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A comparative review of building integrated photovoltaics ecosystems in selected European countries

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ABSTRACT

Building integrated photovoltaics (BIPV) is one of the most promising contributors to net-zero energy buildings, while also increasing the aesthetic value of the built environment. Nevertheless, it currently is predominantly operating in a niche market of ~ 1% of the global photovoltaics market. In this paper we provide a thorough Multi Criteria Decision Analysis of the BIPV ecosystem (markets, stakeholders, and policy and legislation) in various European countries, i.e. the Netherlands, France, Germany, Switzerland, and the United Kingdom. Environmental legislation and building requirements were found to be similar, as all countries have the European Energy Performance of Buildings Directive (EPBD) in common. It was found that implementation of the EPBD differs per country, evidenced by different support schemes in effect. Also, harmonisation of building codes hampers BIPV development. The analysis provides a basis for developing a BIPV ecosystem, which may differ per country. Also, clearly the BIPV sector crosses national boundaries, and should therefore be reviewed and developed from an international perspective.

1. Introduction

The market for Photovoltaics (PV) has been turbulent in the past years, with sharp price reductions in 2012 and increasing interest in the technology and its gains. It now has entered a more mature phase, after a severe shakeout of PV companies. Prices have stabilized, market volumes show a healthy growth and national support schemes are being reduced or redefined. At the same time an interesting market segment is emerging: building integrated photovoltaics (BIPV) [1–4], that integrates PV into the building envelope.

The contribution of photovoltaics to renewable electricity generation is 1.8% globally (status end 2016) [5], and in the 28 member states of the European Union (EU28) PV electricity is responsible for ~ 10% of the total renewable energy production [6]. Also, the EU28 is well under way to reach the 20% renewables target in 2020 [6], and policy is now being developed to reach the 27% renewables target in 2030 [7]. Roof and façade PV potential have been analysed and a near 1 TWp capacity for EU has been determined [8]. Compared to the present PV capacity of 103 GW in EU28 a huge potential exists, especially noting that a considerable amount of PV is installed in large-scale field installations. In fact, another paper [9] reported that PV integrated or added to buildings would be able to cover 24% (France) to 40% (Italy) of electricity demand in various EU member states.

The main definition of BIPV is that it involves (construction) elements in the building envelope that contain at least one additional function besides generating electricity (e.g. insulation or exterior weather barrier). Generating decentralized energy within the built environment aids to provide a redundancy of the current electricity network, defines a state of independence, improves energy efficiency in the building and avoids transportation losses in electricity grids [10]. Its key market driver is the European Energy Performance of Buildings Directive (EPBD) 2010/31/EU [11], which is being renewed in the so-called 'Winter Package' [12]. The present directive states that all new buildings of the 28 EU member states should be nearly zero energy buildings (NZEBs) by 2020. Clearly, one possible solution to realize NZEBs is the generation of renewable electricity on-site, by means of (BI)PV, or even urban wind.

Adding PV on the roofs of buildings, especially when these buildings are taller than 3 storeys, may not be generating sufficient energy to meet the building electricity demand. Façades offer additional potential for PV [8], either applied to the façade surface itself (Building Added/Attached/Applied PV, BAPV), or integrated in the façade (BIPV) in

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particular as the use of large glass façades is a growing trend. Specific BIPV designs and engineering have been reviewed recently, see, e.g., [1–4,13–16], and references therein. BIPV applications offer the possibility to replace regular building envelope components into prefab integrated components that at the same time generate electricity [3] BIPV applications are flexible in size, shape, colour, and appearance and can be combined with materials commonly used in construction, such as glass or metal [2]. This contributes to the aesthetic value of a building, allowing flexibility in architectural design [17]. Performance of BIPV in urban areas depends on orientation and tilt, just like PV panels on roofs, but more importantly on the surrounding buildings or other shadow-casting structures. Modeling of performance to predict annual yield of BIPV is more complex than regular PV [18].

The present size of the global BIPV market is about 2.3 GW (or ~ 1% of the global PV market) [19], with Europe constituting the largest market (42% of global market) in particular due to attractive incentives in France, Italy and Germany. The BIPV market is still a niche market. Based on the EPBD and its renewal to include building renovations a ten-fold increase of the European BIPV market is estimated for 2020, leading to a market share of 3% of the global PV market [19]. Several barriers need to be surpassed though, which relate to integration of the PV industry and the building industry. This may hamper the relative market size of BIPV to the market size of PV itself. Interestingly, about two-thirds of the European BIPV market is realized in new buildings, and one-third in renovation [20]. Façade BIPV accounts for half of the projects. A recent inventory shows hundreds of BIPV products offered [4].

On a global level, Europe and the United States dominate the BIPV market, while Asia is addressing BIPV as well [21]. Table 1 shows the results of a BIPV market analysis by region including expectations up to 2020. Irrespective of the region, the compounded annual growth rate is > 30%, except for Japan. This is envisaged as the costs are expected to decrease fast while the attractiveness of BIPV in terms of aesthetics and flexibility lead to market growth. In addition, the construction industry is recovering from the economical crisis, allowing for new constructions and renovation of buildings in the commercial and residential sectors.

In support of the development of BIPV in the Netherlands a BIPV roadmap has been developed, which identifies eleven of challenges in the field of technology (T), market (M) and ecosystem (E) to achieve a 5% BIPV share of total PV capacity in the Netherlands by 2020 [22], see Fig. 1. These challenges are integration of functions (T1), flexibility in colour, shape and size versus acceptable cost (T2), flexibility in colour, shape and size versus acceptable efficiency (T3), flexible choice of substrate materials (T4), unifying demand (M5), collective market approach (M6), information/communication of BIPV (M7), new business models (M8), collaboration in the value chain (E9), cross-sectorial collaboration (E10), BIPV in education and training (E11).

