Energy Research & Social Science 102 (2023) 103149

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

Crossing multiple solar energy gaps: A Dutch case study on intermediation for building-integrated photovoltaics

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ARTICLE INFO

Keywords:
Intermediation
Multi-stage decision process
Building-integrated photovoltaics (BIPV)
Diffusion of innovations
Renewable energy

ABSTRACT

Building-integrated photovoltaics are a promising technology to enhance renewable energy production in the built environment while improving the aesthetics of buildings at the same time. Several challenges hinder this technology's uptake, such as information asymmetry and limited value chain coordination. Prior work demonstrates that the support of intermediaries can play a crucial role in coping with these challenges, but this aspect has not yet been previously investigated for this technology. A comprehensive overview is lacking of how various intermediaries can support a multi-stage decision process. Rather than focusing on specific intermediary actors, we explore the Dutch system for building-integrated photovoltaics, identifying which actors act or can act as an intermediary, and what intermediation activities can support the decision process. This article identifies the need for intermediation at the various stages of the decision process and the actors best suited to providing this. Drawing from our empirical findings from 26 in-depth interviews and the literature on innovation adoption and intermediaries, the results reveal that a dynamic 'ecology of intermediaries' is necessary to perform various intermediation activities at different system levels in the multi-stage decision process. As these activities and actors are highly interrelated and interdependent, we argue that it is vital to assess intermediation in a holistic way. These findings are significant for suppliers, potential intermediaries, and governments because they can support improving the decision process with the help of intermediation. The present paper contributes to innovation and intermediation studies by demonstrating that intermediation is an interrelated, multi-level, and variegated phenomenon.

1. Introduction

The European Union aims to cut greenhouse gas emissions by at least 55 % by 2030, compared to 1990 levels [1]. Buildings account for 36 % of these greenhouse gas emissions in 2020 [2] and are therefore an important sector to address. Reductions can be achieved via the adoption of energy efficiency measures (e.g., insulation, efficient ventilation, and heating appliances), the replacement of natural gas-based heating systems with low-carbon methods of heating, and the implementation of photovoltaics (PV). Photovoltaics (ground-mounted and rooftop) account for a 5.2 % share of total net electricity generation in the European Union in 2020 [3], but rooftop PV alone has the potential to grow to a quarter of total electricity demand in Europe [4]. One reason for the non-use of solar PV panels is that people find solar panels aesthetically unattractive, and a promising technical innovation in this regard are building-integrated photovoltaics (BIPV) [5]. Building-integrated photovoltaics differ from traditional PV in that they are integrated into the building envelope and fulfil at least one additional function besides generating electricity, such as weather protection, insulation, or shading [6]. A key advantage of BIPV is that these products have improved aesthetic qualities compared to traditional PV. Moreover, prior research points out that these improved aesthetics can increase society's social acceptance of renewables [5,7–9], thus facilitating the transition to a low-carbon society.

The Netherlands have an active BIPV sector but despite several governmental initiatives and pilot projects, it is still a niche market as

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https://doi.org/10.1016/j.erss.2023.103149
Received 13 November 2022; Received in revised form 22 May 2023; Accepted 23 May 2023
Available online 7 June 2023

diffusion is low [10]. The uptake of BIPV still faces challenges, such as a lack of awareness and knowledge in the construction sector and among potential adopters [10,11], limited value chain coordination between the BIPV and construction sectors [10,12,13], and perceived high investment costs [9–11,14]. With a share of 1 % in the global PV market [11], BIPV potentials are far from being fully exploited as BIPV continues to struggle to compete with incumbent technologies such as traditional PV [10].

There are several recent studies on the techno-economic aspects of BIPV, such as energy performance and building integration [e.g. 9,10,11,15], but less is known about the factors influencing the BIPV decision process. As innovation-diffusion pioneer Rogers [16] points out, decision-makers can be individuals, groups or organisations. Rogers' model for the innovation-decision process includes five stages: I. the knowledge stage, II. the persuasion stage, III. the decision stage, IV. the implementation stage, and V. the confirmation stage [16]. These decision-making stages have been tested and proved useful in contexts relevant to BIPV, such as traditional PV and energy renovation measures for dwellings [e.g. 17,18,19]. In general, for any innovation, various challenges can emerge in the different stages of the decision process, such as a lack of awareness or disinformation about the innovation in the knowledge stage, and difficulties in financing in the persuasion stage [20–22]. These challenges can hamper the diffusion of the innovation [20]. To cope with such challenges, previous research demonstrates that the support of intermediaries plays a crucial role in the diffusion of innovations [e.g. 20,23,24–27]. Intermediaries can affect innovation decision processes positively by connecting diverse visions and interests, actors and activities, and their resources and expectations; moreover, they can create new networks and collaborations [21,23] to enhance the diffusion of the innovation.

Various studies have investigated the importance of intermediation in the development and diffusion of technical innovations related to BIPV, but not to BIPV as such; for example, large-scale solar and wind power [26,28], small-scale renewable energy technologies [29], heat pumps [25,29,30] low-energy/net-zero housing and retrofits [23,25,30–36], and local energy and climate initiatives [37–40]. Most of these studies have focused on intermediaries acting at the system level [24], but several studies point out that there is a lack of systemized knowledge about intermediaries located downstream in the supply chain between the technology adopter and supplier [e.g. 26,28] and that there is a need for more knowledge about user [34,36,41] and diffusion intermediation [24,26,42] because the more prominent supply-side intermediaries tend to overbalance the often more informal but crucial user-side intermediaries in most studies [41]. This can cause problems because technologies need not only to be developed but also adopted at a large scale to contribute to sustainable transitions [24]. Investigation of the role of intermediation across all stages of the decision process is also rare [43]. An exception is a recent study by Glaa and Mignon [20], who identified gaps and overlaps in intermediary support in the various stages of the decision process in the context of renewable energy technology in Sweden. However, they focused on organisations with a designated and specific intermediation role for supporting adopters, neglecting the role of not-designated intermediaries such as architects and engineers as potential intermediaries. Both architects and engineers could be essential intermediaries in the BIPV decision process as they advise potential adopters in the building process.

The purpose of this paper is to contribute to a better understanding of how intermediation affects the multiple stages of the BIPV decision process in the Netherlands, what type of intermediation is needed, who can/may act as an intermediary, between which actors intermediation is needed, and at what system level intermediation is required. The following research questions have been formulated for our empirical investigation:

RQ1: What kind of intermediaries and intermediary activities exist in the BIPV decision process in the Netherlands?

RQ2: What kind of intermediation gaps and challenges slow down the diffusion of BIPV?

RQ3: How can intermediation improve the multiple stages of the BIPV decision process in the Netherlands?

We start by setting the scene for BIPV in Section 2, followed by a discussion of the literature on innovation adoption and intermediaries in Section 3. Subsequently, we report on our research method in Section 4. The results of the analysis of the semi-structured interviews with 26 stakeholders from the BIPV system in the Netherlands are presented in Section 5. In Section 6, we offer a discussion of the results and present our main conclusions, together with recommendations for intermediation for the case of BIPV.

2. Building-integrated photovoltaics: key actors and challenges

There is a wide range of BIPV products available, such as roof and façade products, semi-transparent and non-transparent systems, custom-made and 'off-the-shelf' products (see Figs. 1 and 2). This wide variety of products and actors makes the BIPV system complex. An often-used framework to determine the network of involved actors and institutions that interact in a specific technological system is the technical innovation system (TIS). TIS is described as a set of networks of actors and institutions that interact in a specific technological field and support the development and diffusion of technologies [44,45]. TIS includes five components (e.g. actors) and relations (see Fig. 3): (1) the supply side, which develops, manufactures, and supplies BIPV products; (2) the demand side, consisting of the potential adopters; (3) the governmental infrastructure; (4) the supportive infrastructure; and (5) intermediaries that function as brokers between the various parties [45–49]. The TIS framework is used in a recent Dutch BIPV study by Vroon, Teunissen, Drent, Negro and van Sark [10] to study the actors in the Dutch BIPV system. We used this overview and complemented it with results from other Dutch [12,50,51] and European BIPV studies [13,14,52–54]. However, these studies did not include or study intermediaries specifically in their framework. Therefore, we address this research gap by incorporating intermediaries into the BIPV system [based on 46,47–49]. Fig. 3 is based on our review and presents the TIS system for the BIPV ecosystem including intermediaries and gives also examples of actors. It demonstrates that intermediaries can connect different actors in the BIPV system, which we will further investigate in this study.

