and my colleague Jacques Kimman (lecturer Hogeschool Zuyd and RVO).

The data for this report has been collected over the years by several scholars in chronological order; David Meijvogel (2016), Martje van Horrik (2016) and mainly Tjebbe Vroon (2020). David Meijvogel drew specific attention to the different interests at play between project partners, Martje van de Horrik gave an in depth view of the barriers as viewed from the construction sector itself (in Dutch) and Tjebbe Vroon provided a very complete TIS analysis together with the staff of prof. Wilfried van Sark at the University of Utrecht and the consultancy firm Berenschot. The report builds upon these findings and in addition more attention is given to the changing perceptions of BIPV over time, the varying interest of the different government bodies and the inherent differences between the solar and construction sectors.

This report received valuable contributions from several IEA-PVPS Task 15 members and other international experts from task 13. Our special gratitude goes out to Michiel van Noord (Lund University) for his Task 15 Subtask leadership and his support.

LIST OF ABBREVIATIONS

BAPV	Building Applied Photovoltaics
BIM	Building Information Model
BIPV	Building Integrated Photovoltaics
IEA	International Energy Agency
IEA PVPS	International Energy Agency Photovoltaic Power Systems Programme
IEC	International Electrotechnical Commission
RVO	Netherlands Enterprise Agency (part of the Ministry of Economic Affairs and Climate)
SEAC	Solar energy Application Centre
TIS	Technology Innovation System
TRL	Technological Readiness Level

EXECUTIVE SUMMARY

This report uses a technology innovation system (TIS) guide, provided by the IEA PVPS task 15, to describe the dynamics of the national innovation system for BIPV in the Netherlands. This technology is (of course) part of the wider technological innovation system for solar energy but as such it has enough different characteristics and specialised players to set it apart. It also takes into account the innovation dynamics of the construction sector where the BIPV technology is applied. The construction sector is generally more regionally oriented while the solar sector is part of an international value chain. The latest geopolitical developments and upheaval in Europe fall outside the scope and period of the report.

The specific geographical circumstances in the densely populated Netherlands are a main national driver for BIPV and explains partially why multifunctionality of solar applications in general is becoming increasingly important in the Netherlands. Hence the integration of solar PV not only in the built environment but also in the infrastructure, landscape and on water surfaces is set high on the innovation agenda. This potential of BIPV has come to the attention of policymakers from both an innovation point of view and in order to reach the climate goals. The large scale market uptake however remains dependent on the next phase of investment, standardization, education and market demand. If these aspects are addressed, BIPV could become a viable option for the building sector to achieving zero-energy buildings and decarbonized cities in the Netherlands. Therefore several national ministries have become involved over time and with different perspectives. However, the current BIPV technologies have been predominantly implemented in the higher end, B2B market segment and encountered barriers outside that specific market segment which are inherent to innovations in general in the construction sector. In the building "supply market", innovations are mainly driven by cutting overhead costs and failure costs. The early pioneers, before 2000, acknowledged these particular innovation dynamics and tried to overcome these constraints by collaborating directly with local and national governments, while aiming at the renewable energy benefits of local production. The expectation at the time was that solar thin film technologies would deliver on lower costs and more flexibility in form, shape and colour. Although the later has been achieved, the reduction of costs and market uptake of BIPV did not follow the general trend of solar PV. Only lately and thanks to the introduction of thinner crystalline solar panels, did BIPV cost started to decline. While the deployment of regular solar panels took off after 2014, caused by the serendipity of favourable market conditions in Europe and costs reduction by scaling up production in Asia, the BIPV technology and innovation ecosystem remained restricted to a high-end niche market and an innovation ecosystem consisting predominantly of academic circles joined by start-ups and innovative product developers. Although the BIPV innovation system has expanded in absolute size, the dynamics of the innovation system seem remarkable constant over the last decade.

In other words, this TIS analysis shows that BIPV technology is not a niche market waiting to be scaled up but that systemic problems still exit which inhibit its growth. The so called "science & technology" and " entrepreneurial" push motors work well enough in the Netherlands but the "system building" and " market" motors are stalling. There exist several negative feedback loops that have to be addressed before a take-off can take place. The BIPV innovation system is basically a balancing act between two innovation systems with actors trying to bridge the gap between the solar and construction sector. It needs to expand beyond the science and technology driven parties and address broad societal issues with innovative business cases that include "energy ownership". A far reaching integration between the two sectors is necessary that would entail the entire building process and adhering to standards in both sectors, product compatibility and finally training. Bridging this gap is a precondition for escaping the niche market and for BIPV to take off. A number of recommendations are made that follow from this TIS analysis and in a specific order. The main recommendations are; first to identify new markets that address societal needs and address energy ownership, second to undertake large demonstration projects in these markets segments with stakeholders along the value chain to further integrate the solar and building sector, validate the proposed solutions and finally to include them in the building codes, preferably on an European scale, regulation and inform all stakeholders.

1 INTRODUCTION

The goal of this Task 15 Technological Innovation System (TIS) analysis is to provide policymakers and other parties with insights into the dynamics of the national innovation system concerning BIPV in the Netherlands. This study describes the Dutch innovation system concerning BIPV up and to the year 2022.

It uses as a framework the technology innovation system (TIS) analysis, see for a general introduction Bergek e.a. 2008 (1), Hekkert e.a.2011 (2), as a template the Task 15 TIS Guide by Noord e.a. (3) and especially the TIS analysis for policymakers by Wieczorek 2009 (4) and Hekkert & Ossenbaard 2010 (5) to define its object and scope. The analysis first identifies which actors participate, the networks they use to interact and the institutions that condition the playing field. Secondly the functions of the Dutch innovation systems are described and scored separately which establishes a pattern for the TIS analysis. Subsequently, the existing positive or negative feed-back loops between the functions are discussed which together form the dynamics of the innovation system. Finally, key policy issues are identified based upon this analysis.

The report structure is aligned with TIS studies performed by other countries such as Sweden, Spain, Italy and Australia and based on this well-established practise and methodology. This standardised TIS framework offers a method and a tools for analysing the national innovation system in a structured way in order to be able to compare between countries. The lessons learned are important to facilitate and support implementation of BIPV in the Netherlands and support innovation and industrial development of BIPV solutions. The data in the report is based on several previous studies, notably the report “Barriers for BIPV” in Dutch by Martje van Horrik e.a. 2016 (6) and the master thesis of Tjebbe Vroon “Escaping the Niche Market: An Innovation System Analysis of the Dutch Building Integrated Photovoltaics (BIPV) Sector 2021 (7).

The IEA PVPS TCP (technology collaboration program) has took an early lead in the analysis and development of BIPV by starting a now closed PVPS task 7 on the same topic. In this international task, which lasted from 1997 to 2002, the Netherlands was the operating agent and participated alongside Australia, Austria, Canada, Denmark, Germany, Spain, Sweden, Switzerland, United Kingdom and the USA, as operating agent and contributing to the different subtasks. The current TIS analysis offers an update, an “360 degrees” round view on the national innovation system concerning BIPV technologies and application.

2 DEFINITION OF THE TECHNOLOGICAL INNOVATION SYSTEM FOR BUILDING-INTEGRATED PHOTOVOLTAICS

This section gives a brief initial overview of building-integrated photovoltaics (BIPV) in the Netherlands in order to clearly show and define which technology is the focus of the analysis. To do this, we define the scope of the analysis and describe how the technology and the innovation system (actors, networks and institutions) around it have developed over time.

2.1 Scope of this analysis

The technical scope of this analysis is: BIPV modules and systems and the following definitions are used:

- A BIPV module is a PV module and a construction product together, designed to be a component of the building. A BIPV product is the smallest (electrically and mechanically) non-divisible photovoltaic unit in a BIPV system which retains building-related functionality. If the BIPV product is dismounted, it would have to be replaced by an appropriate construction product, see Berger 2018 [8].
- A BIPV system is a photovoltaic system in which the photovoltaic modules satisfy the definition above for BIPV products. It includes the electrical components needed to connect the PV modules to external AC or DC circuits and the mechanical mounting systems to integrate the BIPV products into the building, Berger 2018 [8].

In this TIS analysis there is no limitation with respect to the application categories as defined in IEC 63092 (International Electrotechnical Commission 2020). In the Netherlands a wide range of products are being developed, tested and implemented. What constitutes a building may be debatable. In this context a building is a stable construction to be inhabited or for other uses having at least two walls and a roof.

2.2 Historical technological development

The idea of replacing building materials by multifunctional photovoltaic modules and integrating them into the building structure has been around since the nineties of the previous century. In 1997 the REMU, the regional energy utility of Utrecht in the Netherlands, initiated a new building project with over 500 houses and public buildings, fitted out with silicon crystalline (c-Si) PV modules and some with BIPV products, integrated in roofs, facades and screens. Although some PV technologies are better suited for different functions in the built environment, at that time there was no specific BIPV technology as such on the solar cell level. BIPV still is only defined on a module or application level by its functionality. Both first generation c-Si and, later, second generation solar cells, so called “thin film” solar cells were applied. The thin-film photovoltaic module technologies include CIGS (copper indium gallium selenide), CIS (copper indium selenide), CdTe (cadmium telluride), and a-Si (amorphous silicon) solar cells. Thin film technologies allow for flexible products, which can be attractive for BIPV designs. Since c-Si cells have become thinner they have also become an option which combines this characteristic with the stability and efficiency performance of crystalline silicon. For practical purposes solar thermal (PVT) and organic solar cells are not considered in this report and neither are third generation solar cells under development, such as perovskites (PSC) and tandem cells. The relative rapid degradation of organic solar cells has proven hard to overcome in general, and remains an obstacle in buildings where product life span is measured in decades. Also the third generation prototypes made up of tandem cells, in BIPV have yet to appear in field trials. On a module level, BIPV products can be categorized in different ways by application and products, (e.g., Jelle & Breivik, 2012 (8), in tiles, windows, facades and integrated roofs. Other product categories are just as valid, and new ones may appear in the course of product development, for example lightweight solar modules or solar textiles.