A first BIPV ecosystem analysis for the Netherlands was presented recently [23], and the present study has continued on these outcomes by reviewing the international situation for BIPV and the role of the Netherlands in this. The focus countries that were studied in this research are France, Germany, Switzerland and the United Kingdom. The purpose of this research was twofold, to determine what a specific country can learn from the situation for BIPV in other European countries (internal analysis) and to assess which countries show interesting opportunities for BIPV companies from that particular country (external analysis). Such a combined internal and external analysis could be performed for every country, but in this paper the Netherlands is taken as a case study example.

Table 1
Global market BIPV development and forecast from 2014 to 2020 in MW and compounded annual growth rate (CAGR) [19].

Region/Country	2014	2015	2016	2017	2018	2019	2020	CAGR (%)
Asia/Pacific	300	492	772	1159	1672	2329	3134	47.8
Europe	650	967	1441	2103	2929	3807	4838	39.7
Rest of world	81	125	184	263	355	451	561	37.9
USA	319	476	675	917	1200	1491	1766	33.0
Canada	42	61	86	119	157	190	228	32.6
Japan	143	201	268	349	434	520	612	27.5
Total (GW)	1.5	2.3	3.4	4.9	6.7	8.8	11.1	

2. Methodology

The steps that were taken during the study are shown in Fig. 2. By using a stakeholder analysis and a so-called DESTEP-analysis (Demographic, Ecological, Socio-cultural, Technological, Economic and Political ecosystem factors) it was assessed per country, which parts of the ecosystem are already well established, and which gaps are still existing. This information was analysed in both an external and internal analysis for the case of the Netherlands, from which recommendations were derived.

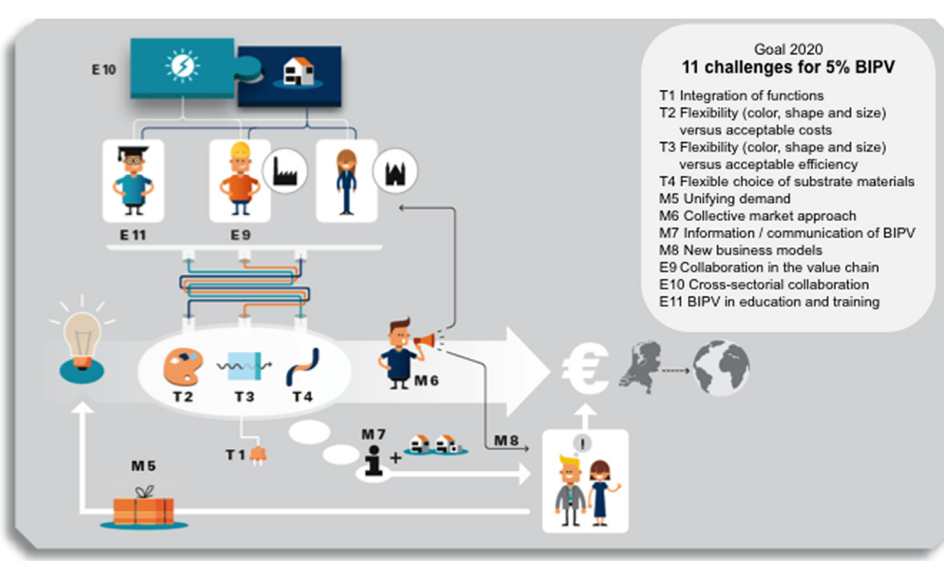

Fig. 1. Challenges to achieve a 5% BIPV share of total PV capacity in the Netherlands by 2020 [22].

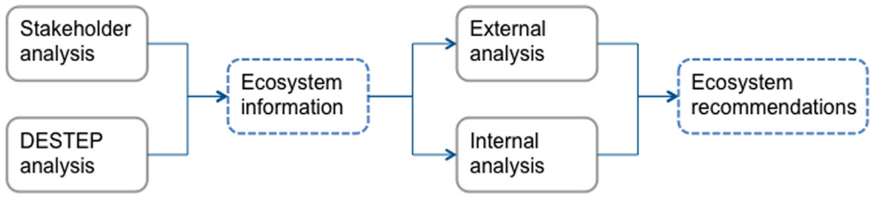

Fig. 2. Schematic representation of the methodology structure of the research.

2.1. Stakeholder analysis

The stakeholder analysis consisted of the following phases [24]:

1. Inventory of involved parties: The inventory was made at the sectorial level. The parties have been identified in consultation according to the Triple Helix model (Government, Industry and Academia) [25]
2. Define interest of each stakeholder: For the stakeholders that were identified in phase 1, market parties were identified and their interests as well as their perspective on BIPV were defined. Information was acquired from desk research and through Netherlands Business Support Offices (NBSO) and Dutch Embassies.
3. Determine relationship(s) between involved parties and their position within the ecosystem: This step visualizes how the stakeholders are related to each other within the BIPV sector. Points of differentiation for primary stakeholders, secondary and tertiary stakeholders were used as a guidance.