Even though there is a vibrant BIPV market in the Netherlands, it still struggles to compete with incumbent technologies such as traditional PV [10], as do other (European) countries. Table 1 presents an overview of the reported challenges in BIPV systems in prior studies divided into European and Dutch BIPV studies. Main challenges are, for instance, a lack of awareness among potential adopters and in the construction sector, a lack of policy support, and a lack of large construction companies within the system. These reported challenges could influence the BIPV decision process which can hamper diffusion. Based on our analysis, we assorted these challenges per decision stage, which these challenges could affect directly or indirectly. Multiple studies report that intermediaries can play an essential role in overcoming challenges in the diffusion of an emerging technology [e.g. 22,24,25], such as BIPV. There is, however, a lack of insight into what these roles and activities are and who should act as an intermediary between the various actors in the BIPV system. This paper, therefore, explores these questions further.

3. Innovation intermediaries

3.1. Intermediary functions and activities

Intermediation is a way to overcome challenges in the innovation decision process through a variety of intermediation activities [22]. There are valid theoretical reasons for assuming that intermediation can help to align different actors whose activities are needed for innovation.

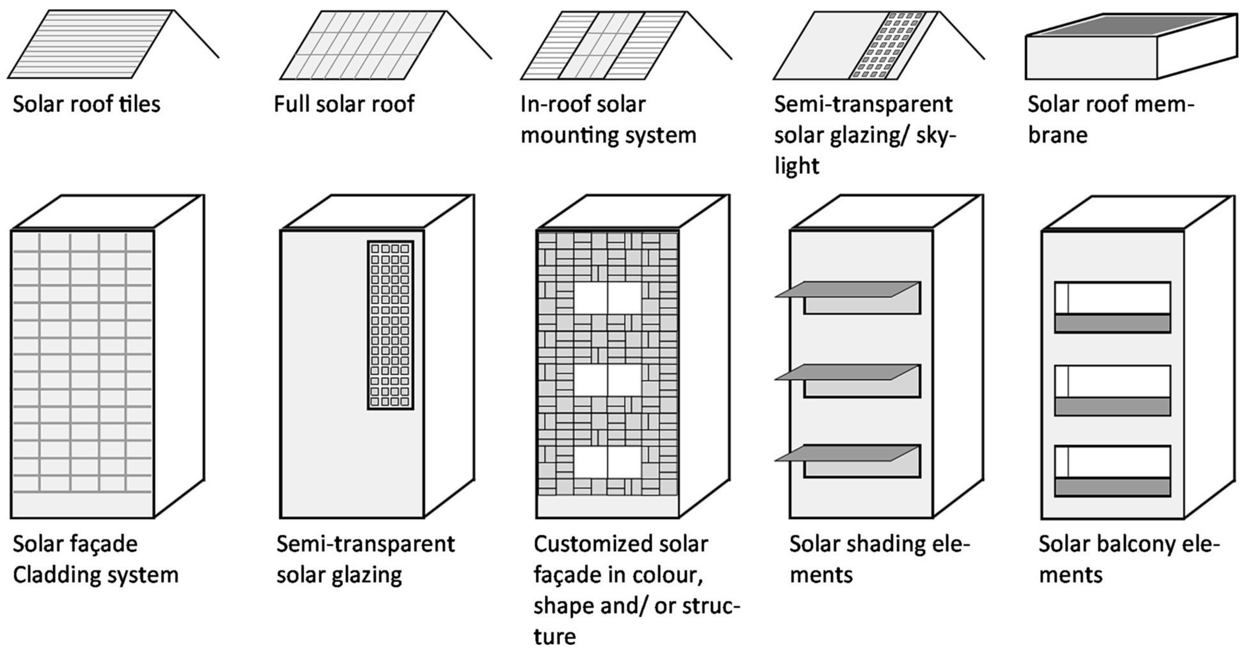

Fig. 1. Examples of BIPV applications, [authors own work based on 13,55,56].
For a comprehensive overview of BIPV products: https://www.bipv.ch/images/Report%202017_SUPSI_SEAC_BIPV.pdf.

Fig. 2. Examples of realised BIPV projects in the Netherlands. Top-left: full solar roof (source: Exasun); top-right: solar facade (source: Zigzagsolar); middle-left: solar roof tiles (source: Solinso); bottem-left: coloured solar facade (source: Solarix-solar); bottem-right: solar roof membrane (source: HyET Solar).

Many intermediary studies have investigated these activities and generally arrived at an enabling role for intermediation. Table 2 presents a compilation of these intermediation activities, drawn from the literature. Based on common emerging themes from the literature, we grouped the intermediation activities into five main intermediation functions: 1. knowledge development and exchange, 2. networking, 3. facilitating projects, 4. visioning, and 5. institutional change. Based on this overview it can be concluded that intermediation can cover a wide variety of activities, but it is not clear what intermediation activities are needed at which stage of the decision process and specifically for BIPV.

3.2. Intermediary actors

As described in previous literature, intermediation functions and activities can be performed by a variety of actors, such as private, public or non-profit organisations [24,68,74]. Table 3 presents an overview of actors identified in prior studies as intermediaries, ranging from industry associations to voluntary groups. A study by Bergek [24] reveals that some of these intermediary actors are specifically assigned to be an intermediary, while others are not. This means that they sometimes act as an intermediary but are primarily engaged in other activities. Many intermediary studies focus on specialised intermediaries, but 'unspecialised intermediaries' make up a large share of the intermediaries, and it is therefore imperative not to exclude them in intermediation studies [24]. In the construction sector, in particular, intermediation is often performed by actors who are not specifically assigned to be an intermediary [33,42] such as architects and building managers. Therefore, this paper investigates all key actors in the BIPV system to identify specialised and unspecialised intermediaries in the BIPV system.

3.3. Intermediation and system levels

Prior intermediation studies conclude that an 'ecology of intermediaries' is needed to enhance the diffusion of innovations, especially in and between the supply and user side [25,41,81]. This means that specific types of intermediaries are required, with different competences, activities, and roles that can also change over time. However, most studies have focused on a specific type of intermediary [81] or specialised intermediaries [24]. Therefore, rather than focusing on specific types of intermediaries, we will explore a variety of intermediation activities and actors in the multi-stage BIPV decision process in the Netherlands.

In their comprehensive review of intermediaries, Kivimaa, Boon, Hyysalo and Klerkx [21] introduce a typology of intermediaries based on the multi-level perspective (MLP). Table 4 gives an overview of these five intermediary types ranging from a system to a user level. The MLP distinguishes three different system levels: the landscape level, the socio-technical regime, and the micro-level of socio-technical niches [82,83]. The landscape level is '*a set of heterogeneous factors, such as oil prices, economic growth, wars, emigration, broad political coalitions, cultural*

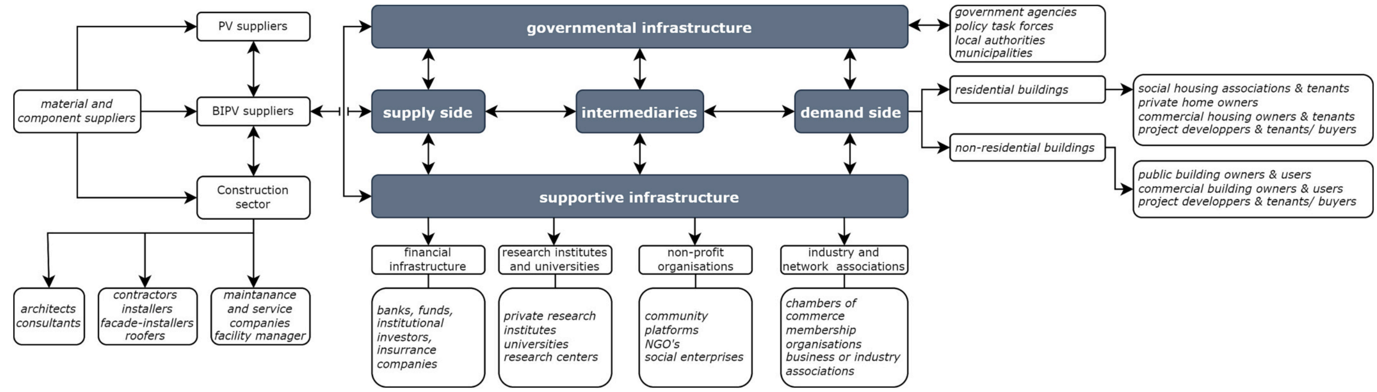

Fig. 3. Diversity of actors in the BIPV system. The main TIS framework (grey) is based on [46–49]; the examples of the actors are derived from [10,12–14,50–54].