2.3 Historical development of the innovation system

Early period & pioneers 1990 – 2000

In the Netherlands the aesthetics of roof top mounted solar systems were from the start a major societal concern, and not only on historic buildings but in general. Building-integrated PV started receiving attention in the Netherlands in 1990s and from the start, architects were included in its development and application. The Dutch PV program concentrated on developing products for low-cost integration into inclined roofs of mainly new buildings and facades, but also onto existing building stock in renovation projects. Watertight profile systems had to be developed, tested, and applied in projects on a growing scale, often in real life pilot projects. Cost reduction of BIPV could also be achieved by improving and simplifying the integration in the roof construction, the electric system and in installation procedures. The initial expectation was that BIPV could be cheaper by the square meter than added on PV (BAPV) because of its multifunctionality and savings on construction materials. Alsema (9) calculated the payback time for BIPV between 20 and 30 years which was deemed acceptable for such long-term investments. Projects were carried out on an increasing large scale to learn about the integration of PV into the building process as such. In total, a capacity of more than 8 MW was installed by the end of the year 1999, with demonstration projects ranging from individual dwellings and offices to entire solar neighborhoods, such as the Nieuw Sloten project in Amsterdam (250 kWp) and Nieuwland in Amersfoort (1 MW), see Mierlo & Cramer 2002 (10). In 2002 also the Expo Haarlemmermeer took place, and the main pavilion was a show case for the possibilities of BIPV with a total of 2.2 MWp installed. The aesthetical undesirable rollout on roof tops of this patch work of solar panels was also addressed early on in the task 7 (closed 2001) of the IEA PVPS program. It mentioned an additional number of problems that hindered social acceptance, such as the lack of independent and reliable information, mistrust of planners and project developers concerning the products, the lack of specific regulation, guidelines, certification, unclear liabilities and lack of after sales support. Some of these issues have since been solved by the solar sector and policymakers but not all, and some can indeed be found again in the current task 15 on BIPV. In 2002 the task 7 published a report on the potential of BIPV in different countries, see Gutschner, Nowak, Ruoss, Toggweiler, & Schoen, 2002 (11) and estimated a potential surface of 356,62 km2 in the Netherlands, which corresponds roughly to 36 GWp installed capacity of BIPV alone. The current installed capacity of BIPV is less than 2 % of the total amount of the almost 15 GWp installed PV in the Netherlands in 2021.

Thin film great expectations 2000 - 2015

In this period the application of thin film technologies from an R&D perspective received more attention. The expectations were that further cost reductions could be realized by mass (roll2roll) production of CIGS, CIS and Amorphous Silicon, while new functionalities could be implemented like flexible panels and lightweight modules. This would also grant architects with the necessary freedom of design and the development of custom-made products alongside mass production. Helianthos (part of Nuon and formerly AkzoNobel) worked closely together with the TU Delft and Tata Steel on thin film solar foils that could be glued to steel surfaces and opened an experimental production line in Arnhem in 2009. Shell moved its subsidiary, focused on CIS (Copper, Indium, Selenium) technology Solar Frontier first to the East of Germany where major EU structural funds were available and later to Japan. In the South of the Netherlands, in the province of Limburg, a cluster of solar companies was formed with the support of the local government, establishing the experimental business park of “De Wijk van Morgen” (translated as the District of Tomorrow) with Hogeschool Zuyd, the Applied Sciences University, that latter linked up with Solliance. The TU Eindhoven joined forces with ECN, TNO, Holst Centre and IMEC and opened the Solliance knowledge center for thin layer deposition technologies in general, and thin film solar research in the city of Eindhoven in 2010. A year later, in 2011 a dedicated unit was created at Solliance for the testing and development of commercially viable BIPV applications called SEAC. With the liberalization and privatization of the energy sector in the Netherlands, the local government sold of their shares in the energy utilities and three provinces (Limburg, Noord Brabant and Gelderland) decided to reinvest some of these funds into the development of solar technologies, among which BIPV applications. Brabant and Eindhoven specialized on thin film and Gelderland in the Amorphous technology specifically.

In 2010, the national government R&D scheme for energy research & development in general (EOS) was replaced by more specific innovation programs. The state agency (Novem and Senter merged and later changed their name to the Netherlands Enterprise Agency RVO). It launched the first specific BIPV R&D program (IPZ-SBIR) in the Netherlands, targeting SME's and start-ups, see Janson e.a. 2014 (12). Four experimental projects were selected which showed the diversity and explorative character of the BIPV field at the time. Several market segments were further explored, such as social housing and the agricultural sector. Notwithstanding many barriers were encountered, beside the higher costs, that inhibit the necessary innovative business cases and deployment of BIPV at large, see Horrik 2016 (6). To a great extent, the solar sector in the Netherlands focused on the one hand on the manufacturing process, and on the other hand on the installation on roof tops, but both were dominated by crystalline technology at the time.

In 2011 the Top Sector Energy (TSE) programme was set up by the national government with the participation of private partners. Initially there was as specific program (TKI Zon) for solar energy which later merged with other technologies concerning the built environment (TKI Urban Energy). Although this led to more organisation of the solar sector in the Netherlands, it meant also in absolute terms a cut back on the available R&D funds after the financial crisis of 2009. In the following years, the number of R&D project on BIPV increased nevertheless steadily (see Figure 3 BIPV R&D projects) until 2016, when the amount of subsidized projects stabilized even though more ministries became active with supporting programs. In the Netherlands PV integration into the infrastructure became another line of R&D, supported by the Ministry for Infrastructure and Waterways. The number of European projects increased significantly in these years.

In 2015 the consultancy firm Berenschot published a roadmap for BIPV "Bouwen aan BIPV" (13) in which they presented the main challenges for the BIPV technology, followed by a roadmap from Energyville in Flanders by Saelens 2016 (14) which also predicted a breakthrough of the technology in the coming years. During this period, the various generic incentives for sustainable energy production, such as the Energy Label required since 2006 for buildings, neither promoted specifically innovative BIPV products in the market, nor did the SDE (Stimulation of Sustainable Energy Production and Climate Transition), and later the SDE+ schemes, nor the net metering scheme in the Netherlands. Instead, they all targeted solar PV generation. BIPV also did not benefit as much from the reduced electricity tax for PV systems for local cooperatives, as few systems where installed, and not at all from reclaiming the 21 % VAT on solar panels. While the rollout of BAPV was on a steady, progressive climb, the BIPV market remained a relatively small but innovative niche market.

Solar crystalline breakthrough 2016 - 2020

After 2014 the prices of solar panels started to decline at a historical low rate with the scaling up of production in Asia, initially for export to the European market. Subsequent falling prices of solar panels worldwide, combined with record low interest rates, put solar on the path to becoming the cheapest energy source in 2020 according to the IEA (2020). In the Netherlands that meant that in 2016 solar qualified in the SDE (> 15 kWp systems) subsidy schemes (a reversed auction for all renewable energy sources) as the cheapest renewable energy producing option. Solar MW parks became a reality in the Netherlands, where before the market had been mainly driven by roof top systems, and the conventional wisdom in the sector was that large scale solar parks were something for Southern Europe and North Africa. Only one group of analysts at QCells had predicted in 2014 that because of the relative high energy prices, low interest rates and low costs of installation, both the Danish and Dutch markets would become among the first to adopt a large-scale solar rollout. The Dutch homeowner market was supported by a straightforward net metering scheme and tax exemptions for the purchase of solar panels among others.

In addition and somewhat unexpectedly, the Dutch government decides in 2018 to phase out the natural gas exploitation of the Groningen fields and replace natural gas as the main energy source for heating in the built environment by electrification. One of the few ways to achieve this in the short term is by deploying solar panels in an accelerated pace in combination with heat pumps, which also use additional electricity.

That said, the BIPV systems did not benefit from these changing market conditions in the same way as the regular solar panels. Costs remained relatively high and installation cumbersome within the context of a building project. Some BIPV projects were granted within the HER+ (Renewable Energy Transition) subsidy scheme, not because

they were the cheapest, but because they allowed the utilization of otherwise unused surfaces for solar power, and thus contributed to achieving the Dutch climate goals. BIPV however, could not compete with BAPV in the generic subsidy SDE + schemes for implementation and remained a niche market with mainly SME's developing new and innovative products. Companies like Solinso, Tulipp Solar and SCX Solar in the meanwhile developed mature in roof systems for the B2B market that have proven themselves over the years. Some BIPV companies chased BIPV subsidy scheme around Europe without consolidating their business case.

The large, international, industrial initiatives meanwhile, with initially Shell Solar, AkzoNobel, Tata Steel and Han Energy had all failed to deliver on the promise of high throughput production and stable processes for thin film technologies such as CIGS and Asi which would have reduced the costs of BIPV applications. Instead, the SMEs specialised in the upper echelon market of custom-made products, facades, lightweight products with higher margins. In light of a stalling housing market and fewer building projects, a renewed interest surged for renovation projects. These would entail for example putting a "second skin" or completely integrated BIPV roofs on entire housing blocks thereby cutting the costs and lead time. Several ministries supported this upgrade of the existing building stock with again general, not technology specific, programs which included energy efficiency, electrification at large and replacing natural gas as the main energy source. The Ministry of the Interior and Kingdom Relation and the Ministry of Infrastructure and Water Management became involved with "integrated solar PV" which showed a large overlap with the existing BIPV.

So, while the solar market in the Netherlands grew exponentially, each subsequent year to a yearly gigawatt market in 2018, the BIPV market did not keep up. The BIPV costs remained relatively high, and because installation costs had not declined, there was still a (perceived) financial risk involved. The production process of BIPV technologies as said were not scaled up either. While the interest from both policymakers and the R&D community had not changed and even widened, there were still no integrated approaches for BIPV innovations. From the innovation policy perspective, specific incentives existed only on a temporary base to bridge the gap between the cost price of the technology and the market price, something BIPV had not been able to demonstrate yet. From the Climate Goals policy view, BIPV still remained a relatively costly alternative and small scale among the other technological options. BIPV is still on the R&D map as a viable long-term option in the light of the obvious scarce surfaces for solar in the Netherlands and need to decarbonise the existing building stock. The main question remained when and how would it be deployed in large scale?

3 STRUCTURAL ANALYSIS

3.1 Technologies and areas of knowledge

In this section, the structural components of the Dutch BIPV innovation system are identified. To start the structural analysis of the TIS, it is useful to understand the entire value chain for BIPV (see below by Martje van de Horrik 2016 (6). Thereafter, the technology and actor analysis takes place within the framework of this value chain and focuses on product development as the most identifiable with BIPV.