2.2. DESTEP-analysis

A DESTEP (**d**emographic, **e**cological, **s**ocio-cultural, **t**echnological, **e**conomic and **p**olitical-legal)-analysis is a generic marketing tool, which provides an overview of the environment a specific sector is operating in and what developments, trends and uncertainties it faces. It provides a systematic analysis of the external factors the sector is subjected to [26], as shown in Fig. 3. By focusing on six categories, a context was provided to prevent the research from becoming too broad. In this paper, we focus on the BIPV sector. Each category was qualitatively described by means of desk research on all impacts that are applicable to the BIPV sector. Main sources for the desk research were the statistical databases of the focus countries, the World Bank and Eurostat, as well as scientific literature and reports from the International Energy Agency (IEA) and the United Nations Development Programme (UNDP). Where necessary, additional information was acquired by contacting NBSO and Dutch Embassies.

2.3. Single country case: the Netherlands

2.3.1. External analysis

The purpose of the external analysis was to determine which countries show interesting business opportunities for Dutch BIPV companies. By taking the following steps, a comparative review was made between the focus countries:

1. Based on the outcomes of the stakeholder and DESTEP analyses, fifteen criteria were identified that would influence the implementation potential of BIPV. For each of the countries it was known from the stakeholder and DESTEP analyses how they score on each criterion, using a scale of 0 (no influence) to 5 (high influence)
2. These criteria were presented to 21 stakeholders that are active in the BIPV industry, mostly manufacturers and suppliers. This was done by a digital survey, distributed per e-mail. The stakeholders were asked to indicate what weight they would give to each of the criteria on a scale of 0 (no weight) to 3 (heavy), when determining market potential for BIPV.
3. From the responses to the survey, an averaged weighting factor could be determined for each of the criteria.

These steps served as a basis to compare the different countries by means of a Multi Criteria Decision Analysis (MCDA). Such an analysis provides the possibility of making decisions based on a weighted comparison of qualitative information. The focus countries were rated

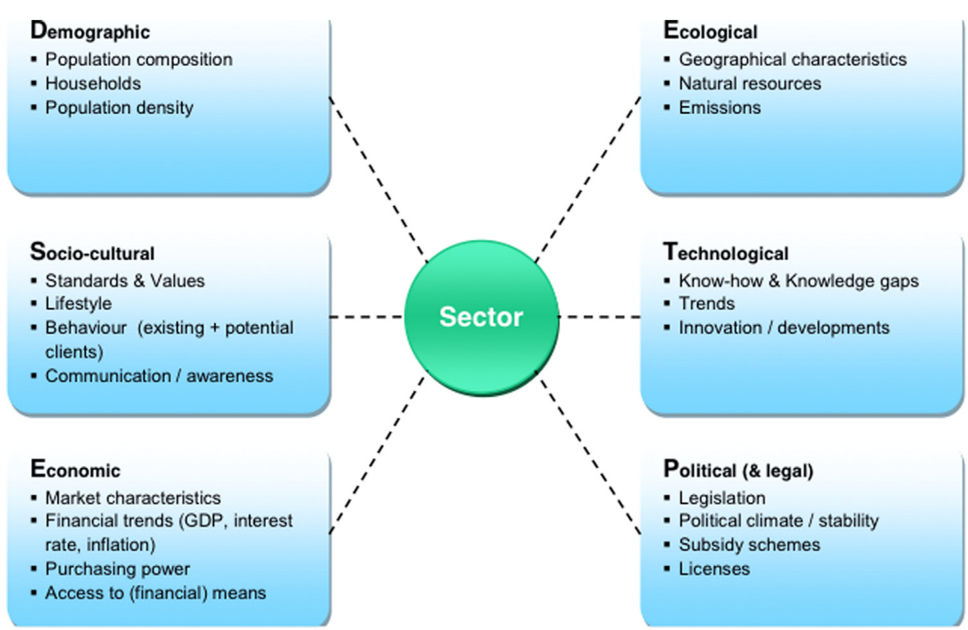

Fig. 3. Schematic representation of a DESTEP analysis.

on the fifteen weighted criteria, based on the information that was acquired in the stakeholder and DESTEP analyses. The scoring is not absolute, rather relative.

Multi Criteria (Decision) Analyses (MCDA) have been performed in many fields, including in (renewable) energy studies, see, e.g., for energy planning [27,28], location of wind turbines [29], best to use shading device with integrated PV [30], investment possibilities for PV systems based on local policies [31], and have been reviewed recently [32–34]. There are several methods that have been used in the MCDA of which the most common one is to include the following aspects [35]: problem determination and choice of possible alternative scenarios, criteria choice and description, evaluation of each criterion by priority, classification of each criterion, evaluation model, definition of possible restrictive criteria depending on the subject of the research problem, and final classification of possible scenarios by score. The scenario with the best score is deemed the most suitable.

2.3.2. Internal analysis

The purpose of the internal analysis was to determine what a country, in this case the Netherlands, could learn from the situation regarding BIPV in other countries. The results from the stakeholder and DESTEP analyses for the different countries were now compared in a qualitative way. To frame this comparison, the eleven challenges that have been identified for the Dutch BIPV sector were used as a basis [22]. The challenges were evaluated separately by comparing the applicable information that was found for the focus countries. Based on this, recommendations were made for the Dutch BIPV ecosystem to address each challenge.

3. Results

3.1. Stakeholder analysis

3.1.1. Inventory of involved parties

The identified parties are presented in Table 2 and checked with the preference of small and medium enterprises (SMEs) that are active in the BIPV sector of the Netherlands [10].

3.1.2. Interests of involved parties

A detailed description of interests, perspectives and challenges for the various market parties in BIPV in the Netherlands is given in Table 3.