Table 1
Reported challenges in the BIPV system assorted per decision stage.

Decision stages [16]	Description	Reported challenges in the BIPV system	BIPV studies	
			EU	NL
I. Knowledge stage	A potential adopter is exposed to the existence of BIPV (awareness) and gains an understanding of how it functions and can be used. Prior conditions are needed to make this happen; for example, a perceived need or problem, social norms, or current related practices	Lack of awareness among potential adopters and the construction sector (contractors, architects, engineers); Many BIPV suppliers spent a lot of time informing potential adopters	[11,13]	[10]
		Many BIPV suppliers focus more on product development and less on marketing and business development		[12]
		Limited coordination between the BIPV industry and the construction sector; the BIPV system is largely dominated by research institutes and BIPV start-ups, but the construction sector is lacking	[13]	[10,12]
		Hard to find objective and detailed product information on BIPV for the demand side and construction sector	[53]	[12]
		BIPV is not part of current education programmes/ vocational training	[52,55]	[10,50,54]
II. Persuasion stage	A potential adopter develops a general perception of BIPV for their situation and forms a favourable or unfavourable attitude towards BIPV.	The construction industry is risk-averse and reluctant to change	[13]	[51]
		Lack of confidence among insurance companies due to an (over)estimation of risk perception	[13]	
		Perceived uncertainty about guarantees, as many BIPV suppliers are still start-ups or SMEs		[12,51]
		For small BIPV companies, it is difficult to pre-finance testing for certification and standardisation		[12,51]
		Perceived uncertainty about the durability of the products and maintenance procedures	[11,13]	[10]
		Current procurement culture in the construction sector on the lowest price, rather than on total lifespan costs and benefits and/or multiple value creation of BIPV; Hard to monetise the additional features of BIPV, such as aesthetics and building-related functions.	[13,57]	[12,51]
		(Perceived) high investment costs	[9,11,13,14,53]	[10,12,51]
		Inexperience often leads to an overestimation of costs by the construction sector		[12,51]
		Lack of governmental support for the implementation of BIPV for the demand side	[11]	
		Lack of governmental support for upscaling BIPV production (supply side)		[10]
		Unreliable and complex regulatory frameworks, such as lack of codes, certifications, or guidelines combining PV and building requirements	[11,53]	[12,51]
III. Decision stage	A potential adopter engages in activities that lead to a decision to adopt or reject BIPV.	Lack of BIPV demonstration examples	[55]	
IV. Implementation stage	A potential adopter implements BIPV in their building(s) and puts it to use.	BIPV products have to be more compatible and complementary with traditional building components and suitable for renovations		[10]
V. Confirmation stage	An adopter experiences BIPV and forms a positive or negative attitude towards it, based on their own experiences, and/or seeks reinforcement of the decision already made, and sometimes promotes (or discourages) BIPV to others.	Negative publicity regarding the installation of BIPV products on site, such as failure of fixings, rain effects, incorrect cabling and connections, and poor waterproofing makes the demand side reluctant to implement BIPV	[11]	
		Negative publicity regarding fire safety makes contractors reluctant to implement BIPV		[58]

Table 2
Main intermediary functions and examples of activities, based on the literature review of intermediation studies related to energy and sustainability transitions.

Main function	Examples of intermediation activities	Authors
1. Knowledge development and exchange	Supporting learning processes, exploration and dissemination, reducing information gaps	[21,23,30,33,35,38,42,47,59–62]
	Facilitating experimentation and pilots	[32,38,59,61]
	Consulting demand side about implementation	[24,42,59,63–65]
2. Networking	Building and managing networks of multiple stakeholders	[23,30,32,33,35,40–42,44,59,60,62,66]
	Translating and mediating between actors and interests and developing consensus	[23,30,32,59,61,66]
	Enabling and coordinating cooperation between actors	[31,64,67,68]
	Putting suppliers in contact with end-users	[23,24]
3. Facilitating projects	Facilitating/ supporting the adoption and implementation of innovations	[24,26,28,33,65]
	Facilitating and managing change processes or innovative projects.	[21,23,30,33,40,59,61]
	Resource mobilisation/ funding	[23,26,33,40–44,59,61,64,68]
	Configuration of the innovation	[30,35,41,42,69]
4. Visioning	Articulation of expectations, requirements and creating visions	[21,23,27,32,33,35,42,47,59–62,70–72]
5. Institutional change	Political advocacy & lobbying	[23,28,30,32,33,38,42,59,64]
	Policy implementation	[23,32,38,42,67]
	Legitimising institutional change	[23,32,38,68]
	Developing standards	[23,73]

and normative values and environmental problems' [83, pg 1260]. The landscape level generally develops autonomously but directly influences the regime and niche level [49,83]. The regime level refers to widely-used technologies, practices and institutions [61,83], whose presence influences the micro-level of niches for '*the generation and development of radical innovations*' [83, pg 1261]. Niches are the protective space for radical and path-breaking technical alternatives that are currently too weak to compete with the current socio-technical regime [62]. The defined intermediation typologies, based on the MLP in Table 4, are not mutually exclusive as many intermediaries can be profiled as more than one type [21]. As the micro-level of user intermediation can shape and influence transitions on the system level [34] and vice versa, we will not focus on specific intermediaries which act on a certain system level but investigate the ecology of intermediaries within the BIPV system.

Overall, this paper investigates how intermediation can improve the multiple decision-making stages of the BIPV adoption process in the Netherlands. We examine what the challenges are in the adoption process in the Dutch BIPV ecosystem, who acts or can act as an intermediary, at what system level, and between which actors; and what intermediation is needed at what stage of the decision process.

4. Research methods

4.1. Case study selection

Implementing low-carbon technologies is necessary for the built environment to live up to the EU's 2030 Climate Target Plan. This plan means cutting greenhouse gas emissions by at least 55 % by 2030 and becoming climate neutral by 2050 [84]. These targets need to be met by the Netherlands as well. However, the Netherlands have a high population density of 513 people per square kilometre, compared to the EU's average of 109 [85]. Since there is limited space for large-scale wind and solar parks, integrating low-carbon technologies in the Dutch built environment is essential to making the transition to a low-carbon society [86]. Due to its improved aesthetics, BIPV can enhance social acceptance by integrating better with the built environment [5]. Despite this, BIPV is still considered a niche market that only accounts for 2 % of the Dutch PV market [10]. Vroon, Teunissen, Drent, Negro and van Sark [10] studied the historical development of the Dutch BIPV system. They reveal that since the dawn of the BIPV system in 1995, it has increased, developed and accelerated till 2015 due to diverse research projects, governmental initiatives and pilot projects. Nevertheless, from 2016 to 2019, the Dutch BIPV system stagnated which hinders the uptake of the technology and also the integration of PV in the built environment. Therefore, the Dutch BIPV market represents a highly relevant case for the analysis of low-carbon innovations for the transition to a low-carbon built environment within Europe.

4.2. Data collection

The study was conducted using a qualitative case study method to investigate the Dutch BIPV decision process. There have been prior studies on the Dutch BIPV system but they did not include intermediaries into their studies specifically. We address this research gap by investigating what kind of intermediaries and intermediary activities exist in the Dutch BIPV decision process (RQ1), what kind of intermediation gaps and challenges slow down the diffusion of BIPV (RQ2), and how intermediation can improve the multiple stages of the BIPV decision process in the Netherlands (RQ3). As part of the data collection process, we first reviewed relevant academic literature about intermediaries and the BIPV system; and second, we conducted semi-structured interviews with actors from the Dutch BIPV system. Sample selection was based on the literature review and actor analysis of the BIPV system (presented in Fig. 3). Fig. 4 reveals an overview of the interviewed respondents per actor-group in the TIS of BIPV, and Table 5 demonstrates the key characteristics of the respondents.