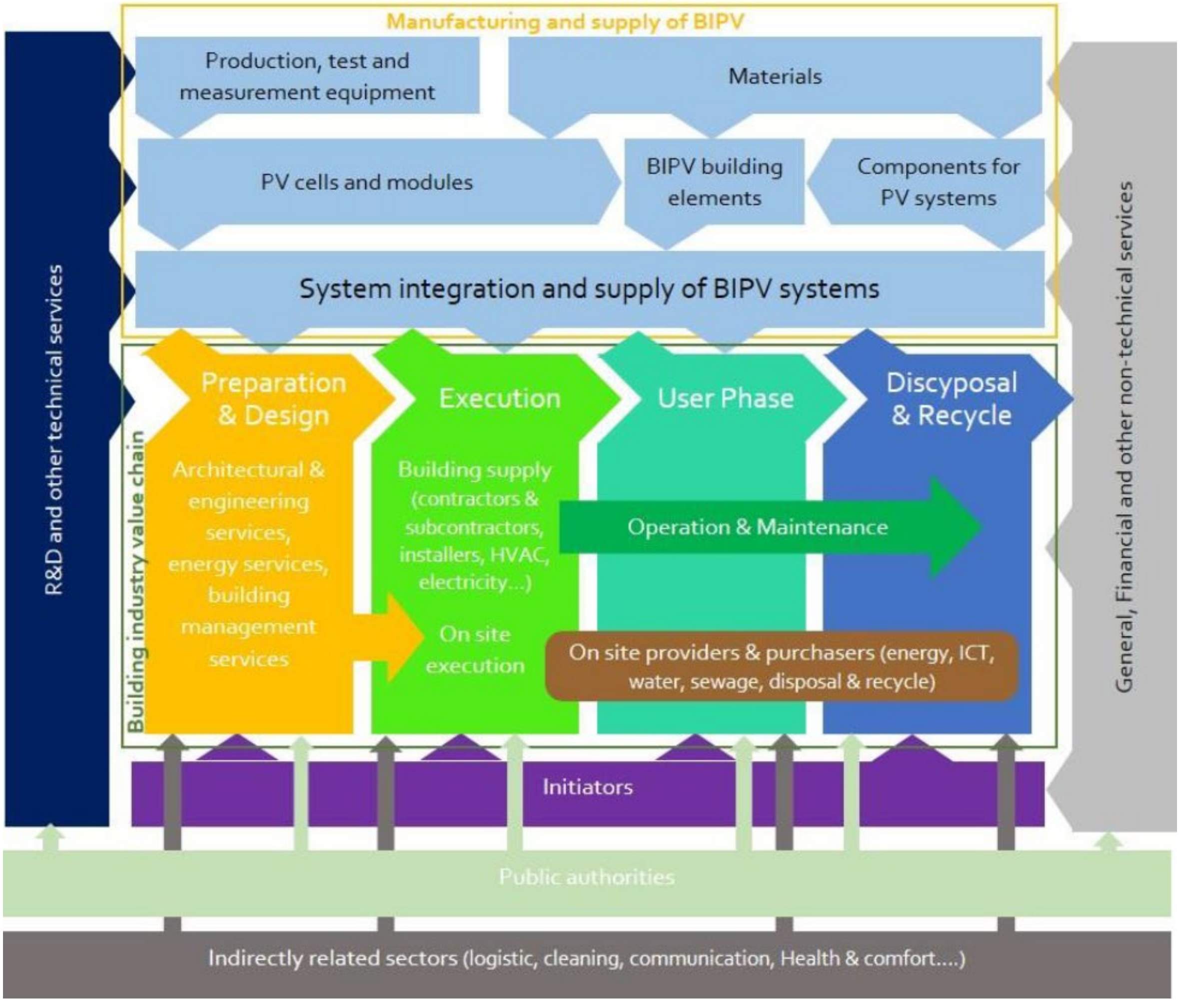

Figure 1. BIPV Value chain (Martje van de Horrik 2016)

The BIPV R&D topics fall within the following categories of the wider solar research in the Netherlands: Wafer-based, Thin Film Luminescent concentrated solar cells. For this last technology, see Wiegman & van der Kolk 2012 (15) we did not however find projects that qualified as BIPV.

BIPV applications are usually divided in two main categories: roof-integrated and facade-integrated (Berger et al. (8); see also the IEA PVPS task 15 report on Categorization of BIPV Applications from 2021. In this report external integrated elements are included such as car ports and shade screens, which are not considered here. For a product overview by SUPSI and SEAC, see Zanetti e.a 2017 (16). The BIPVT or PVT (photovoltaic thermal) system fall outside the scope of this report. Other categories or subcategories can also be applied according to materials used.

On the Dutch market most products fall in to the following categories; integrated in-roofs systems, solar tiles, foils, lightweight modules, that can be assembled into integrated roof systems, skylights and facades of various shape and forms.

Figure 2. In-Roof solar panels, RVO database

Specifically notable for the Netherlands is the broad basis of knowledge of Amorphous Silicon (A-si) which also shows up in the network analysis as a part of thin film technologies and foils. The TU Delft specifically has built up the competences and holds a considerable patent position. The building sector in the Netherlands can be divided in;

A. Housing (apartments, terraced housing etc.)

B. Utility (offices, halls, factories etc.)

C. Infrastructure (sound barriers etc.)

This means there is a strong overlap with infrastructure integrated PV in the Netherlands. This application of solar however is not considered in this TIS analyses, just the overlap is noted here and the possibility of collaboration.

3.2 Actors and networks

This section describes the different actors in the BIPV value chain as shown in Table 1 and refers the earlier network analysis by Meijvogel 2016 (17) and Vroon 2020 (7).

BIPV Developers

The market in the Netherlands is relatively small (estimated around 1 % of the total amount installed solar PV) notwithstanding the optimistic earlier estimates following studies about the potential of BIPV. These were based on the absolute, available amount of roof surfaces in the Netherlands. The market is dominated by small enterprises that operate in the high-end segment and business2business trade. Although several multinationals such as AkzoNobel, Tata Steel and Han Energy, have tried to develop mass products and enter the market. These products were still too expensive and the scaling up of production proved to be more complicated than envisioned. Since the BIPV market consists mostly of the high-end market segment, the major customers are businesses that prefer BIPV for their headquarters and architectural landmarks. However several alternative market segments are still available and explored sometimes in local projects or European Horizon projects and represented in this overview by companies like Physee and ZigZag Solar. Especially the Hogeschool Zuyd has been active in this field of renovation of social housing projects with a focus on the specific issues of turn over, lead time, costs and user acceptance, see for example Project BRIMM | Brightlands These alternative market segments would typically combine different business cases at the same time including societal benefits such as the officially required replacement of asbestos roofs with BIPV in roof systems. Several provinces and municipalities offer subsidies for the removal of asbestos which can be combined with the investment in solar technology. A complicating factor has also been the fact that costs have often been translated into significantly higher rental prices by the social housing corporations as compensation for the improvements. Also, owner associations run into the obstacle of reaching a consensus in order to make the upfront investment which cause the monthly contributions to increase. The IEA PVPS task 15 Subtask B – Transition towards sound BIPV business models (2018) does not mention such barriers though.

Table 1. Companies active in BIPV product development (2015 and 2021), from RVO database. Some companies have ceased to exist by the date of publication.

2015	2021
Aerspire	Aerspire
Beausolar	Beausolar
Bear Architects	Bear ID Architects
(RBB -Monier) BMI Group	BMI Group
DSMSolar	> Worthen USA
Exasun	Exasun
Helianthos	> Hyet Solar > FFI AU
Oskomera Solar Solutions	-
Parkstad Solar	Parkstad Solar
Peer+	> Merck USA
Physee	Physee
Ubbink Solar	Ubbink Solar
Scheuten Solar	Scheuten Glas
-	Kameleon Solar
SCX-Solar	SCX-Solar
-	Solarge
-	Solarix
-	SolarSwing
Solinso	Solinso
Staffier Solar	Staffier Solar

Synroof	-
Tulipp Solar	Tulipp Solar
Wellsun	Wellsun
ZEP	ZEP/TESLA
ZigZag Solar	ZigZag Solar (Wallvision)

Network analysis

On numerous occasions Dutch network analysis have used the RVO project base. A subset of these overviews was also transferred to the top sector energy (TSE) and published on their website. The first analysis mentioned here is from the master thesis by David Meijvogel (17) and the second is by Tjebbe Vroon (7). In this later thesis a more extensive explanation and discussion can be found of the network analysis. The network analysis by Meijvogel (17) concerns parties in 33 projects up to 2015 in the RVO database. Notable is that most SMEs participate in only one project and there is almost no knowledge exchange between the parties between the projects. In the next analysis by Vroon (7) parties up to 2020 are considered. Although various characteristics and developments of the network can be studied, for the purposes of this TIS analysis it suffices to note the growth of the network in total and the increasing centralization around the network node of ECN/TNO as is clear Vroon (7). Partly this can be explained by the union of the two formerly separate applied research institutes and the joining of the Crystalline and Thin Film research areas, already mentioned. It however also illustrates one of the main findings of the TIS analysis, namely that the BIPV activities in the Netherlands are driven by an active science and technology motor. Discernable in both studies is also the smaller network node of the TUDelft consisting of projects with Hyet Solar (formerly Helianthos) which have a focus on Amorphous silicon technology.

Research Institutes and Universities

Fundamental research into solar technologies is conducted by the national science foundation NWO and in most Dutch Universities in some form. Research institutes include TNO (the national institute for applied research), merged in 2018 with ECN (Energy Centre Netherlands) which concentrates on scaling up the technology from small to larger surfaces and mass production. Several other research centres are worth mentioning for BIPV; SEAC (Solar Energy Application Centre for systems & application) at TU/e in collaboration with TNO/ECN, Solliance (TNO, ECN, TU/e, Holst Centre, IMEC in Belgium and FZ Jülich in Germany) for thin-film technologies, These institutes all tend to have their own perspective. TNO focuses on both the PV systems side and building physics side. Utrecht University and the University of Twente focus on new concepts. Utrecht University has also developed a BIPV course modules for students and professionals. Eindhoven University of Technology and Delft University of Technology focus on performance modelling of both crystalline and thin film technologies. Zuyd University of Applied Sciences is involved in reliability testing and field tests through its R&D district called “De Wijk van Morgen” and Investment (including innovation vouchers) for the BIHTS which is about building integrated high-tech systems. Energy Valley is a regional collaboration between the three applied research centres in the three Northern provinces.

A more thorough discussion of the R&D agenda can be found in the EU ETIP (European technology and innovation platform for solar as this EU agenda overlaps almost 100% with the Dutch agenda including BIPV. In this TIS analysis the focus however is on the analysis of the number of the Dutch R&D projects.