3.1.3. Relationships between involved parties and their position within the ecosystem

The stakeholders that are part of the BIPV ecosystem are mapped in Fig. 4. The primary stakeholders are the ones who initiate the main activities and are responsible for execution of the work: they are displayed in the inner shell. The second shell represents the secondary stakeholders, who are the key partners without whom operations would not be possible, e.g., direct suppliers or customers. The tertiary stakeholders have a mainly supporting role and are positioned in the outermost shell. Some stakeholders are positioned in between the shells, e.g., contractors are a customer in the first place but also highly influence the product output.

3.2. DESTEP analysis

Relevant impact factors on the BIPV national ecosystems are listed in Table 4.

3.3. External analysis

Based on the outcomes of the stakeholder and DESTEP analyses, fifteen criteria have been identified that potentially influence the implementation potential of BIPV, see Table 5. As the DESTEP analysis methodology is a generic tool, the number of criteria per DESTEP category generally can differ, and the criteria do not necessarily have to be equally spread over all categories. DESTEP rather provides a framework by which a sector should be analysed. In the BIPV case, this leads to 1, 2, or 3 criteria per category, as detailed in Table 5, with different weights. The fifteen criteria serve as a basis to compare the different countries by means of the Multi Criteria Decision Analysis. The weighting of the criteria is determined through a survey among the 21 stakeholders in the BIPV industry. The scoring of the focus countries on these criteria is based on the outcomes of the stakeholder and DESTEP analyses. Table 4 presents the results of the survey providing the input for the MCDA.

The outcomes of the MCDA per country are presented in Fig. 5, showing the results when weighting is applied. Note that a score of 100% reflects full compliance to all criteria. Germany and Switzerland score best when it comes to opportunities for Dutch BIPV companies, with a total score of 75% and 74%, respectively. The United Kingdom and the Netherlands score the lowest, i.e. 54%. France is in the middle with 62%. When no weighting would be applied results are not very much different: Germany still scores best, with 75%, closely followed by Switzerland with 72%. The United Kingdom then has the lowest score, i.e. 53%. The Netherlands and France respectively score 56% and 63%.

Stakeholder criteria #1 and #2 (for details see Table 5) show the main differences for the availability of research centers for BIPV (technology). Demographic criteria (#3, #4, and #5) show little difference between the focus countries. Germany has a significantly higher established PV capacity per capita, indicating interest in the technology. In Switzerland the unemployment rate is considerably higher than in the other focus countries, indicating a more stable economy. Low influence can be seen from the ecological factor for large amount of solar radiation (Criterion #6). This is expected to be of minor importance compared to the efficiency and orientation of PV applications. Socio-cultural criteria (#7, and #8) show average to high influence on the attractiveness of a country to implement BIPV. Especially criterion #8, high share of expenditures to energy and housing, is weighted with 2.48 out of 3. This indicates a willingness to reduce the electricity bill by potentially using BIPV. The impact of economic criteria (#9, #10, and #11) is average to minor. Although criteria #9 and #10 are related, the housing market situation was taken as a separate criterion. A flourishing economy would provide sufficient equity for investment in general, while BIPV investment is expected to benefit from a flourishing housing market. Criterion #11, relating to differences in currency, was weighted as the least important, i.e. 1.19 out of 3. The fact that Switzerland and the United Kingdom do not have the Euro as a currency is therefore not regarded as a potential threat. The highest weighting by

Table 2
Inventory of parties that are involved in the BIPV sector, classified according to the Triple Helix model [25].

Triple Helix parties	BIPV stakeholders
Government	European Union; National government; Provinces & Municipalities; Federation spatial quality & Design Review Committees
Industry	BIPV manufacturers/suppliers/wholesale; Construction industry (contractors; material suppliers; PV-module installation; architects); Industry associations
Academia	Research institutes; Universities
End Users	Housing associations and their tenants; Business Rental (office spaces); Private homeowners

Table 3
Interests, perspectives and challenges for BIPV stakeholders in the focus countries. A distinction is made between general findings and, if applicable, country-specific findings.

Stakeholder	Interests, Perspective and Challenges	Netherlands	France	Germany	Switzerland	United Kingdom
Academia						
Universities	Universities serve as a supporting party within the BIPV ecosystem. They hold and develop extensive knowledge on technological developments for (BI)PV and sustainable construction by conducting independent research. This can be valuable input for the BIPV industry. Furthermore, they provide education on (BI)PV technology and applications to provide the necessary skills for future (BI)PV professionals. Regarding the relatively small scale on which BIPV is currently implemented, it remains a challenge to give sufficient attention to BIPV within study, education and training programmes [22]. Utrecht University therefore has started an Erasmus+ project, together with institutions from Austria, Germany and Cyprus, to develop an innovative and multidisciplinary, high quality course for BIPV [36]. This illustrates the growing interest in BIPV in the academic world. No guarantee can be given that this overview of universities that are involved with BIPV is complete.	Avans Hogeschool Hogeschool Zuyd Technical Universities of Delft, Eindhoven and Twente Utrecht University	Universities of Bordeaux, Lille, Lorraine, Montpellier, Nantes, Paris-Est Créteil, Savoie, Strasbourg [37]	University of Stuttgart University of Technology Darmstadt	SUPSI (University of Applied Sciences and Arts of Southern Switzerland)	Universities of: Bath, Bristol, Derby, Southampton Loughborough University
Research Institutes	Research institutes have a position similar to universities. They conduct independent research projects that are often commissioned by external parties, e.g. government or industry. Therefore they are very important for the creation and maintenance of a strong (national) knowledge base. Subsidy schemes are an important driving force behind the research. This provides a challenge to continuously secure funding to support parties in their research activities. No guarantee can be given that this overview of research institutes that are involved with BIPV is complete, the most important and most cited institutes are included.	Solar Energy Application Centre (SEAC) TNO ECN Solliance	INES (French National Solar Institute) IRDEP (Research and development institute for photovoltaic energy)	Fraunhofer ISE Batelle Institute	ISAAC (Institute for Applied Sustainability to the Built Environment) Swiss BIPV Competence Centre	SISER (Scottish Institute for Solar Energy Research) Sustainable Product Engineering Centre for Innovative Functional Industrial Coatings (SPECIFIC)
Industry						