The first round of interviewees was selected based on their participation in a research project ($n = 9$, see Table 5). This project runs from XXX-XXX and aims at XXX (add info after review process). One of the key actors was the Dutch Association for BIPV (BIPVNL). This association was founded in 2018 with the main goal of increasing the market and product awareness of BIPV in the Netherlands. The Dutch Association for BIPV has members from the supply side and research institutes, which pay a participation fee. As part of the second round of interviews, actors outside the project were interviewed ($n = 17$), including actors from the construction sector, the demand side, and a national government organization, which were not well represented in the project. This study did not focus on individual end-users as this group is very diverse and their decisions are influenced by a wide range of factors that differ from person to person [17,18,87–90]. Moreover, the demand side was addressed by focusing on actors who can support the transition from early adopters, who are typically private homeowners, to mainstream adopters (early majority). We included, therefore, social housing associations and project developers as they make decisions for a large group of end-users, which can help to accelerate BIPV diffusion.

The interviews were conducted from October 2021 to April 2022. The semi-structured interview guide (see supplementary material) was organised around the main functions presented earlier in Table 2. The interview method was used to gain a better understanding of intermediation in the BIPV decision process and the interaction between actors, but it also allowed the researcher to be responsive to unexpected relevant issues raised in the interviews [91]. It gave the respondents the opportunity to satisfactorily describe their experiences and their views on the topic. The interviews were conducted in person by the first author, and the interview data were analysed every 5 to 10 interviews

Table 3
Actors that take on intermediary roles.

Private	Public	Private/ public / public-private partnership	Non-profit
Business or industry associations [24,47,64,71]	Government agencies [23,24]	Research institutes/ centres/ organisations [24,47,64]	Environmental NGOs [24,30,66]
Membership organisations [23,33]	Local authorities [23,33]	Network organisations [23,33]	Social enterprises [23,33]
Business development organisations [64]	Cities and city-level organisations [30,64,71,75,76]	Incubators and acceleration centres [24,68]	Charity organisations [23,24,33]
Architects [23,30,33,64,71]	Policy task forces [66]	Innovation centres/platforms [23,33,47]	Voluntary groups [24]
Building managers [23,31,33]	Energy agencies [23,30,33,66]	Science parks [27,30,33]	Local actors supporting technology use [27,30]
Project development companies [64,66]	Innovation funding agencies [30,33,64,66]	Universities [23,24,27]	Community energy actors [30,70,77]
Consultant companies [23,24,27,30,33,60,64,66]		University technology transfer offices/agencies/ liaison offices [23,27,30,33,47,64,66,71]	Religious congregations [23,78]
Chambers of commerce [47]		Knowledge-intensive business services [47]	Internet discussion forums and platforms [23,29,30,64,66,71,79,80]

Table 4
Intermediary types derived from Kivimaa, Boon, Hyysalo and Klerkx [21].

Intermediary types	Definition
Systematic intermediary	Intermediation at system level between multiple actors & interests and across niches and sometimes regimes. Operates on niche, regime, and landscape level. Aims for change of the whole system, promotes an explicit transition agenda.
Regime-based transition intermediary	Intermediation on system level between multiple actors, within mandate given by dominant regime actors. Interacts with a range of niches or the whole system. Has a specific goal to promote transition.
Niche intermediary	Intermediation between local projects, individual companies or across them. Can also intermediate with higher levels of aggregation. Is an insider to a specific niche. Tries to influence the prevailing regime.
Process intermediary	Intermediation within experimental projects or specific processes contributing to transitions. Intermediate day-to-day action in transition projects or processes. Facilitates a change process or a niche project.
User intermediary	Intermediation at project level between technologies and end-users of the technology. Support demand side in innovation adoption process. Can be tied to a particular niche or cover multiple niches.

and discussed in the research team (all authors). The interviews were digitally recorded, stored (with permission of the respondents), and transcribed. Additional data were collected in 16 project meetings (see supplementary materials for an overview), and intermediate results were also discussed within the project group. These meetings were recorded in meeting notes.

4.3. Data analysis

The literature, interview transcripts, and meeting notes were systematically analysed with qualitative software (Atlas.ti 9) and by using the thick analysis method. This method allows a more comprehensive analysis by combining several analysis methods [92]. Thematic coding was used, based on the theoretical framework (intermediary actors, functions and activities, types, challenges, decision-making stages) and open coding, to adopt an inductive approach to identify other methods of data organization that could lead to different results [93]. Analysis reports were used to determine which intermediation activity occurred in what decision-making stage, by which stakeholder intermediary, between which stakeholders, and on what system level. The findings were used to explore how intermediation can improve the multiple stages of the BIPV decision process in the Netherlands.

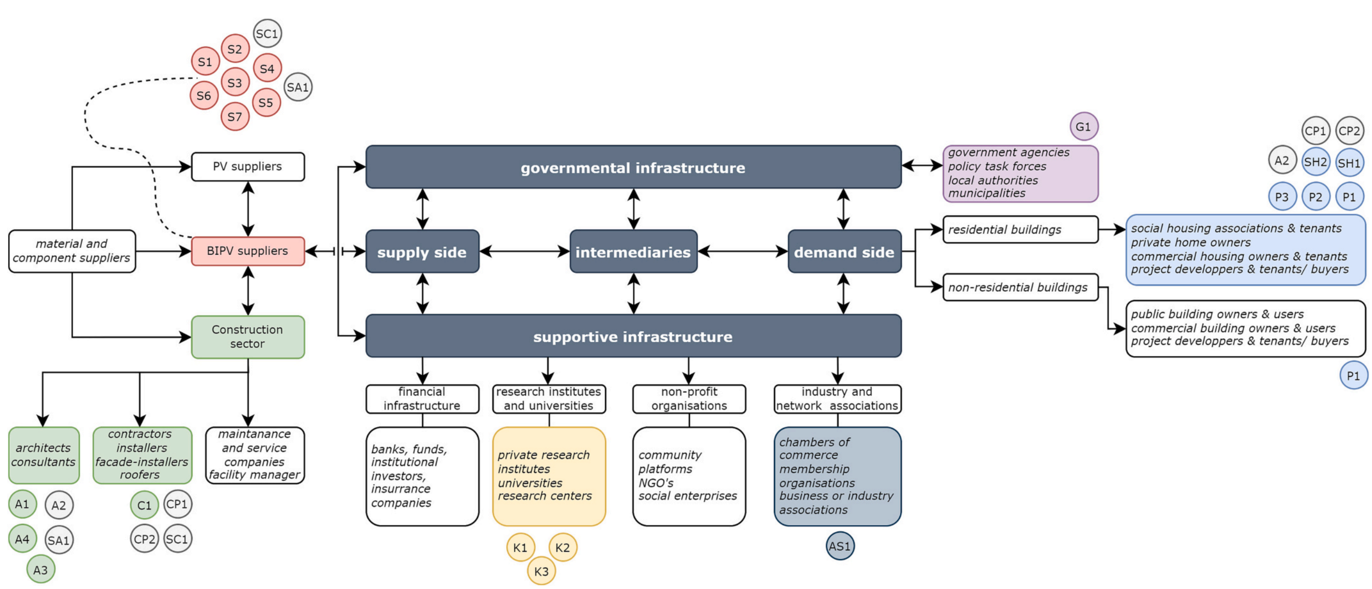

Fig. 4. Sample selection based on the actor analysis presented in Section 2. The respondents are presented as circles; the abbreviations are explained in Table 5 (some respondents belong to multiple actor groups, these are coloured white).

Table 5
Overview of interviewees.