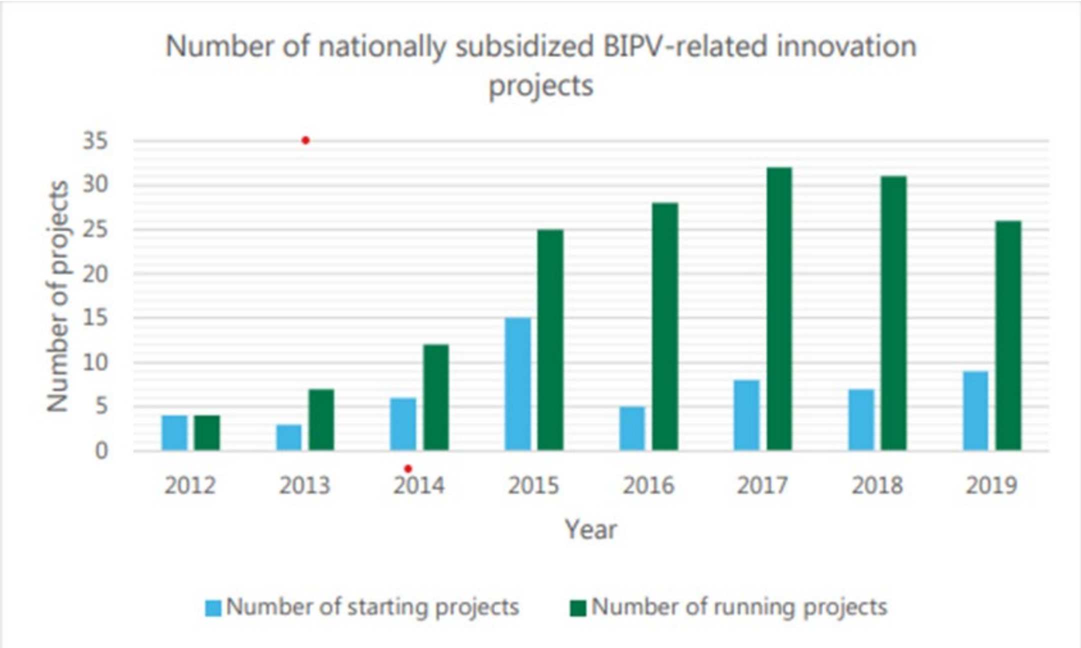

Figure 3. Number of starting and cumulative R&D projects RVO database by Vroon 2021 (7)

Financing

Supporting organizations such as Commercial Banks, Regional Development Banks and private investors have been active in BIPV projects and financing production capacity. Besides the already mentioned BOM and LIOFF these include Netherlands Development Bank (FMO), Rabobank, ASN and Triodos (Franken and Meijer, 2014 (18).

In principle Dutch consumers, companies and energy cooperatives can also request a green loan (Groenlening) against favourable interest rates to achieve sustainability goals but this depends on the municipality of residence and falls outside the scope of this report.

Government

The number of governmental bodies involved in BIPV has changed over time significantly which illustrates an important shift in interest and perception and is perhaps inherent to the development of BIPV. From the outset of the national policy making for renewable energy sources, BIPV was clearly a subset of solar technologies, and as such supported by general innovation policies and for achieving the national climate goals. The main and coordinating actor was the Ministry Economic Affairs and Climate and its implementing agency RVO. Within the framework of the general policy for energy innovation and solar in particular, RVO supported BIPV financially as part of the thin film research and development. As a separate application it was first support from 1997-2001 by the first international activity on BIPV (IEA PVPS task 7 on BIPV). Several attempts had been made by France and the USA to prolong the IEA PVPS task on BIPV but had failed due different perspectives and goals by the parties involved. Specifically the absence of international standards and the peculiarities of each national building sector inhibited a joint action. A subsequent action in PVPS task 15 on BIPV by Sweden and the Netherlands was much more coherent and organised along similar lines in both countries.

A specific national SBIR (Small Business Innovation research) for BIPV was undertaken by RVO only in 2011. That year also the Dutch Top Energy (TSE) started, which is a public private partnerships (PPP) for programming industry led R&D projects and matchmaking. It constituted initially a cost cutting operation after the financial crisis of 2009. Only in the light of the Climate Agreement in 2019 did budgets for innovation, particularly demonstration,

start to rise again, see RVO Monitor[i]. The interest of the TSE followed two tracks, the general electrification route of the energy sector with solar power and by the climate goals set specifically for the urban environment where BIPV might play a prominent role on the road to zero emission buildings (ZEB).
In the same period (2000-2010), many municipalities and provinces cashed in on selling of their shares in energy suppliers following the privatization of the Dutch energy market. Especially the province of Gelderland and the southern provinces of Limburg and North Brabant re-invested some of their funds in the development of renewable energy sources including BIPV. Using their regional development agencies, they allocated considerable amounts for R&D and local production of solar technologies. The program for regional development "Peaks in the Delta" also allocated fund to CIGS technology and BIPV. Brabant (BOM) followed the route of thin film technologies which lined up with their existing expertise in semiconductors and the many spin offs from Philips research. Limburg (LIOF) focused on SMEs supported by a cross-border demonstration site at a business park and a Center of expertise (NEBER) for solar in the built environment working in close collaboration with the academy Hogeschool Zuyd. Gelderland dedicated funding almost exclusively to thin film amorphous silicon technology developed by Helianthos, later taken over by Hyet Solar. Meanwhile five municipalities where far ahead of their peers and in 2009 together realised 5 Mwp of BIPV on a newly developed neighbourhood in the municipality of Heerhugowaard. Other municipalities in the Netherlands followed suit; Amersfoort and the before mentioned Parkstad in Limburg. However, the oldest BIPV building resides in Haarlemmermeer, as part of the world horticulture exhibition site Floriade, dates from 2002 (19.383 solar panels made by Shell and installed by Siemens). In the Climate Agreement 2016 was also stipulated thar the then 342 Dutch municipalities were going to be organised in 30 so-called RES (Regional Energy Strategy) regions which are tasked with implementing specific regional climate goals, alongside national plans for industry, offshore, transportation etc. In 2020 they were to subject their initial plans. These delegated tasks are also supported by the national agencies but less directly and in an advisory role.
After 2012 two other ministries and their agencies became active in BIPV: first the Ministry of the Interior and Kingdom Relations, which is directly in charge of the Dutch housing stock among others, including the Caribbean municipalities, and second the Ministry of Infrastructure and Water Management which oversees the integration of solar into the infrastructure. There exists still a considerable overlap between the technologies for BIPV and PV for infrastructural projects and the later ministry made available the public spaces managed alongside the infrastructure such as sound barriers along highways and floating PV. The Ministry of the Interior focused explicitly on consumers, comfort and renovation of the existing building stock including replacing the natural gas as the main energy source for buildings. Other ministries might still become more active within their mandate and/or where the opportunity arises.

3.1 Institutions

Institutions can be described as the rules of the game that describe why actors act as they do. They can be roughly divided into soft and hard. The hard ones are e.g. laws, standards, support and regulations, and soft ones are e.g. norms, values, beliefs, and culture. In the case of BIPV the technology has to deal with the practises in the construction sector and in the Dutch case specifically both BIPV and Thin Film Solar were part of multinational endeavours to breakthrough internationally. Different perspectives on the same institutions by different players do not fall within the current scope of the TIS analysis on BIPV technologies and would involve a more social sciences techniques and methodologies to describe the "discourse" and what is sometimes called "negotiated realities". For this analysis it suffices to state that there are several innovation systems with their own institutions converge on the topic of BIPV, such as the energy sector, the building industry, infrastructure, agriculture and others. Here the building sector is highlighted as the main partner for the moment. This implies that there exists not only differences between the sectors in standards and regulation, to which BIPV has to comply, but also differences in customs,

---

[i] RVO Monitor https://www.rvo.nl/sites/default/files/2022-09/Monitor-Publiek-Gefinancierd-Energie-Onderzoek-2021.pdf

culture and technological background which are even harder to bridge and these different innovation dynamics are referred to in chapter 6.2 “Institutional problems”.

BIPV falls within the generic incentives and practices for solar established by the Ministry of Economic Affairs & Climate including the regulator ACM, see overview:

- Right to self-consume both individually and collectively (Postal Code administrative grouping)
- Straightforward net metering scheme being phased out in the coming years.
- SDE+ contribution (electricity price markup) for larger systems above 15 Kwp for land based, floating and roof top systems.
- VAT refund after the purchase of solar panels..
- Only for companies, renewable energy investments contributions (EIA/Vamil)
- Energy performance label for buildings as of 2016 (EPC).

Only recently, after 2016, have specific measures been taken targeting the built environment as such and solar technologies, notably the Innovation program for reducing the natural gas dependency and the energy label EPC.

These additional programs focus on different aspects of buildings which is in itself a positive development, but it also illustrates a lack of coordination and long term perspectives concerning the urban planning and renovation of the building stock. in the Netherlands. It is assumed in general by policymakers that the market will pick up on innovations once the costs have declined sufficiently and therefore no government intervention is needed. However even within this liberal market orientation, little attention has been paid to transaction costs, education & training and socialized costs while policy focuses exclusively on the product prices.

The regulation compliancy of BIPV falls both in the existing (IEC) standards of the solar sector and the construction practices.

National subsidy schemes for solar in general and relevant for BIPV include:

1. HER+ (cost reduction on SDE+ scheme or addition surfaces)
2. DEI+ (demonstration and pilot projects including replacing natural gas)
3. MOOI (Societal challenges and the energy transition)
4. TSE energy studies (feasibility studies)
5. TSE Built environment (energy neutral buildings or zero energy buildings ZEB)

There are no specific government measures for BIPV outside these innovation subsidy schemes. Apart from national regulation and incentives many regional and local permits are applicable that concern planning procedures, environmental licensing and aesthetic aspects.

Dutch municipalities may take initiatives to stimulate BIPV, usually targeting specific historical building periods found within their boundaries or the completely new building projects. Some provinces also stimulated the replacement of asbestos which made for an excellent opportunity to replace roofs with BIPV. As of 2021, thirty regional energy strategy (RES) regions started to function but no specific mention of BIPV can be found in their overall plans. This is remarkable given the early initiatives by a number of municipalities, see the historical overview ‘Early period & pioneers 1990 – 2000’ and the high visibility of the early projects.

4 PHASE OF DEVELOPMENT AND TARGET DEFINITION

The main target of the TIS analysis and this chapter is to evaluate the state of the technology in terms of market readiness. This in practise implies not only a competitive business proposal but also compliance with the rules and regulation in the market and acceptance by a major share of the market players as a viable alternative for existing options. However, the development phases of BIPV are linked not only to their "technology readiness level" (TRL) or market share, but also to the development phases of the more generic solar technologies such as crystalline and thin film. This dependency has been described in the historical overview of BIPV.