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Table 3 (*continued*)

Stakeholder	Interests, Perspective and Challenges	Netherlands	France	Germany	Switzerland	United Kingdom
Manufacturers & Suppliers	The amount of BIPV manufacturers is growing. This mostly concerns existing companies that are originally either solar panel manufacturers or manufacturers of building parts (e.g. roofs and façades). The BIPV suppliers work closely together with the manufacturers or sometimes comprise even the same entity. Currently, suppliers are mostly SMEs that provide a full solar roofing or solar façade solution. This overview of BIPV manufacturers and suppliers is far from complete [2]. Since BIPV is a fast developing field, the number of parties involved is changing rapidly as well.	AERspire; BEAUsolar; Centrosolar; EXASUN; Linesolar Orange Solar'; Stafier Solar Systems; Scheuten; SCX solar; SolarSwing; Solinso; Synroof; Tulipps; Unidek; Zep BV.; ZigZagSolar; Zonnepanelen-Parkstad	Bosch Solar Energy; Fonroche; Francewatts; Imerys; Mecosun; Systovi; SUNIntegration SAS; Sunpower; Voltec Solar [37]	Abakus Solar; Asola Technologies; FATH Solar; Galaxy Energy; NaturHaus Solar; Schletter Solarmontagesysteme; SolteQ Group; Solarwatt; SolarWorld; Soltech; SUNOVATION; Sunways	Büro Dach & Wand; ClickCon & Co; Colt International; Electro-sol; Fornace Fonti; Helvetic Energy; Jansen/Schüco; Megasol Energie; Meyer Burger; Panotron; Rheinzink; Société d'Energie Solaire SES; Solstis; SOLTERRA; Star Unity; SUNAGE; Tritec	Oxford Photovoltaics; PolySolar; Romag; Solarcentury; Suntech
Wholesale	For regular PV components the wholesale market is already well established. For example in the Netherlands, the turnover of PV-wholesalers has already increased with 87% in the first three quarters of 2015 [38]. For BIPV components large-scale production is yet limited, since it is currently often designed per specific purpose [3]. This implies that the share of BIPV in total PV wholesale is yet relatively small. To increase the awareness of BIPV it is important that the product is easily accessible; BIPV should therefore become standard stock in PV wholesale. The wholesalers presented in the columns on the right trade mostly in regular PV system components. This overview of BIPV wholesalers is far from complete. Since BIPV is a fast developing field, the number of parties involved is changing rapidly as well.	4BestSolar; IBC Solar; IkBenRa; Klimaatgarant Solar; Mijn Energie-fabriek; Novasole; ProfiNRG; Sirius Solar Solutions; Zonel Energy Systems	Activ Eco; ALMA Solar; Atacama Solar; Capenergie; EOLANE Solar; KDI Solar; Krannich Solar; Portail-Solaire; PVG (Photovoltaïque Grossiste); Solaris Store; Solar Trade; SolarWorld; Tritec	AEET Energy; Antaris Solar; BayWa r.e. Solarsysteme; Conergy Deutschland; Energetik Solartechno-logie Vertriebs; IBC Solar; Krannich Solar; Schmitt und Zerreissen; SEN Solare Energie-systeme Nord	Bbsolar; EME Solar; ILB Helios AG; IWS Solar; PVMarkt; RAH Kraft; Solar Swiss; Sumatrix; Tritec	Baywa R.E. Solar Systems; Buy PV Direct; Krannich Solar; Metgen; Midsummer Solar PV; Segen; Solar NI; Solarvis Energy; Rexel Energy Solutions; Zenex Solar

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Table 3 (*continued*)

Stakeholder	Interests, Perspective and Challenges	Netherlands	France	Germany	Switzerland	United Kingdom
Building energy consultant	In utility building projects, consultants provide advice on criteria such as energy regulation and performance, noise isolation, material saving procedures et cetera. More and more buildings have to comply with BREEAM, LEED, other certification procedures and requirements. This stakeholder can recommend the use of BIPV in the building. It is therefore important that building consultants are familiar with the opportunities of BIPV in (utility) buildings and collaborate with architects.	Dutch Green Building Council (DGBC)	France Green Building Council (France GBC)	German Sustainable Building Council (DGNB)	Swiss Sustainable Building Council (SGNI)	UK Green Building Council (UKGBC)
Architects	An architect designs a building or building component in consultation with the client and a contractor. In this phase decisions are made on the energy neutrality goals of a building and the application of solar energy. It is therefore very important that these parties are familiar with the concept of BIPV and promote its implementation [22]. Costs of (BI)PV are often expressed in €/Wp. For architects this is not an interesting figure, especially not when the component has a building function. Therefore, expressing costs as €/m^2 has to become the standard for BIPV [13,39]. The role of an architect varies in different countries. Differences can be found in liability, obligation to be registered, scope of responsibilities and the role of other parties in the field, such as contractors [40].	Architects do not have a decisive role in the Netherlands. Apart from the general design they mainly provide recommendations and ideas, but the final decision is made by the client or the contractor [41].	In France, planning applications larger than 170 m^2 are required to be produced by an architect [42]. Also, projects are experienced to be more cost and resource efficient, as well as of higher quality [43].	German architects have far reaching liabilities when compared to other countries. The architect is responsible for the project until the building is completed. This includes artistic as well as technological aspects of the building, in compliance with building laws and regulations [44].	In Switzerland, the situation is different for small buildings, such as single-family houses, and large buildings, such as office or public buildings [45]. In the first case, the architect plays a strategic role and is, together with the client, the main driver behind renewable energy technologies. Therefore it is important that the architect is aware of BIPV. The second case however is more complex. The architect is responsible for the project, but can also leave this responsibility to the general contractor. Therefore, the architect is very important in the preliminary design phase, but choosing the right contractor that is involved with BIPV is essential for the rest of the project [45]. Overall, the main driver behind BIPV implementation in Switzerland seems to be the energy policy in the form of the building code.	In the United Kingdom, the education programme for architects is intense. To be able to work in the UK, architects require a registration at the Royal Institute for British Architects (RIBA), for which strict requirements are in force. More in-depth information about the specific role of architects in the UK could not be found within the time-span of this research.