Actor group*	Code	Description stakeholder	Project partner	Position respondent
Association (As)	AS1	BIPVNL	X	Chairman
Construction sector (C)	A1	Architectural firm	X	Architect-owner
	A2	Architectural firm & private homeowner with BIPV roof tiles		Architect-owner
	A3	Architectural firm		Building engineer
	A4	Architectural firm		Architect
	C1	Façade contractor		Lead concept designer & civil engineer
	CP1	Building contractor & project developer		Director region South
	CP2	Building contractor & project developer		Project leader
Demand side (D)	P1	Real estate developer		Owner/project developer
	P2	Real estate developer		Director/ CEO
	P3	Real estate developer		Project developer
	SH1	Social housing association		Project developer
	SH2	Social housing association		Project developer
Government (G)	G1	Governmental agency		Senior advisor energy transition
Knowledge institutions (K)	K1	University	X	Professor/researcher
	K2	Private research institution		Researcher/project coordinator
	K3	Private research institution		Business developer
BIPV suppliers (S)	S1	Supplier BIPV façade elements (mainly residential multi-storey housing)	X	Owner/director
	S2_a	Supplier PV-power foil (mainly commercial/ industry buildings)	X	Research and development manager
	S2_b	Supplier PV-power foil (mainly commercial/ industry buildings)	X	Chief technology officer
	S3	Supplier integrated thermal solar roof	X	Owner/managing director
	S4	Supplier BIPV roof tiles (mainly single family homes)	X	Owner/director
	S5	Supplier (coloured) BIPV facades (mainly residential & non-residential multi-storey buildings)		Owner/director
	S6	Supplier PV roof tiles & BIPV roofs (mainly residential terraced dwellings)		Owner/director
	S7	Supplier BIPV facades (mainly commercial buildings)		Owner/director
	SA1	Supplier (coloured) BIPV facades (mainly residential & non-residential multi-storey buildings) & architectural firm	X	Business developer
	SC1	Supplier BIPV facades (mainly non-residential buildings), infra integrated PV & building contractor		Owner/ CEO

5. Intermediation in the BIPV decision process: empirical findings

5.1. Knowledge stage

In the knowledge stage of the decision process, it is important that potential adopters become aware of BIPV and gain more knowledge about the technology and its possibilities. The findings indicated that intermediation is needed in this stage between different stakeholders of the BIPV system, which is discussed in more detail in the sections below.

5.1.1. Intermediation between supply and demand side: BIPV suppliers - demand side

The interviews revealed that there is an intermediation gap between the BIPV suppliers and the demand side. It was reported that potential adopters are unaware of the possibilities of BIPV, which makes them reluctant to choose this technology. As a result, the interviewed suppliers declared that they have to spend a lot of time informing potential adopters individually in order to raise awareness and share information about their products (see also Table A1 in the Supplementary materials). The Dutch Association for BIPV stated that their objective was to raise awareness of BIPV by publishing in mass media, attending consumer fairs and the like, but that at this time their resources were limited to fulfil this role satisfactorily:

> 'We do not play a very active role in informing potential adopters. There is information on the website and in the handbook, but they have to contact the individual supplier if they want more information. We do not have the means to do more' (AS1).

Furthermore, the interviewed stakeholders from the demand side reported that in the current situation it is hard to find detailed and objective information about BIPV. Project developer P3 explained as follows:

> 'There is a lack of objective, non-commercial information about BIPV but also other innovations. Maybe the government could play a role in this' (P3).

The interviews reveal that government(s) or another impartial organization could play an intermediary role between suppliers and the demand side. Overall, no main platform exists for raising awareness among potential adopters, and systematic intermediation between supply and demand side has to be improved in order to increase BIPV adoption. The required intermediation activities include raising awareness, knowledge exchange about BIPV products (systemic and accessible for a large audience), and networking with potential adopters such as private homeowner associations, social housing (associations), and project developers.

5.1.2. Intermediation within the supply side: BIPV suppliers - construction sector

Another identified challenge is that most BIPV start-ups originate from the PV sector and are less familiar with the construction sector (see also Table A1 in the Supplementary materials). As BIPV are integrated products, collaboration is needed between these two sectors. An important stakeholder in the construction sector is the construction supply sector, which supplies building components such as roofs, facades, and windows. The interviews revealed that there is an intermediation gap between the BIPV suppliers and the construction supply sector. It became clear from the results that the construction supply sector can play an important intermediation role between demand and supply, as BIPV can be integrated into their (traditional) building components. However, the findings indicated that certain BIPV products are less compatible with traditional building components (e.g., in size and construction) and therefore more difficult to incorporate in the current building process. In addition, the construction sector in general was regarded as risk averse by the interviewees and reluctant to change, which leaves little room for innovations such as BIPV. Project developer

P1 and knowledge institution K2 stated that the BIPV-products have to be more compatible with traditional building components, so that they can be more easily integrated in the traditional way of building:

> 'You cannot change the construction sector, so BIPV products have to be adapted to traditional building products, such as prefab cladding or insulation systems for large facades' (P1).

> 'It is hard to change existing regimes such as the construction sector, so it is better to look how to work together. Being too disruptive will slow down market introduction' (K2).

It was discussed in the interviews that when BIPV suppliers become sub-suppliers to construction suppliers, they can benefit from their large marketing and sales resources which is helpful for increasing market volume. Moreover, it was suggested that BIPV suppliers could reduce their current individual business-to-client activities which will be done by the marketing and sales department of the construction supplier. Some interviewed suppliers declared that they already have started to organise their business this way (S4, S6, SC1) and that they work together with large construction suppliers who have incorporated the BIPV product in their product range:

> 'To make a better connection between BIPV and the construction sector, we have a partnership with a façade builder, a glass producer, a metal worker, and a supplier of aluminium products' (SC1).

However, these collaborations are still quite recent, and other BIPV suppliers do not engage in such collaborations. Overall, there is too little connection between the BIPV and construction sectors; in addition, there is a need for intermediation between these two sectors concerning the exchange and development of knowledge, as well as networking, to improve the BIPV decision process.

5.1.3. Intermediation within the supply side: BIPV suppliers - architects & engineers

In the interviews it was revealed that architects and engineers could play an important role as intermediaries between the BIPV supply side and the demand side. Martiskainen and Kivimaa [94] indeed contend that an architect can be a crucial intermediary with the demand side and facilitate the progress of zero-carbon building. In the knowledge stage (as well as the persuasion stage), architects and engineers can create awareness about BIPV among potential adopters by furnishing them with information about the possibilities of BIPV. Furthermore, architects were also mentioned in the interviews as important intermediaries between the supply side and contractors:

> 'We receive most information about innovative products via architects; they are more aware of these developments than we do as contractors' (PC2).

> 'We follow up with new developments, but specifying the products – that's really up to architects' (C1).

While architects and engineers do have the potential to be intermediaries between BIPV suppliers and the demand side, at present most of them do not have sufficient knowledge of BIPV products; nor are they facilitated to act as intermediaries:

> 'There is someone missing in the design and building process who makes sure that BIPV is integrated in the design but also implemented at the end. This needs negotiation with all the stakeholders in the process, such as the client, contractor, installer and electrician. However, we as architects are not paid to play this role' (A1).

Several interviewees (see Table A2, Supplementary materials) have suggested in the interviews that knowledge about BIPV should be integrated in training and vocational and educational programmes for architects and engineers to raise awareness and knowledge levels. The Dutch Association for BIPV (AS1) reported that they had organised some information sessions for architects, but that these were not well structured as their means are limited. In order to organise this in a more structured manner, intermediation in the form of knowledge exchange and networking is needed between the BIPV suppliers and architects and engineers (associations). The results also suggested the development of uniform 3D-design tools for BIPV applications, which can assist architects and engineers to implement the BIPV products early in the design process and receive the required information about the product:

> 'We work with 3D modelling tools in which building products are integrated. Within the library of the model all kinds of technical specifications of the product are available. We need this also for BIPV so we can quickly integrate it into our designs. At this time, we have to send our drawings to the BIPV supplier to ask for the specifications, but this takes too much time for us and them' (A1).

Lobbying for funding will also be needed to bring about these educational changes and the development of the 3D tools which can help to raise awareness of BIPV among architects and engineers.

5.1.4. Intermediation within the supply side: BIPV suppliers - energy coaches

The findings revealed that local energy coaches (volunteers or financed by local governments) could play an intermediating role in knowledge exchange between the supply and demand sides, a point that has also been made in prior studies [18]. The Dutch Association for BIPV revealed in the interview that they organised this on a small scale in 'woonwijzerwinkels'[1] (home advice shop). This is a Dutch initiative of several local governments and is a physical place where several low carbon technologies are demonstrated and information is provided by energy coaches to potential adopters on making dwellings more energy efficient. Certain BIPV products are displayed at the Rotterdam location, but this could be expanded to other locations in order to raise more awareness and exchange objective knowledge about BIPV. Nevertheless, energy coaches need to have sufficient knowledge about the BIPV products so that they can advise their clients on them, as was the case for architects and engineers in the previous section. Therefore, at present there is an intermediation gap between the BIPV suppliers and energy coaches concerning knowledge exchange, development, and networking.