For each BIPV application (facades, roofs and external applications) commercial products in the Netherlands are already available but when looking at the RVO R&D project database (fig) many BIPV projects are still in development or demonstration. The pre-development phase seems to be left behind. In-roof mounted systems are perhaps already in the commercial take-off phase. Several companies also offer integrated roof tiles, but these are still in a small niche market. Facades and windows are arguably also in the take-off phase when considering the fast market growth of Physee, a start-up which offers "solar glazing" products which are not just integrated into the building, but also can be used for regulating the internal climate of the building. Another seasoned Dutch company offering solar glazing is Scheuten Glas with their product Optisol After the solar panel manufacturer Scheuten Solar went bankrupt in 2012 they specialised in BIPV. In all BIPV applications a trend is noticeable towards the use of thin layered and more price competitive crystalline cells. This trend follows the developments of generic solar PV.

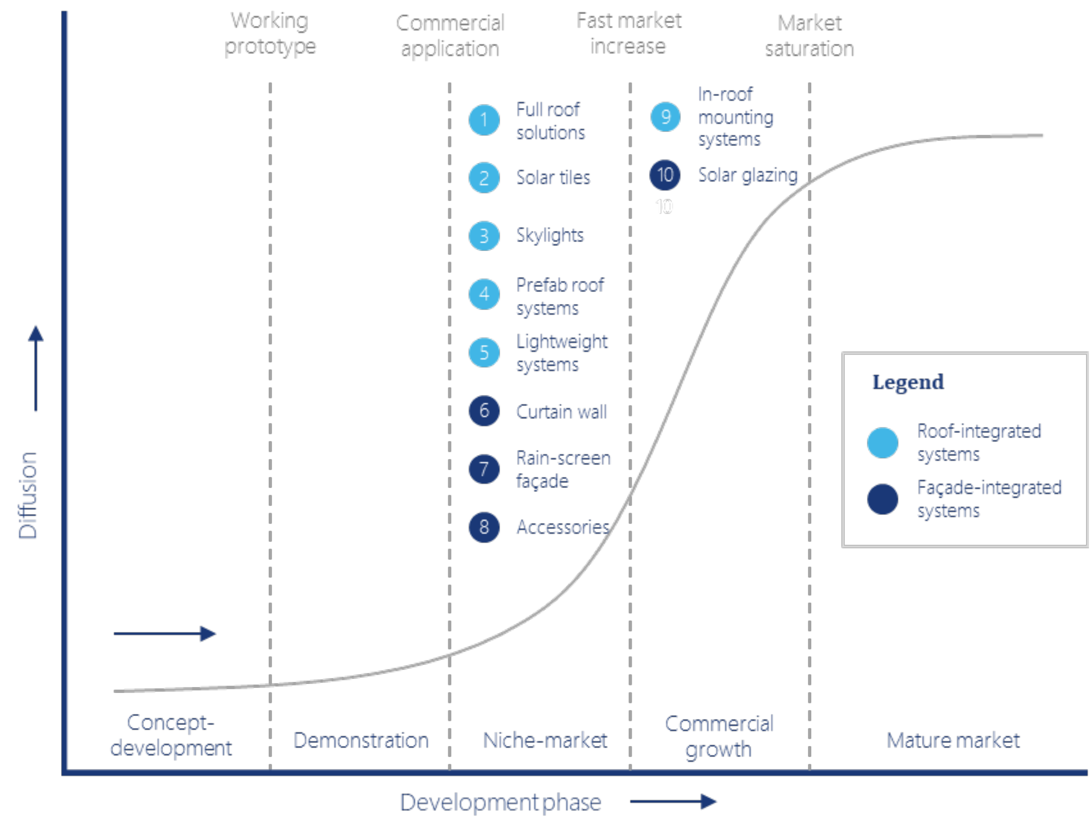

Figure 4. Development phases for BIPV in the Netherlands, by Tjebbe Vroon and Berenschot.2020 (7)

The absolute market share of the total amount of cumulated installed solar capacity of 15 GWp in 2021 is estimated at around 1%. A detailed figure is missing, and the estimates are based on interviews and sales of individual companies. This market share in the Netherlands falls far behind the earlier projected estimates by SEAC and the TKI Solar.

A completely other way of looking at these figures would be to consider the technologies which BIPV is actually replacing, in a more classical “Schumpeterian style”, with a focus on products near the end of their business cycle. Seen from that historic and economic perspective, replacing traditional clay baked roof tyles is a hard act to follow for BIPV as these have been around for several millennia and are still cheap and functional, carbon emission prices not included. A more industrial approach to lower costs even further and large scale new build and/or renovation projects seem the most viable option in the future. Replacing costly facade materials and canopies of sheds and factory halls seems to be more realistic approach in the Netherlands seen from that perspective and in the short term. Replacing glass in windows has turned out to be a more costly option although highly appreciated by end users.

5 FUNCTIONAL ANALYSIS

Functions and their interaction represent the core of the innovation system. This chapter describes and assesses the seven functions as excellent (5), strong (4), medium (3), weak (2) and absent (1) to identify what is challenging to a further development. We adopted the eight functions and the function analysis proposed in STA (van Noord 2021), which included the description, the assessment, and the key indicators for each function. We consulted different databases (publications, projects, patents), although the most important data source for this analysis was the survey study with experts and interviews with other relevant stakeholders within the BIPV innovation system.

This section builds among others on the TIS analysis made previously by Tjebbe Vroon (7) and afterwards publishing together with Berenschot in 2022. The scores are duplicated from that analysis, however the accompanying text has been adapted and expanded on specific topics not covered in those studies.

5.1 Knowledge development

Summary.

The function knowledge development (F1) appears strongly fulfilled (4) given the number of research projects and publications on BIPV and related thin film technologies, the number of participating parties in the projects and the number of knowledge institutions active in BIPV related research. The SEAC (Solar energy application centre) opened its doors in 2013 specifically for BIPV and Infrastructural integrated solar PV products. The knowledge development is however heavily tilted towards generic thin film solar technologies and somewhat towards PV manufacturing. Internationally the Dutch knowledge position is moderate given the number of BIPV specific patents over time. Although there exists a large body of knowledge on BIPV in the Netherlands, there however remain some gaps in the knowledge development, especially in addressing societal issues such as fire safety, standards and compatibility of products. Knowledge is inadequate about the timing of the innovation process and how to simultaneously scale up the production and enlarge the market demand the rollout of BIPV.

5.2 Knowledge dissemination

Summary

The function knowledge diffusion (F2) is weakly fulfilled (2) since there is a lack of available information in the construction sector, policymakers and the public at large, see Martje van de Horrik (6). In addition, the demonstration projects realized receive widespread recognition within the solar sector and even internationally, but seem to fail to reach other players, the building sector, municipalities or lead to a standardized BIPV solution for certain types of buildings. The information is shared within the solar community, front runners, and early adopters in the market. The national platform for BIPV has certainly facilitated the exchange of information within the solar sector, which was absent at the outset. The international activities within the IEA tasks on BIPV received some national attention but in general do not reach policymakers also because the contribution to the climate goals is still very moderate.. This situation is improving by the use of building information model (BIM) tools for BIPV products in the construction sector. The entry in the BIM database and their availability in the design phase of the construction process seems to be a condition for market formation which is function F8.

5.3 Entrepreneurship Experimentation

Summary

The Entrepreneurial (Function 3) is moderately fulfilled (3) since although many SME's and larger companies have been active especially in R&D projects and demonstrations, only a certain number of SME' s have had a sustainable business throughout the entire period of the analysis (see Table 1). The diversity and innovation are high (see function 1) but the activities lack standardization and mass production. Larger companies, including multinationals, have not succeeded in scaling up the BIPV technologies themselves and set a standard. They prefer to mitigated their risk by supporting SME' s, waiting for a breakthrough and then take over a successful business. (personal communications). In addition the construction sector in the Netherlands is locally oriented with the exception of more technical companies involved in the utility sector and infrastructural projects. The national production capacity for BIPV in the Netherlands is estimated at 100 Mwp a year, given the joined production capacity of these companies. The absence of larger companies and their sustained effort impacts several functions among which F4, F5 and F6.

5.4 Resources

Summary

The function resource mobilization (F6) is weakly fulfilled (2), because of the limited availability of specific funding and/or educational services with dedicated budgets. Regional funding originated mainly to the indirect investments in solar thin film technologies by the three provinces and the various municipalities within those provinces that supported BIPV SME's and start-ups. Some interviewees point out the amount of capital that was invested in thin film technologies as related to BIPV products, but that relationship is not that direct. The EU projects on BIPV were realised later in the trajectory and compensated somewhat for a slowdown in national BIPV projects after 2015, see Figure 3. Without a proven track record and a grow strategy on a national or European level including substantial costs reductions, the financial possibilities seem limited.

5.5 Development of social capital

Summary

The BIPV options are not well known to the public, and when enquiries are made by potential customers it is difficult to find installers that do anything besides standard BAPV. Even within the construction sector itself the option is debated, according to several interviews. This signals a lack of social capital in the sector and the successful BIPV business have invested a lot in their relationships B2B or as project partners of construction companies. Additional convincing is often required with respect to topics such as standards, certification, ease of installation, product lifespan, maintenance and lately fire safety. This last issue of fire safety has been displayed widely in the press and the few cases have undermined the public trust. Although the BIPV products themselves may not be a fire hazard the solar sector seems to neglect the statistical given that fires do occur more regularly on buildings with solar panels installed. This might be caused by many reasons such as errors with the wiring or accumulation of heat under the solar modules in combinations with inflammable materials used previously, which can not be attributed to the BIPV products but it shows the need for a more integrated approach.

Although the BIPV technology is well received by architects in general (especially when included in the BIM product database), their role is limited in the decision-making process. The aesthetic benefits are appreciated by all but the discussions and authorisation with and from the “welstand” committees at the municipality level can be cumbersome and the results vary from town to town. To tackle the social acceptance, again the solar and construction sectors could collaborate more effectively in city planning. A shared vision of a sustainable building future is lacking and also not required by regulations or “technology neutral” policy makers. As noted before some regional and municipal activities are the exception for the early days of BIPV.