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Table 3 (*continued*)

Stakeholder	Interests, Perspective and Challenges	Netherlands	France	Germany	Switzerland	United Kingdom
Contractors	The contractor usually coordinates a project after the design phase and is responsible for realisation of the building. It is therefore important that the contractor is familiar with the BIPV industry, regarding collaboration with sub-contractors and suppliers of building material [22]. The main bottleneck is often the availability of sufficient financing to establish the design of an architect. In most cases, when the client and/or contractor are not familiar with the advantages of BIPV, this will be one of the first components that is replaced by a cheaper alternative [41]. This emphasizes the need of awareness creation. For the contractors it is also important that BIPV costs are expressed as €/m^2 instead of €/Wp.	The main differences between the countries, other than those mentioned in the Architects section, can be found in building techniques. In the Netherlands, bricks are commonly used and prefab is becoming more and more common. For Belgium prefab components are not common to be used at all, construction is more considered as craftsmanship. In Germany, wood is a commonly used building material. The importance of aesthetical details is viewed different as well. In the United Kingdom water pipes often are visible in the bathroom, whereas this would not be acceptable in the Netherlands [39].				
Material suppliers	The proximity of suppliers of building materials is important for a value chain, in order to function as efficient as possible. These suppliers are mostly contacted through (sub-) contractors. This however holds for any type of value chain, not specifically for BIPV. What is important in the BIPV market is that the standard building materials can be integrated with the BIPV components, both practically and aesthetically. This can for example also concern the sustainability of the building materials. Acquiring aesthetical and sustainable materials at a suitable price level can be a challenge.					
PV-module installation	The installation of BIPV-modules in a building requires electricians who have expert knowledge in PV-connections as well as in construction. Compared to regular PV, the installation costs for BIPV increase because a larger number of usually smaller components need to be installed at a relatively larger area. This requires more interconnections and electrical wiring [46]. Furthermore, the roof is not only required to produce electricity, but also to be weatherproof. On the other hand, the efforts for covering a traditional roof are diminished. It depends on the BIPV supplier whether they are limited to delivery of the BIPV modules or also include the installation.					
Industry associations	Organizations that cover specific branches exist in most countries, but mostly cover the entire solar industry, or at least multiple niches. The European industry association for PV and BIPV is Solar Power Europe, led by the industry, and the European Photovoltaic Technology Platform (EU PV TP), led by the industry and academic and research institutes.	Ned.Vereniging Duurzame Energie Holland Solar Uneto-VNI	ENF Solar France Solar Industry SES (Syndicat des Energies Renouvelables)	BSW Solar Bundesverband Erneuerbare Energien Bundesverband Bausysteme	SwisSolar	BPVA (British Photovoltaic Association) Solar Trade Association
Government						
Levels	European Union; Government; Provinces & Municipalities. The role of the government will be mainly supportive and to serve as an example. This will be further discussed in the DESTEP-analysis.					
Federation spatial quality	The federation of spatial quality has the goal to promote and improve the quality of the built environment. This quality can be expressed in terms of safety, health and attractiveness of the surroundings. In most countries this concept is merely incorporated in the building code and not further addressed by a specific body.	Federatie Ruimtelijke Kwaliteit	n.a.	Landesdenkmal-schutzämter	Some regulations available on the municipal level	n.a.
End users						

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Table 3 (*continued*)

Stakeholder	Interests, Perspective and Challenges	Netherlands	France	Germany	Switzerland	United Kingdom
Housing associations + tenants	Housing associations can decide themselves to implement BIPV in their buildings, but can also be influenced by the wishes of their tenants or the municipality. Housing associations are responsible for energy supply being sustainable and affordable, which can be realized by investments in the real estate to decentralize electricity production [47]. Furthermore, housing associations have a social role since other buildings within the residential environment can be influenced by their decisions. In the Netherlands, both private rental and rental organized by housing associations is abundant. Housing associations in the Netherlands can almost be seen as a governmental body with specific rights and duties [41]. In other countries, the rental sector is not regulated that much. Housing associations are not as abundant, and rental is mostly organized by private investors [41]. These are less influential in (BI)PV implementation.					
Business rental (office spaces	Buildings that are rented for business purposes can be important initiators of BIPV projects. The building can have various purposes, e.g. office spaces for both private companies and the government, parking area, shopping area or a venue for events. The building can also be an indication of how much attention a business has for green activities. BIPV can therefore contribute to the message a business wants to convey [48].					
Private homeowners	Various reasons exist for private individuals to invest in renewable energy projects [49]. Homeowners can for example be interested in the technology, want to produce electricity themselves, have the wish to become self-sufficient, want to demonstrate a green or dedicated image to their environment et cetera. Through these visible investments, they can influence their direct environment. The amount of private homeowners that implements (BI)PV in their home is growing in the Netherlands [50].					