5.1.5. Intermediation between supply side and government: BIPV suppliers and government

The interview results revealed that there is an intermediation gap between BIPV suppliers and the government. The results identified that under current Dutch energy regulations, it is not necessary or obligatory to implement full solar roofs and facades, and therefore traditional PV panels are most frequently installed rather than BIPV. Project developer P3 revealed the following:

> 'We will only implement more innovations when the energy regulations are amended, or if there is a large demand from buyers, for instance because of high energy prices' (P3).

In their studies on intermediation, Kanda, Kuisma, Kivimaa and Hjelm [71] and Hargreaves, Hielscher, Seyfang and Smith [70] point out that lobbying for institutional change of national policy is an important intermediation activity. In our interviews, BIPVNL reported that they do try to lobby but that they have very little capacity to do so (see also Table A1 in the Supplementary materials). Moreover, there is no clear national vision on how to integrate photovoltaics into the built environment on a large scale. As a result, systematic intermediation is needed between BIPV suppliers and the government concerning visioning and institutional change.

[1] *For more information:* https://www.woonwijzerwinkel.nl/

5.2. Persuasion stage

In the persuasion stage, potential adopters develop a general perception of BIPV for their situation and form a favourable or unfavourable attitude towards BIPV, based on the knowledge they accumulated in the knowledge stage. They will consider the advantages and disadvantages for their specific situation.

5.2.1. Intermediation between supply and demand side: BIPV suppliers - demand side

The results demonstrated that in this stage there is an intermediation gap between the supply and demand side regarding knowledge exchange, networking, and facilitating. As discussed in Section 5.1, architects, engineers, and energy coaches are potential intermediaries between the BIPV suppliers and the demand side, and this also applies to the persuasion stage.

5.2.2. Intermediation within supply side: BIPV suppliers - construction sector

In general, the construction sector was regarded by the interviewees as risk averse and reluctant to change, which leaves little room for innovations such as BIPV (see also Table A1 in the Supplementary materials). In addition, prior studies report that the diffusion of innovations in the construction sector is difficult due to a multitude of factors which make the current regime very stable and conservative [e.g. 33,57]. Social housing association SH1 had the following to say on this:

> 'Within our organization it was sometimes difficult to implement BIPV; it disrupts our smooth-running building process, and that is never appreciated so much, and it also creates a bit of uncertainty' (SH1)

The findings demonstrated that this attitude of the construction sector is often caused by a feeling of insecurity about the durability of the innovative BIPV products, because the products have not been on the market that long. Product guarantees could help to reduce these risks. However, the findings from the interviews also revealed that there is often a lack of confidence in the guarantees of the BIPV products as many BIPV suppliers are start-ups or small companies, and it is uncertain whether these companies will still exist in a few years' time. This is illustrated by the following input from supplier S1:

> 'Insurance companies want to have a business risk profile which is based on historic data. This is difficult for a start-up if the product was developed two years ago.'

In addition to guarantees, the development of certifications and standards could also offer more security. Nevertheless, the findings pointed out that the certification procedures for BIPV are not very clear as they combine separate codes for PV and the building envelope – a point that has also been reported in other BIPV studies [e.g. 11,53]. Supplier S4 stated the following on this subject:

> 'Certification for BIPV products is very complex and many start-ups do not know how to deal with this' (S4).

In addition, BIPV start-ups often have limited financial resources to finance testing for certification, which hinders the upscaling of their products. Some of the suppliers interviewed mentioned that they serve on these kind of committees, but that they are not organised in a very structured manner and are not financed. Sovacool, Turnheim, Martiskainen, Brown and Kivimaa [23] identified the development of standards in order to realise an institutional change as an important intermediation activity. In the case of BIPV, this has not been designated to any particular organization or actor. An intermediary should negotiate with national government(s) to improve certification for BIPV products and lobby for funding for certification.

Another challenge identified in the interviews is the procurement culture in the construction sector which insists on lowest price, rather than on total lifespan costs and (non-financial) benefits such as improved aesthetics and building-related functions. This is illustrated by the following statement by project developer PC1:

> 'There are very nice BIPV products but they cost 50% more, and you have to take their measurements into account in your design. You will save on roof tiles, but there are extra costs for labour. If upscaling and industrialisation of the BIPV production process will result in a reduction in the price difference between BIPV and traditional PV from 50% to 30% or 20%, it will make it much more interesting for large construction companies to install BIPV' (PC1).

As a result, A2 explained that at present BIPV are adopted primarily by people who can afford them and want aesthetically integrated solar, which means that it remains a niche market at this time. A lack of experience with BIPV often leads to overestimated costs by contractors and installers:

> 'Installers have too little experience, and therefore too little knowledge about BIPV costs, labour time, and how to install, and therefore they do not offer the product or ask too high a price' (A2).

This makes it challenging for BIPV to enter the market. Intermediation could help to improve the knowledge exchange about how to communicate BIPV costs and benefits with potential adopters and should be shared with potential user-intermediaries such as architects, engineers, and energy coaches.

5.3. Decision stage

Based on their experiences in the first two decision stages, potential adopters will decide to adopt or reject BIPV. Innovations, such as BIPV, carry some degree of uncertainty, and potential adopters will often seek social reinforcement or the opinion of peers in this stage to reduce this uncertainty [16]. Rogers [16] points out that the perceived uncertainty about an innovation can be reduced if the innovation can be tried out on a partial base. The trial by a peer can be a substitute in the case when this is not possible, such as with BIPV. However, as BIPV have not yet been widely diffused, it is hard for potential adopters to find peers who have adopted BIPV. Several interviewees in this study proposed that pilot projects should be facilitated (see Table A2 in the Supplementary materials) in order for the demand side to gain more awareness and knowledge on BIPV, and reduce uncertainties. Previous research has indicated that pilot projects can be an alternative way to build up trust in the innovation and share knowledge about the experiences with the demand side and other stakeholders [61]. Lobbying for additional (governmental) funding is needed to finance the additional costs of the pilot projects, as well as to share the knowledge in several stakeholder networks.

5.4. Implementation stage

When the adopter choses in favour for the innovation in the prior stage, they will engage in activities to purchase BIPV and will start organising the implementation stage. Glaa and Mignon [20] point out that an incorrect implementation can lead to a suboptimal use of the innovation, which can lead to dissatisfaction on the part of the adopter in the confirmation stage. However, the results indicated that there is a lack of qualified and experienced BIPV installers (see also Table A1 in the Supplementary materials). Some interviewed suppliers (S1, S2, and S4) mentioned that they had to invest a lot of time in instructing installers at the building site, which will no longer be feasible when demand increases. This hampers the uptake of BIPV, and therefore more qualified installers are needed. To facilitate this knowledge exchange, training for installers, electricians, and roofers should be offered more systematically. An intermediary could organise and facilitate this kind of training, but lobbying for additional government funding will also be needed; moreover, educational institutions will have to be lobbied to implement this knowledge in their training programmes.

As discussed earlier in Section 4.1, another solution to improve the implementation stage is that BIPV products can be made more compatible with traditional building components, so that they can be more easily incorporated in the building. Integrating BIPV in large prefab building elements (roofs and facades) can also contribute to a better and faster implementation. A strong collaboration between the BIPV suppliers and the construction supply sector is needed for this. However, as discussed earlier in Section 5.1, there is an intermediation gap between BIPV suppliers and the construction supply sector when it comes to facilitating this change.

5.5. Confirmation stage

In the confirmation stage, adopters experience BIPV and form a positive or negative attitude towards the innovation, based on their own experiences, and/or seek reinforcement of the decision already made [16]. One issue that emerged from the interview results was that negative publicity about BIPV in the past has restrained potential adopters and the construction sector from implementing BIPV (see also Table A1 in the Supplementary materials). The results indicated that there have been certain issues regarding fire safety – issues that continue to influence adoption decisions. Two architects explained this question as follows:

> 'There have been a number of fires with integrated panels in the past, and that has had a very negative impact on the market. In hindsight, this was caused by an unprofessional performance, but still influences perception at this time' (A3).

> 'Many contractors use this argument to convince clients not to install BIPV' (A4).