Experiments with renovation and social housing have met scepticism as some of the investments were translated to higher rents, which nullified the gains made in lower energy bills. Renovation projects seem to stand a better change if BIPV is combined with heating solutions that address the crucial winter period. Many demonstration projects like the one in Eindhoven (neighbourhood ‘t Ven) are still supported by national subsidies. The solar sector and policymakers alike have not been able to make the case for the social benefits of BIPV, other than aesthetical benefits, such as the replacement of asbestos with all in-roof BIPV, reducing the use of natural gas and using all available roof surfaces. The BIPV applications are mainly visibly in the upper “elite” market segment such as company headquarters, façade of skyscrapers and prestige buildings.

All in all, the social capital function is assessed as being weak (2) while depending mostly on highly motivated individuals and a limited number of SMEs while not reaching the larger public or convincing the construction sector.

5.6 Legitimation

Summary

The function legitimization (F6) is moderately fulfilled (3) since its usefulness is still being questioned in the building sector by installers but the need for BIPV in the long run seems to be widely accepted. The original reasons, see historical overview, made much sense in a densely populated country with lots of historical buildings and protected city views. However, the costs did not turn out to be lower, on the contrary, the installation required additional expertise. Still certified, standardized and widely available BIPV products were not developed during the period of this TIS analysis in the Netherlands nor in Europe. The market in 2022 consisted still of tailor-made solutions with a higher perceived aesthetic value but piecemeal implemented, on a project base, and often in the higher market segments. The case for wider societal benefits besides the improved aesthetics has not been accepted broadly in society also because the costs and the benefits often do not fall to the same parties. Especially in larger projects the issue of “energy ownership” has not been resolved yet for BIPV. Facility managers and real estate managers often do not yet see BIPV as a cost-effective solution within their portfolio (interviews with especially hotel chains, hospitals and social housing corporations).

The latest interest of other ministries in the Netherlands, beside Economic Affairs & Climate, is focused on renovation projects for infrastructure, public buildings, social housing and reducing the dependency on natural gas with integrated solutions including isolation, storage and heating. A breakthrough in this market segment will certainly improve its legitimization.

5.7 Guidance of the search

Summary

The function guidance of the search (F4) is moderately fulfilled (3) as the early initiatives originated at local government level, followed by modest support at the national level. Several ministries have become active over the years in supporting BIPV project but not with specific incentives or even coordinated actions among themselves. There exists a shared notion in the Netherlands that because of the limited and very costly available space, that BIPV will play an important role in the climate goals for the built environment and CO2 neutral buildings but that remains a relative costly and complicated option for the time being. Although there is interest from the policy level, the contribution of BIPV to the climate goals remains low. The innovation dynamics in the construction sector follow different logic than in the solar sector, which are very hard to combine, and larger companies from this sector have not shown a vision of BIPV in the building stock or within their own business case yet.

5.8 Market formation

Summary

The function market formation (F5) is weakly (2) fulfilled, given the limited market share and lack of integrated business models for BIPV. In the current market and regulatory framework for solar the competition of BAPV reduces the development of BIPV to a niche market. The BIPV companies have yet to arrive at combined business cases that address societal issues, apart from energy yield and aesthetics, and facilitate its widespread implementation. The improved pay-back time of BIPV over the years has not necessarily reached or convinced all stakeholders in the building sector as their concerns lie elsewhere. Although the appreciation of BIPV products in general is high, there remain legitimate concerns about several topics that influence market adoption such as the lifetime of the product and fire safety. To fulfil the requirements of both the solar and construction sector, a more coordinated approach is required.

Also the existing reservation towards BIPV in both in the market and policy hinders a wider acceptance and rollout of the technology. The establishment of the branch association BIPV Nederland has led to more visibility but not necessarily to more activities or coordination between the solar and the construction sectors. A closer integration of the building and installing of BIPV activities has not materialised and individual companies find their own solutions on a project basis, which as such is very typical for the building sector.

5.9 Summary of the functional analysis

The results of the functional analysis of BIPV in the Netherlands are presented below in Figure 5; Numbers indicate the degree of fulfilment: 1 – absent; 2 – weak; 3 – moderate; 4 – strong; 5 – excellent

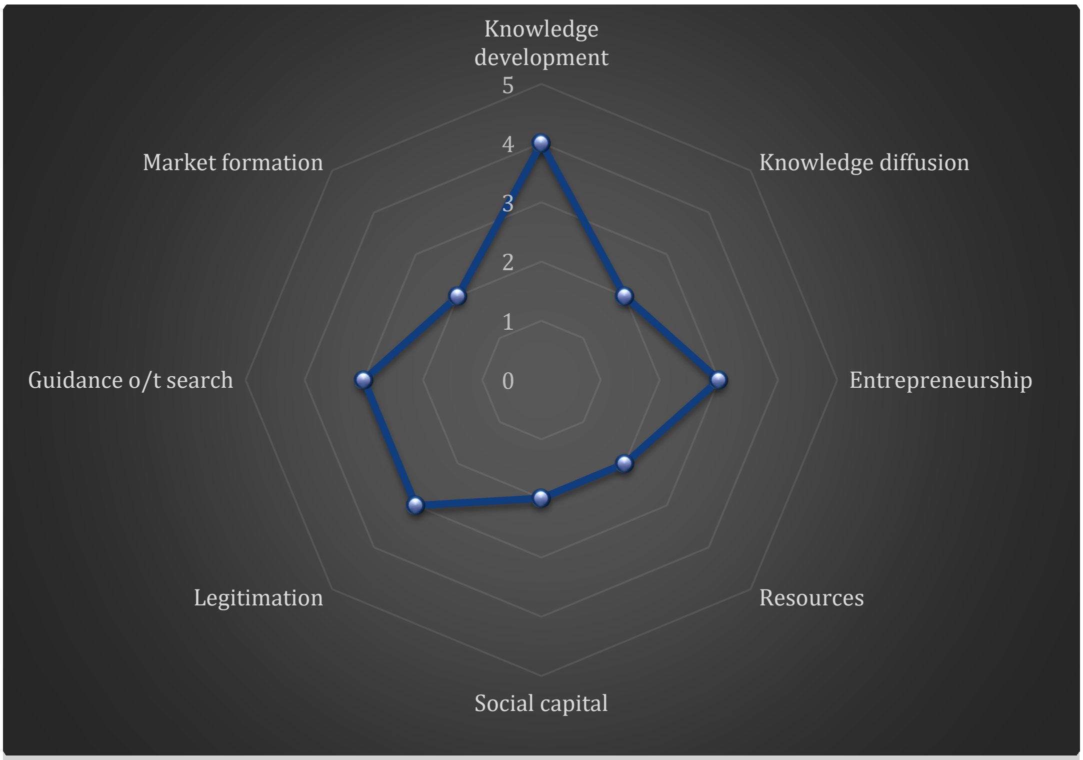

Figure 5. Scores of Function analysis of the Dutch BIPV Innovation System 2022.

The Knowledge Development (F1) is reasonably well developed followed by Entrepreneurial activities F3 (though mainly SME's) and Legitimation F6 and the Guidance of the Search F7 (though mainly governments). The other functions score low, well below the threshold for a mature innovation system.

The functions of the BIPV innovation system are not completely developed and the overall picture show the characteristics of an innovation system still at its early stages. Suurs 2009 (19) describes these initial phases as technology driven, supported by very motivated SME's and with high expectations. The guidance of the search F7 is present and not an obstacle but together with F1 and F3 they are not enough to mobilize more resources outside R&D projects and reach a wider rollout in the market.

An innovation system can take decades to mature and as such a long-term view is in place to evaluate the potential of BIPV. This TIS analysis is a snapshot in time and represents the state of the system during the observed period. In this case several previous studies have been used to describe the development of the innovation system over a longer period of time in the Netherlands. The dynamics between the different functions of this particular innovation system for BIPV are remarkably stable over the last ten years although the systems as such has grown in size. The innovation ecosystem has expanded and consolidated with more active players(see network analysis), the costs have been reduced (though typically still 2-3 times longer the ROI of regular solar panels), and form free and coloured panels are available now. Still only the B2B upper market segment is well developed and therefore it remains a niche market. Some companies are doing well in specific market segments such as in-roof mounting systems and others that offer more integral solutions Vroon (7).

Following Suurs (19) the Science and Technology Push Motor functions well enough, the Entrepreneurial Motor shows modest growth, but the System Building Motor and Market Motors have not developed for BIPV.

Table 2. The results of the functional analysis summarized.

Functions	Strengths- Opportunities	Weaknesses	Score
1. Knowledge development	+A broad technological knowledge base and steady flow of innovative R&D projects for over more than two decades.. +Long lasting collaboration with some building companies during product development. +Very innovative entrepreneurs making use of the latest solar technologies.	-There exist some essential gaps in national knowledge development concerning integration into the building structures and scaling up of production. -Availability product information is limited. BIM is starting to be implemented. -Lack of responsibility all through the value chain.	4
2. Knowledge diffusion	+Dissemination of manufacturing knowledge is increasing. +The possibilities for innovative product market combinations show great potential, especially in combination with isolation, prefab, facades and installation routines. .	-Knowledge does not reach construction industry, authorities and the larger public and the impact of BIPV is low compared to BAPV. -There is little knowledge about BIPV within the construction sector which innovates on a project by project basis. -The BIPV sector has still not managed to supply consistent information about costs, benefits, quality, life span and risks which inhibits the creation of a demand. -The communication & marketing of BIPV does not address the market questions. It is limited to a closed circuit of specialists and scientists.	2
3. Entrepreneurship	+Strong focus on new product/market combinations. +Active and innovative SME's. +Major business have invested in prototypes but	-The professional development has been strongly dependent on R&D projects which limits effectiveness and market orientation.	3

	without success so far. However new markets could be opened once market conditions improve notably by adjusting business models.	-Unsuccessful involvement of major businesses with strong focus on new products. -Existing entrepreneurs only target the BIPV product. Construction sector has often a local orientation while solar is much more international.	
4. Resources	+R&D funding by national and local governments. +More ministries have become involved lately.	-Major companies have tried to invest in BIPV but with little to show for it up to now. The perception is that there is certainly a high risk involved.	2
5. Social capital	+Aesthetics have clearly improved and are appreciated.	-The SME's and researcher are not well connected to the public at large.	2
6. Legitimation	+The BIPV technology is well known in a relatively small circle and not very accessible to the public at large. One reason is that the sector is focused on the high end B2B market segment. +The latest interest of other ministries in the Netherlands, beside Economic Affairs & Climate, is focused on renovation projects for infrastructure, public buildings, social housing and reducing the dependency on natural gas with integrated solutions including isolation, storage and heating.	-There exists a negative perceptive lately because of press releases about fire safety. -Also insecurities exist about life span, insurances and the lack of information in general at the right moment and time.	3
7. Guidance Search	+Land scarcity is an obvious reason why BIPV sooner or later will take of in the Netherlands. +The use of thin film technologies for integration into building components was an early on and clear message from the sector.	-The possibilities and impact of BIPV have been estimated too optimistically time and again by the sector. -The narrow focus on price reduction (also European see ETIP and SET plan) and a technical push strategy has inhibited a market outlook and massive uptake. -Larger companies mitigate the risk by joining only in R&D projects and or	3