the stakeholders was given to political-legal criteria #13 and #14, relating to the renewable energy and building performance strategy of countries, i.e., 2.48 out of 3. Commonalities between the ecosystems of the focus countries stem from the fact that they all have to comply with the same EU directives. Therefore, the basis of their building performance and renewable energy strategies are similar. However, the way each country has interpreted and translated these directives into a national strategy differs.

3.4. Internal analysis

The internal analysis is aimed at identifying lessons and recommendations for the Dutch BIPV ecosystem. The developments in the BIPV market are dependent on market drivers and market restraints. Market drivers that are applicable to PV in general are the rising energy demand, the increasing costs of fossil fuels, the increasing need to differentiate the energy mix to enhance security of supply, the increasing environmental concerns about conventional energy, and government subsidies and financial incentives. Examples of market restraints are the high reliance on government subsidies and incentives, relatively high PV electricity costs and high administrative barriers in some countries [13].

The Dutch Roadmap for BIPV has identified eleven challenges in the field of technology, market and ecosystem to achieve a 5% BIPV share of total PV capacity in the Netherlands by 2020, as was shown in Fig. 1 [22]. It was found throughout this research that market drivers could be found in the perceived aesthetic benefits of BIPV and the need for energy efficiency and renewables in the built environment to achieve net zero energy buildings. Market restraints however are the higher costs compared to regular PV, low awareness of the public, the government and the construction industry, the limited collaboration between the PV- and construction industry, and the compatibility with existing buildings and building practices. This section proposes ways to deal with these challenges, by assessing how other countries act upon them. This is based on the information that was acquired in the stakeholder- and DESTEP analysis and some additional sources, and resulted in the lessons and recommendations for the (Dutch) BIPV sector presented in Table 6.

4. Discussion

This research focused on the Netherlands and four additional focus countries, i.e., Germany, France, Switzerland and the United Kingdom. This has provided many insights, however for a more complete image of the international situation for BIPV, additional research on other countries would be valuable. In our view, the present study therefore mainly serves as a starting point.

The stakeholder analysis provides a rather complete overview of the parties that are involved in BIPV at the academic, industrial and governmental level at the time of writing. However, since BIPV is a rapidly changing market, it has to be acknowledged that this situation is subject to change as well. Shifting regulatory regimes highly influence the composition of the market and its active stakeholders. This has to be kept in mind when using this information. Furthermore, some information for the stakeholder analysis could not be easily acquired from literature; this pertains mainly to information regarding the role or architects and contractors in the focus countries. In these cases, a combination of literature and expert opinions from various parties has been used. This could have led to biased results.

The DESTEP analysis provides an extensive overview of the recent dynamics in the demographic, ecological, socio-cultural, technological, economic and political-legal factors of the focus countries. In reality, more parameters may play a role in these factors, some more relevant than others. For the purposes of this study however, it can be said that the reviewed parameters are sufficient. If parties are interested to expand their business activities to one of the focus countries, it is

Table 4
Summary of relevant impact factors on the BIPV ecosystems in the focus countries in each category of the DESTEP-model. Data from national statistics bureaus [51–55].