A study by Bende and Dekker [58] has demonstrated that these problems were caused by poor installations. Therefore, a proper installation of BIPV in the implementation stage is crucial as it directly influences the confirmation stage, as well as the perception of BIPV by the new potential adopters. However, further knowledge exchange is needed on the exact circumstances of these incidents and how to prevent them. In addition, training installers on how to implement BIPV correctly is crucial in this regard.

Another way to counter negative experiences is to exchange knowledge about positive experiences with BIPV, as potential adopters look to early adopters for advice, information, and best practice examples [16]. Since BIPV is not widely diffused yet, it is difficult for potential adopters to find peers. This can be improved by publishing information about previous projects to raise awareness (see also 4.1), as well as by pilot projects (see 4.2). In addition, the literature points out that exchanging knowledge on innovations in social networks can have a positive effect on the adoption rate [e.g. 18,95]. Supplier S4 explained how they organise this:

> 'We have an aftersales talk with our clients and leave brochures behind. They act as our ambassadors and this leads to new customers' (S4).

This exchange of positive experiences is currently done on a very limited scale. To address this problem, an intermediary organization could enhance and facilitate this knowledge exchange on previous projects between adopters and potential adopters in a more structured way.

6. Discussion and conclusions

The objective of this study was to contribute to an improved understanding of how intermediation affects the multiple stages of the BIPV decision process in the Netherlands. It contributes to the existing literature by empirically ascertaining: 1) what kind of intermediaries and intermediary activities exist in the Dutch BIPV decision process, 2) what kind of intermediation gaps and challenges slow down the diffusion of BIPV, and 3) how intermediation can improve the multiple stages of the BIPV decision process. The remainder of this section discusses a number of findings arising from our specific focus on the demand for intermediary activities and actors within the BIPV decision process, as well as key practical and policy implications and recommendations.

6.1. Diversity in intermediation actors and functions

Our analysis identified a number of actors who can act as intermediaries in the BIPV decision process. First, private actors, such as architects, engineers, and companies in the construction supply chain. Second, public actors, such as local energy coaches. Third, public-private actors such as the BIPV Association, and fourth, non-profit actors, such as BIPV adopters who can act as intermediaries for their peers. These (potential) intermediation actors were also identified in prior studies (see Table 3). Our results indicated also that not only designated intermediaries (as studied by Glaa and Mignon [20]) can perform intermediation activities, but that un-designated intermediaries play a key role in the BIPV decision process. It is therefore imperative to apply a holistic approach when studying intermediation.

The findings of our study demonstrated that a variety of intermediation functions and activities are required to enhance the BIPV decision process in the Netherlands. All five intermediation functions were found to be essential. However, the emphasis is most on knowledge exchange and networking at all stages of the decision process, because this is an emerging technology and more awareness is essential among potential adopters and other actors within the system. The function of facilitating is mostly needed in the persuasion and implementation stage, as adopters need assistance with configuring the BIPV technology to their specific contexts, and with integrating BIPV into their building. It was found that the functions of visioning and institutional change are more crucial between the BIPV suppliers and the government, but also between suppliers and the construction supply sector. This higher system level intermediation is needed to perpetuate and accelerate the diffusion of BIPV.

6.2. Maturation of the BIPV decision process needs a dynamic ecology of intermediaries on different system levels

The study findings highlighted that 'an ecology of intermediaries' [25,41,81] is crucial to perform diverse intermediation activities in the various stages of the BIPV decision process between different actors, but also at different system levels. Based on our analysis, we compiled an overview of the intermediation needs, functions and actors in the BIPV decision process assorted per decision stage. This is presented in Fig. 5. At the top, the stages of the decision process are presented, and below the intermediation needs. Intermediation needs are divided into user and process intermediation needs that directly affect the BIPV decision process, and into niche and regime-based intermediation that indirectly affect the decision process. This higher system level intermediation is needed to improve user and process interaction, to facilitate and educate potential user and process intermediaries such as architects, engineers and energy coaches, but also BIPV adopters (peers). This is discussed in more detail in the following sections.

The construction supply sector can also play a pivotal role as an intermediator between BIPV suppliers on the one hand, and the potential adopters and process intermediaries (architects, engineers, and energy coaches) on the other. Further, construction supply companies can also act as intermediaries between BIPV suppliers and contractors and installers to improve the implementation process. As illustrated in Fig. 5, regime-based intermediation by the construction supply sector can enhance the BIPV decision process in the stages preceding the decision, as well as post-decision. However, Stewart and Hyysalo [41] report that in uncertain and immature markets, such as BIPV, intermediaries play an influential role. However, this position can sometimes be fragile and

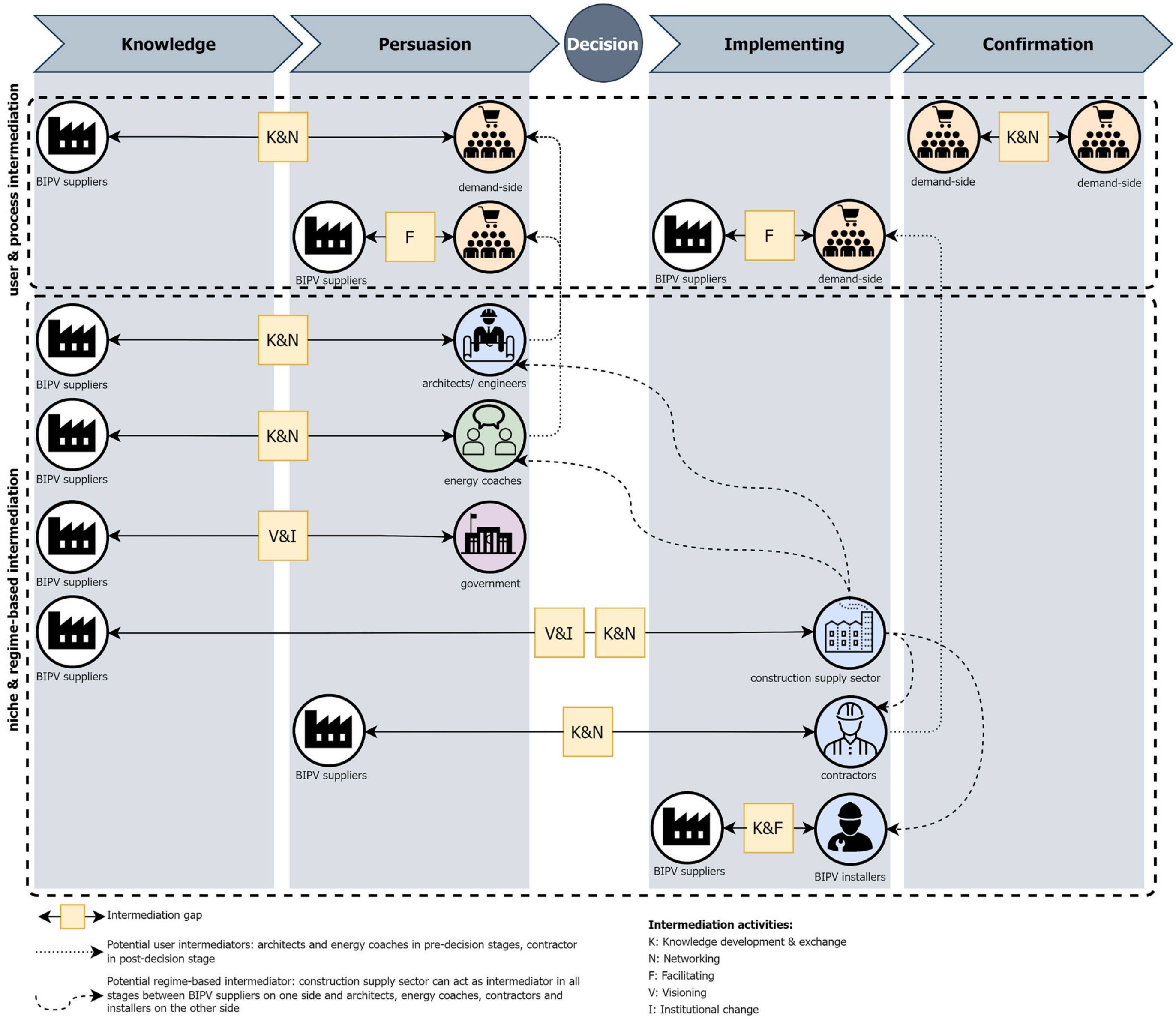

Fig. 5. Structural intermediation needs, functions and actors in the different stages of the BIPV decision process in the Netherlands.

difficult to predict and requires nurturing and protection. It is therefore necessary to implement policies to facilitate these potential intermediaries (peers, architects, engineers, energy coaches, the construction supply sector), as well as to educate them about BIPV technologies.