	+Several Ministries have become active in the field of solar integration into the infrastructure, built environment and transport and these product show a considerable amount of overlap.	separate the business development is SME's.	
8. Formation markets	+Many proven products available and demonstration projects for new applications.	-There is no uniform legal framework for BIPV. -Exclusive focus on technology development and little consideration for market up take on a European scale. -Lack of building experts involved in the development and sometimes complex administrative and legal procedures, see also. (Crassard & Rode, 2007; Kaaijk & Durand, 2016), -Few SME's have succeeded in developing multi-functional business cases and new financial models such as leasing, esco' s, that do exist for BAPV solutions. -Business models for larger rollout in social housing or renovation have not been implemented by the stakeholders. Often the costs and benefits (energy ownership) do not lie with the same parties.	2

6 IDENTIFYING SYSTEM WEAKNESSES AND STRENGTHS

In the report “Barriers for BIPV; scaling up and the rollout of integrated PV systems in the Dutch Market” by van Horrik (6), a large number of constraints are mentioned that are essentially caused by combining two innovation systems. Most of those barriers mentioned in that report were still in place in 2022.

The combination of the technical know-how about solar panels with the domain knowledge for its application in the construction sector has led to specific problems. The BIPV concept seeks to replace passive and cheap building materials with active energy producing solar panels. The trade-offs include for example durability and life span of the components, the scarcity, carbon foot print and price of the materials and a range of other qualities. To solve this inherent dilemma of BIPV, a far-reaching integration of the solar sector with the building sector might be required. Such an integration entails the design phase of building, urban planning, streamlining logistics along the value chain, adhering to requirements of both sectors concerning fire safety and building codes, introducing new business models and finally training and best practises. A similar disconnect of know-how and coordination can be observed at the policy level where first only one ministry was active from an innovation perspective and later joined by two others, each with a own specific understanding and responsibilities in the built environment of the Netherlands

Based upon the extended interviews by both van Horrik (6) and Vroon (7) the scoring of the eight functions of the TIS can be placed in a meaningful context. Several systemic weaknesses and strengths are described and categorized in the following sections.

6.1 Actors’ problems and opportunities

Although initially active, large multinational companies are now all but absent in the Dutch innovation system. Some companies are still providing components (Sabic, DSM etc.) but on a limited scale and not as a core business activity. The main reason, according to management interviews, for these multinational companies to withhold investments is that the energy market is basically a heavily regulated bulk market with relatively low margins. Therefore, they mitigated the risk by supporting just a limited effort by their business development teams and/or SMEs and wait for the technology to become successful. By keeping BIPV products at a distance from their core business in the building process the functions of knowledge diffusion (F3), market formation (F5), resource mobilization (F6) and guidance of the search (F7) are seriously hampered.

It is not to say they have not tried, and spend considerable resources already in doing so, but so far, the results have not lived up to the expectations. BIPV products have been still too costly, too cumbersome to install, lack standardisation, and perhaps most importantly, large-scale production has not materialised. Therefore, the risks are still perceived to be considerable.

A more streamlined effort along the value chain in the building sector, and European collaboration on setting examples for compatible products in the market, could remedy these shortcomings and provide the market with dynamics to counter these uncertainties. European wide demonstration projects could bring these parties together and focus on a limited number of specific market segments that are suitable for scaling up both in the market (business case) and production wise. No such effort has been undertaken yet and it can be observed that for example EU projects like BIPVBOOST (2018) are still heavily biased towards the solar sector and focus on generating overviews of the existing diversity.

Vroon (7) argues that BIPV companies which are spin-offs from previous research projects, often lack the capacity to develop effective network ties and thus face challenges in building social capital and initiating inter-organizational collaboration. They encounter often structural gaps between their scientific research networks and industry.

The strong involvement of the academic networks is positive in the initial stages of the BIPV innovation system but it is not enough for its further development. The inherent function of R&D is to promote diversity of possible solutions, but its role is not to select specific solutions in the demonstration stage or market uptake.

6.2 Institutional problems and opportunities

The policy support in the Netherlands for BIPV initially came from the Ministry of Economic Affairs and Climate (EZK) which was only recently joined by two other ministries with their own and separate supporting programs for integrated solar PV. In addition, the perspective on BIPV has changed over the years, moving from innovation policy to reaching the climate goals and lately to replacing natural gas as a main energy source for heating in the built environment by electrification. Specific measures for BIPV were absent although BIPV did qualify as an R&D topic and benefited from the general R&D subsidies for solar technologies and some special programs for the built environment. In some cases, BIPV experienced competition from BAPV solutions such as in the case of energy label for buildings, the SDE+ scheme and reclaiming the 21 % VAT on solar panels but not for BIPV. The underlying reason being a state policy based merely upon the most efficient and technology neutral solutions and the absence of other selectors in this stage of the development of BIPV. The many pilot and demonstration projects supported by EZK/RVO did not achieve a breakthrough in the market deployment although they did contribute to market diversity. The R&D agenda did result in the availability of more “form free” and coloured panels to choose from, which was an important addition to the toolbox of the architects and highly appreciated by the public.

Support for large scale industrialization lies outside the scope of the measures these ministries can take in this period and are regulated by the European Commission in the various directives on state support, European tenders, and unfair competition. Investments in PV production and machinery in Europe in the period covered in this report, have only been supported by Structural Funds for regional development and in some cases by the Corona Recovery Funds. Only recently since 2022 and under external pressure has the EC relaxed the rules for supporting production and manufacturing (IPCEI) by member states. At the same time the European Commission has not acted upon setting the right market conditions for BIPV or solar PV by introducing for example an ecolabel that would offset the somewhat higher prices but for cleaner production in Europe. A trade-off here is the availability of cheaper Asian panels that keep the upfront costs of renewable energy production down.

Regarding the cultural and historical differences between the construction sector and solar sector a number of differences stand out that have proven hard to overcome by the BIPV innovation system. The construction sector innovates on a project-by-project basis and adopts technological innovations mainly from their technology suppliers see Spekking (19) in Next Generation Scenario ICT in de Bouw, EZK 2002. Knowledge in the Dutch construction sector is also dispersed and there are no dominant players that set the stage or promote a shared vision. Especially in the utility and housing sector, it is a supply market where consumer demand has little influence on the products being build and sales are guaranteed. The major risks are therefore found in financing the projects, coordination of the many parties along the value chain and quality control. The adoption of innovative technologies is usually motivated by costs reduction in the overhead or failure costs. The benefits of BIPV however lie with the end consumer (owner or renter) who has little to no influence. The introduction of BIPV products in ever changing coalitions of companies during the building process only complicates the matters and adds to the management risks. If the BIPV products are not compatible) with other building materials and, included in the BIM (Building Information model) tools, the failure costs will rise considerably. Additional training is another complicating factor that is hard to overcome. Vroon (2021) also points to the more current concerns in the media over fire-safety of solar and in specific BIPV products, see also TNO (2019). Therefore, a certain reluctance to include BIPV in the initial planning and acquisition phases of the building process is understandable from a builders perspective.

While the construction sector usually operates in local markets and uses local materials preferably, the solar sector and its value chain are very internationally oriented.

The infrastructural building projects are much more receptive to innovation since the market is dominated by a few large parties and the technical skill level during the process is generally also much higher. Given the overlap with integrated solar products such as noise barriers (SONOB project) and semi-transparent modules, it is here that lie many chances for standardization and large-scale deployment.

The existing BIPV companies in the Netherlands did establish themselves in the higher end B2B market and in this way avoiding some of the structural differences mentioned above between the solar and construction sector.

However, these different innovation dynamics between sectors negatively influence various functions of the innovation system especially resources mobilization (F4), social capital (F5), legitimation (F6), guidance of the Search (F7) and market formation (F8) and hinder its further development.

6.3 Interaction problems and opportunities

The network analyses provided by Meijvogel (2016) and Vroon (2020) of the active players in BIPV show an increasing concentration of relationships centring around research institutes, notably TNO (including formerly ECN) with some separate clusters around the TUDelft and TUEindhoven. The Top Sector approach, since 2011, has probably contributed to this concentration as matchmaking for R&D projects became more tunnelled. Another plausible reason is that some BIPV start-ups are spin-offs from research projects that maintained their academic networks in subsequent projects. After 2016 research institutes also increasingly collaborate in European projects. The European project landscape however did not necessarily lead to more cooperation between companies, but mostly between knowledge institutions and consultancy firms. Instead of selecting pan European applications and working towards international compatible products, these projects stimulated mostly diversity or focus on best practises from a few countries.

This picture paints however just one side and illustrates the “ technology push” approach of the solar sector. The other side of the picture is the lack of a “market pull” strategy both on a national and a European level. Not only are the institutions not in place to achieve a European market for BIPV, but the parties needed are also not organised in the available platforms and only meet at an ad hoc project base. The industry involvement in the European Technology Innovation Platform for solar has traditionally been low and for BIPV absent. The main indicator in the ETIP BIPV position paper of 2016 was cost price reduction and on a national Dutch level freedom of shape and colour were specifically mentioned.

This means that knowledge diffusion (F3) is dominated by academic circles mainly from the solar sector which affects negatively social capital (F5), legitimation (F6), resources mobilization (F7) and the market formation (F8), in the later deployment stages.

It remains an open question if decisions makers from construction sector would have been receptive to this increasing body of academic knowledge, given the innovation dynamics within that sector. Alternatively together with government stakeholders supporting larger demonstration projects this vicious circle might have been broken by the industry. It is remarkable that the early pioneers in BIPV (see history) did envision such a strategy and worked together with local governments immediately towards a market uptake when the technology was still relatively immature and expensive. By 2018 however improvements had been made and the return of investment had already been reduced to an estimated 2 to 3 times that of regular solar PV. However, the enactors did not meet and come together anymore for an effective lobbying of governments and larger companies.