The representation of the intermediation needs in Fig. 5 could be seen as a rather static portrayal of ecologies of intermediaries as it demonstrates the intermediation needs at this time. Hyysalo, Heiskanen, Lukkarinen, Matschoss, Jalas, Kivimaa, Juntunen, Moilanen, Murto and Primmer [25] point out that intermediaries are part of complex ecologies of intermediation in changing ecological and societal fields. As the BIPV system evolves and technology advances, some challenges will be bridged by intermediaries but could also be overcome by other developments in the system such as expanded supplier offerings, better adjustment to the demand side, and better integration with more standard traditional building products. Consequently, as the BIPV market evolves, also the need for intermediation will change: new intermediary actions, other actors acting as intermediaries, different intermediary support, and intermediation between other actors within the BIPV system.

6.3. *Insufficient facilitation of intermediaries*

This study reported that architects, engineers, and energy coaches are potential user and process intermediaries in the current regime. They can greatly support both projects and the demand side in the decision process, and can therefore play an effective intermediation role by informing and facilitating potential adopters about BIPV in the knowledge and persuasion stage of the decision process. Fischer and Guy [96] also argued that architects can play a crucial role as intermediaries but that this role has not been actualised thus far. This is also the case in the context of BIPV adoption in the Netherlands. Most of these identified potential intermediaries are not facilitated as such, nor do they always have sufficient knowledge of BIPV products. This can make them reluctant to provide potential adopters with positive advice about BIPV. Therefore, intermediation has got to be facilitated within educational institutions for developing training programmes on BIPV for architects, engineers, and energy coaches. This is so that they can more effectively fulfil their role as a user and process intermediary in the knowledge and persuasion stage of the BIPV decision process. To facilitate the required resources and knowledge development, intermediation is needed at a regime-based policy system level.

The BIPV industry association was also identified as a key intermediary between different actors. However, our results showed that they have limited resources to structurally reach out to potential user and process intermediaries (architects, engineers, energy coaches), the demand side, the construction supply side and contractors and installers. Furthermore, they also have a lack of means to structurally lobby the national government for more specific and stricter energy legislation, clear certifications for BIPV, and funding for educational programmes and industrialisation of BIPV. This struggle for resources for intermediation has also been reported in other studies (e.g. Kivimaa, Primmer and Lukkarinen [32]). In order to address this issue, BIPVNL announced in August 2022 (after the interviews) that they will become part of Holland Solar. Holland Solar is an industry association for Dutch solar companies with 246 members. In this way, they hope to improve their operational effectiveness.

6.4. Peers as demand-side intermediaries

Our analysis revealed that BIPV adopters are key potential demand-side intermediaries. They can exchange knowledge, and network with potential adopters on their experiences with the technology. Previous studies reveal that this can be achieved through social networks [18,95], internet-based energy communities [29], and pilot projects [61]. According to Wilson and Dowlatabadi [95], homeowners who have adopted certain energy measures can influence peers in their social network. Likewise, Hyysalo, Juntunen and Martiskainen [29] point out that adopters of energy measures can act as transition intermediaries by helping other citizens '*who demand more exposure, clearer information and less uncertainty about new technology options*' [29, pg 872]. In their study on community energy in the UK, Seyfang, Hielscher, Hargreaves, Martiskainen and Smith [40] found a different source of learning: knowledge sharing between local energy projects and how this can contribute to niche development: '*projects tend to learn from each other rather than from dedicated networking organisations*' [40, pg 42]. However, as BIPV is not widely diffused yet, it is more difficult for potential adopters to find peers. In addition, we found that this interaction between 'experienced' BIPV adopters and potential adopters has not yet been facilitated or organised in the case of BIPV in the Netherlands. This is a challenge because well-resourced intermediaries are likely to achieve more [32]. Therefore, intermediation is needed at the niche or regime-based level to facilitate this demand-side intermediation.

To act as intermediaries, BIPV adopters have to be satisfied with their installed BIPV. A good installation by contractors and installers is therefore essential. Educational training for contractors and installers can improve the implementation and confirmation stage of the decision process, as the BIPV will be properly installed and adopters will be more satisfied, which will assist in the diffusion of the innovation. Intermediation at a regime-based policy level is needed to facilitate this.

6.5. Demand-side configuration

According to our findings, BIPV needs to be better adapted to be widely used in standard building products as well as customizable to different contexts of the demand side. Rogers' diffusion theory points out that re-invention (changing and modifying) of a technology by the demand side can lead to a faster rate of adoption [16]. Moreover, a study by Hyysalo, Juntunen and Freeman [69] demonstrates that sustainable home energy technologies, which have some level of modularity and adaptability, can speed up diffusion, as these technologies can be more easily modified to particular circumstances such as variation in demand-side buildings and needs. This demand-side-led configuration was also reported by Stewart and Hyysalo [41] as one of the distinct actions of intermediaries, next to facilitating and brokering. Especially in the energy retrofit market, this adaptability to the context of the demand side is particularly necessary [36,69], because their current situation is relatively fixed, in contrast to newly built homes in which BIPV can be taken into account in the design. Some of the current BIPV products have these properties already, but many still need adjustment to meet the needs of the demand side. User intermediation between suppliers and the demand side could help to accumulate their wishes and needs regarding BIPV, which can be used to adapt and improve the technology in order to accelerate diffusion.

The demand-side configuration of BIPV products could be improved by better adapting them to widely-used building products in the construction supply sector (standardisation). This will allow the construction supply industry to play an intermediary role between the supply and demand side, as discussed in 6.1. The construction supply sector already performs this intermediary role for other building products, and BIPV suppliers could make use of these existing networks. However, the data demonstrated that collaboration between BIPV suppliers and the construction supply sector is still limited to only a few suppliers at present, and intermediation between BIPV suppliers and the construction supply sector is essential to enhance diffusion. The Dutch Association for BIPV could play an intermediating role as an industry association, but has meagre resources to organise and facilitate this.

6.6. Concluding remarks

In conclusion, this study reveals that the BIPV decision process requires different kinds of intermediation. Rather than focusing on specific types of intermediaries, we explored what intermediation activities can support the decision process. The findings demonstrate that a dynamic 'ecology of intermediaries' is needed to perform various intermediation functions and activities at different system levels, to enhance the multi-stage decision process. As these activities and actors are highly interrelated and interdependent, it is imperative to consider all these aspects and interrelations and not to address intermediation in a one-dimensional way by focusing on certain types of intermediaries or isolated activities. This paper contributes to innovation adoption and intermediation studies as it combines these two lenses, and provides insight into what type of intermediation is essential at each and every stage of the decision process, at what system-level, and who should act as an intermediary in the case of BIPV adoption in the Netherlands and beyond.

6.7. Limitations and further research

While this paper contributes to a better understanding of how intermediation can improve the (BIPV) decision process, the study also has a number of limitations. The main limitation is that we were unable to determine whether intermediation is sufficient for dealing with the identified barriers. We were only able to determine the necessity for intermediation, based on identified barriers for which intermediation is useful and relevant. This relates to the fact that intermediation needs can change over time when the system and technology evolves. Another limitation is that this study focused on one specific type of innovation in one specific country, and with a limited number of respondents. We therefore suggest that further studies should be undertaken relating to intermediation in the decision process for other technologies and other countries. It is likely that in other contexts the required intermediation actors, activities, and functions could differ at the various decision-making stages. Lastly, some actors were not included in this study, such as (potential) individual BIPV users, energy coaches, financial, non-profit and regional governmental organisations, and their inclusion could yield additional information about the decision process.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2023.103149.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

The authors would like to thank the respondents for sharing their insights and experiences in the interviews. This research was funded by the Dutch Organization for Scientific Research (NWO, 023.013.033) and the Rijksdienst voor Ondernemend Nederland (RVO, project MOOI BIPV (T), MOOI32020).

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