Another example of limited interaction in the innovation system is the absence of any reaction on the report by the Systemiq from 2021 (21) on the constructive limitations for solar deployment. Its main conclusion is that 45 % of buildings has slight limitations that can be remedied with roof reinforcement which would add another 1.1 TWh a year to solar energy production. The BIPV sector uses the same argument to push lightweight BIPV products but have not compared this yet to the other available option roof reinforcement.

This lack of knowledge diffusion was however addressed both by the national Branche organization and by the IEA PVPS task 15. At least for reaching architects and designers, working on BIM (building information modelling), they established a first bridge between the solar and construction sectors.

Streamlining and scaling up along the (European) value chain would mean building the ultimate bridge between the two sectors but would require the fulfilment first of some basic financial and market conditions (F8) and a clear European vision (F7 Guidance of the Search).

Opportunities still exist especially in the prefab component market that would allow for scaling up manufacturing. Also, renovation of social housing and apartment blocks, including removal of asbestos, remains an untapped reservoir within the Netherlands and the European market. However, costs and benefits do not lie with the same parties, and these are not organised in such a way that can meet and negotiate a future for BIPV.

6.4 Infrastructural problems and opportunities

Infrastructural problems align largely with the above barriers and can be categorized in;

A. Financial (no specific supporting schemes and no extensive track records)

B. Human capital (scarce skill set required for BIPV installation)

C. Organisational (lack of streamlining along the value chain)

Part of these problems are national and many play out on a European scale. Generally, they inhibit resource mobilisation (F6) and undermine the legitimacy (F7) as the technology does not seem capable to provide (the promised) solutions to societal problems, at least in the short term. These are preconditions to both setting up production at scale (F3) and developing the market (F8) further.

Important here is to envision the longer-term perspective given the specific circumstances of the Netherlands where land and surfaces are and will stay extremely scarce. This means that in the long term, towards the 2030 and 2050 climate goals, the business case for BIPV will continue to improve. BIPV will increasingly be one of the few options left for local, decentralised renewable energy production.

Bridging the gap between the solar and construction sectors will remain a precondition, nonetheless.

6.5 Summary of system weaknesses and opportunities

As mentioned above, a large number of barriers mentioned by Martje van Horrik and Michiel Ritzen (6) still exist in 2022 in the Dutch innovation system for BIPV. These essentially result from the lack of integration between the solar sector and the construction sector.

Large companies where not able to scale up production and set a BIPV standard in the (European) construction sector, policy for implementation of renewable energy sources remained restricted to solar PV as the cheapest option and research institutions stuck to their technical R&D agenda's. These can be described as technology push factors but also from the market side the innovation system did not develop further. Notably are the lack of knowledge of the BIPV products, professional training, the issue of "energy ownerships" in the built environment and the absence of societal challenges in the business cases. Some of these later issues are being addressed by the sector such as the availability now of form free panels and many colours and the efforts to include BIPV products in the BIM databases.

This picture follows broadly the dynamics of what Suurs (19) calls the science and technology push (STP) motor for an emerging technology and it shows both its typical strong and weak points, see functional analysis. The entrepreneurial is starting to form in the Netherlands but is not strong enough developed to start the system building motor which required for a fully developed market motor.

Based on these insights, a number of opportunities arise if these outlined conditions are met. The BIPV innovation network could address several societal issues in the Netherlands which are not consistently explored yet. The early pioneers actively sought the collaborations with local governments and focused on large scale demonstrations. This approach has been abandoned largely in favour of a more technical approach and R&D funding. Major exceptions here are the Hogeschool Zuyd that still seeks regional collaboration and validation of the BIPV technology together with municipalities in the Province of Limburg that apply these insights in renovation projects of the existing building stock. Martje van de Horrik in 2021 summarised the lessons learned as follows "focus on renovation, keep critical of theoretical models, prepare and plan the whole value chain before you start, improve the neighbourhood's living condition and add value for all".

The relative higher cost price of BIPV could be offset by a special feed in tariff but for how long and how sustainable is this option given the social acceptability in the Netherlands and considering the experiences in both France and Italy with such an incentive that may have led to overstimulation?

A more structural solution would be to combine several business case and address the roles and energy ownership in the construction sector. This approach combined perhaps with stronger regulation in the form of building code for energy neutral buildings might tip the balance. Setting up such integrated practises would give an impulse a more market driven approach and start the system building motor and finally a market take off.

7 RECOMMENDATIONS

Based on the identified systemic weaknesses a collection of actions is recommended. This chapter first presents relevant actions for all the weaknesses, according to the classifications from the previous chapter. After a short summary there is a discussion on what could be relevant prioritizations.

According to the TIS Guide the most important activities for further development of a TIS in a niche market phase are to strengthen the emerging entrepreneurial function by identifying social needs and collaborate with (local) governments to establish institutional support from governments and/or other selectors. This will enhance the social capital F4, legitimation F5, guidance of the search F6, resource mobilization F7 and finally market formation F8, if the technology proves mature enough, and the unavoidable setbacks in the demonstration phase are overcome. The recommendations below are in line with these findings and along those action lines.

I. Escape the limited network, consisting of predominately academia, start-ups and consultancy from the solar sector, by networking with (local) government and addressing societal issues. Although the BIPV technology is already established in the B2B high-end market in the Netherlands it reaches only a relatively small circle with low impact on climate goals or societal needs. *Action needed by Industry.*

II. Identify new markets that address societal needs with high visibility, address energy ownership, provide the necessary information and bring together the different stakeholders along the (new) value chain that negotiate a combined business case which includes all the costs and long-term benefits. *Action needed by industry, government end users and academia.*

III. Build these business cases around “energy ownership” with a wider coalition of stakeholder and new organisational models to avoid the pitfalls of the innovation dynamics of the supply-based construction sector. New business cases for new markets like social housing and public buildings may also require new legislation and regulatory frameworks to consolidate the new roles and societal benefits. Organise dissemination sessions and training workshops. *Action needed by industry, government, end users and academia.*

IV. Undertake large demonstration projects in these new markets with a wider range of stakeholders along the value chain in the building sector. *Action needed by government and industry.*

V. Validate the technical solutions by large scale demonstration and pave the way for larger market rollouts, possibly on a European scale and including whole sale companies. *Action needed by (EU) government(s).*

VI. Match local energy production with local demand in so called “energy hubs” and expand the existing sustainable building stock. *Action needed by government, grid operators and regulators.*

VII. Industrialization of the building process by using digital tools and standard prefabricated BIPV materials that reduce elapsed time and fail costs in the execution of the building projects with this new technology. *Action needed by academia and industry.*

VIII. Once these new and larger markets are identified and validated by demonstration projects, more formal measures can be taken such as certification, eco-labels, building codes, and financial incentives that prepare a larger market role out, preferably on an European scale, and mitigate the risks for the investors. *Action needed by (EU) governments(s).*

IX. Favourable institutional and market conditions need to be in place before ramping up production of BIPV preferably on a European scale. This will in turn lead to further benefits of scale and result in price reductions. Getting this timing wrong will lead to unnecessary expenditure of public funding and general disappointment. *Action needed by Industry and governments*.

REFERENCES

[1] A. Bergek, S. Jacobsson, B. Carlsson, S. Lindmark, and A. Rickne, 'Analyzing the functional dynamics of technological innovation systems: A scheme of analysis', *Res. Policy*, vol. 37, no. 3, pp. 407–429, Apr. 2008, doi: 10.1016/j.respol.2007.12.003.

[2] M. Hekkert, S. Negro, G. Heimeriks, and R. Harmsen, 'Technological Innovation System Analysis: A manual for analysts', Utrecht University - Faculty of Geosciences, Utrecht, Nov. 2011.

[3] M. Noord van (ed) Guide for Technological Innovation System Analysis for Building-Integrated Photovoltaics, IEA PVPS Task 15 2023

[4] Wieczorek, A. J. A systemic policy framework for evaluation of transitions pathways. In *Transition Pathways to a Low Carbon Economy : KSI International Conference 2009*

[5] M. Hekkert & M. Ossebaard, De InnovatieMotor 2010

6] M van Horrik & M. Ritzen Horrik, M, Ritzen 'Belemmeringen voor BIPV: Opschaling & uitrol in de Nederlandse markt van gebouw geïntegreerde PV systemen" 2016

[7] T. Vroon " Escaping the Niche Market: An Innovation System Analysis of the Dutch Building Integrated Photovoltaics (BIPV) Sector." Master thesis. 2021

[8] Karl Berger *et al.*, 'International definitions of "BIPV"', International Energy Agency - Photovoltaic Power Systems Programme (IEA-PVPS), Report IEA-PVPS T15-04, 2018.

[9] E. Alsema. Energy Pay-Back Time and CO2 emissions of Photovoltaic Systems 2003

[10] B. Mierlo van & J. Cramer "Kiem van maatschappelijke verandering : verspreiding van zonnecelsystemen in de woningbouw met behulp van pilotprojecten."2010

[11] M. Gutschner, S. Nowak, D. Ruoss, P. Toggweiler, & T. Schoen. (2002). Potential for Building integrated Photovoltaics: IEA PVPS Task7

[12] B. Janson, O. Bernsen, and J. Koch, J. *Advanced monitoring of entrepreneurial activities in solar business, getting insight in innovation niches of connecting solar companies to the building industry*. Paper presented at the EUPVSEC 2014, Amsterdam 2014

[13] L. Hurk van den & E. Teunissen. *Roadmap Building Integrated Photovoltaics*. Berenschot, 2015.

[14] D. Saelens. BIPV Roadmap Energyville, 2017.

[15] J.W Wiegman & E. Kolk van der "Building integrated thin film luminescent solar concentrators: Detailed efficiency characterization and light transport modelling" 2012.

[16] I.Zanetti, P. Bonomo, F.Frontini, E. Saretta, M. Donken, F. Vossen and W. Folkerts *BIPV Status Report SUPSI-SEAC*. 2017.

[17] D. Meijvogel, De Struktuur van het Innovatie Systeem.van BIPV. 2015

[18] R. Franken & Meijer, M. International Positioning of the Dutch PV Sector: Atrivé & Energy indeed in consultation with TKI Solar Energy 2014

[19] R. Suurs. Motors of Sustainable Innovation PHD thesis. 2015.

[20] D. Spekking "Next Generation Scenario ICT in de Bouw." EZK 2002

[21] Systemiq Constructieve Beperkingen voor Zon op Dak 2021

Technology Collaboration Programme
by iea

ISBN 978-3-907281-60-4
9 783907 281604