Focus Country	Demographic	Ecological	Socio-cultural	Technological	Economic	Political-legal
Netherlands	0.4% population growth per year until 2020 Number of single households increasing Unemployment rate decreasing 67% of households are homeowners	11 tonnes CO_2-emissions per capita per year Increasing temperature trend Annually 1521 solar hours and 1000 kWh/m^2 solar radiation	Adequate level of environmental concern ~23% of expenditures to Energy & Housing Transition relationship citizens - government	Technological trends were found to be similar for all focus countries: Further automation of processes; Digitalization of information; Evolution of digitally connected customers, leading to different dynamics in relationships and transactions. Marketing channels are becoming more and more digital	Recovery from economic crisis; 0.9% economic growth in 2014 Growth is projected for export, overall investments and expenditures of consumers Increasing trend house prices	Decentralization of tasks and responsibilities Energy Agreement Focus on energy performance built environment Design Review Committee Solar Energy Application Centre
France	0.4% population growth / year 65% of households are homeowners Unemployment rate increasing; currently 10.3% Recent increase building permits issued	5.6 tonnes CO_2-emissions per capita per year. Low due to large nuclear energy share Largest surface area; high solar radiation in the South In 2014 14.6% renewable energy share; 5.5 TWh from PV	Strong focus BIPV to distinguish from Germany Strong support base for environmental measures and PV ~27% of expenditures to Energy & Housing	New internet revolution: more appliances and machines are interconnected to communicate and exchange data The lack of people with a strong IT background is a serious problem for many industries. This inhibits them to make the right techno-logical decisions and to harness the right emerging disruptive technologies at the right time.	Part of G7 Slow recovery economic crisis; 2014 economic growth 0.2% Unstable housing market, decreasing house prices Low electricity price due to nuclear energy share	19% citizens trust government Energy transition for Green Growth Act Building renovation policy 30% energy renovation cost refund Specific BIPV feed-in tariff
Germany	Fluctuating population growth 53% households are homeowners Unemployment rate only 5% Building permit requests increasing	9.1 tonnes CO_2-emissions per capita per year Increasing temperature trend 1,100 kWh/m^2 solar radiation In 2014 26% renewable electricity; 5.9% PV electricity.	~30% of expenditures to Energy & Housing Strong support Energiewende, many domestic energy projects		Part of G7 Economic growth (1.6% 2014) Increasing house prices Increasing electricity price due to grid fees (EEG-anlage) Domestic PV production declining	50% citizens trust government Renewable Energy Act (EEG) and Energiewende Focus on energy performance built environment Feed-in tariff for renewable energy
Switzerland	4 official languages: German, French, Italian, Romansh 1.2% population growth / year Unemployment rate only 3.16% High house prices, only 44% households are homeowners Construction sector declining	5.0 tonnes CO_2-emissions per capita per year. Low due to large hydropower capacity. Annually 1700 solar hours and 1250 kWh/m^2 solar radiation Snowfall can cover PV panels In 2014 842 GWh from PV	Swiss have high level of environmental concern ~27% of expenditures to Energy & Housing Large share of energy demand fulfilled by electricity		Not part of EU and Economic and Monetary Union (EMU) Currency Swiss Franc (CHF) High(er) import duties Open and innovating economy Economic growth (1.9% 2013)	80% citizens trust government CO_2 law; Energy Strategy 2050 Focus on building renovation; directive for BIPV Specific BIPV feed-in tariff Swiss BIPV Competence Centre
United Kingdom	0.75% population growth / year 20% households ≥ 4 persons 64% households are homeowners Decreasing unemployment rate; currently 5.4% Stable construction sector	7.93 tonnes CO_2-emissions per capita per year 1,300 solar hours per year 900 kWh/m^2 solar radiation 7% renewable energy in 2014; 15% planned for 2020	~20% of expenditures to Energy & Housing Strong level of support for environmental-friendly measures in politics Consumer behaviour to reduce energy use can be improved		Not part of the Economic and Monetary Union (EMU) Recovery from economic crisis Moderate increase house prices will lead to more rental Relatively low energy taxes	Climate Change Act: 80% GHG reduction in 2050 Electricity Market Reform towards competition for low-carbon energy All new homes carbon neutral by 2016

Table 5
Criteria, weighting and scoring for the MCDA of the focus countries.

#	Criterion	Average criterion weight	Scoring based on stakeholder and DESTEP analyses				
			NL	FR	GER	CH	UK
1	Large amount of established BIPV companies, indicating a flourishing but high entry market	1.38	3	3	3	3	2
			BIPV suppliers, manufacturers and wholesale companies are present in all countries, and the amount is growing. The UK seems to lag a little behind the other focus countries.				
2	Availability of (BI)PV research center(s), indicating research potential and knowledge transfer	1.57	4	2	3	4	2
			Switzerland has a research center specifically for BIPV. The Dutch PV research center SEAC collaborates at a high level with the Swiss and has a major focus on BIPV. Germany's Fraunhofer ISE performsspecialized PV research, but BIPV expertise seems to be less abundant. The research institutes of France and the UK were found to be less specialized.				
3	Low unemployment rate, indicating a more stable economy	1.43	3	2	4	5	4
			The unemployment rate in Switzerland was found to be very low, i.e. 3.36%. The UK and Germany score almost as good with respectively 5.4 and 5.0%. In the Netherlands, unemployment rate is 7.4% and France was found to have the highest unemployment rate, at 10.3%.				
4	High share of homeowners vs. renters, indicating a larger potential market	1.57	4	4	3	2	4
			The share of homeowners in the Netherlands, France and the UK were found to be similar, respectively 67%, 65% and 64%. In Germany 53% of households owned their home, in Switzerland this was only 44%.				
5	Large established PV capacity per capita, indicating interest in PV but at the same time a possibly high entry market	1.62	2	3	5	3	2
			Germany obviously has the highest share of PV capacity per capita, at 436 W/cap. France and Switzerland score significantly lower, at respectively 71 and 92 W/cap. The Netherlands and the UK only have an established PV capacity of respectively 40 and 53 W/cap.				
6	Large amount of solar radiation	1.57	2	4	3	4	2
			France and Switzerland have the highest average annual solar radiation, at respectively 1,300 and 1,250 kWh/m^2. In Germany 1,100 kWh/m^2 is average, followed by the Netherlands and the UK (1,000 and 900 kWh/m^2).				
7	High level of environmental concern, indicating willingness to implement environmental friendly measures	2.14	2	3	4	4	2
			In Switzerland and Germany, research shows that the average citizen is very willing to invest in renewable options to protect the environment. French also were found to be supportive of environmental friendly measures. For the Netherlands and the UK, no clear evidence for a high level of environmental concern could be found.				
8	High share of expenditures to Energy & Housing, indicating willingness to reduce the electricity bill	2.48	2	3	4	3	2
			The expenditures to Energy and Housing in Germany was found to be very high, i.e. 30.3%. France and Switzerland score almost as high with respectively 26.8 and 27.7%. In the Netherlands, energy and housing expenditures are 23.3% and the UK was found to have the lowest expenditures to this category, at 18.0%.				
9	Economic welfare	2.29	2	2	3	4	3
			The Swiss economy was found to perform best, with the highest disposable income and purchasing power, as all as significant economic growth. The situation for the UK and Germany was found to be relatively similar, with moderate economic growth and average purchasing power. In the Netherlands and France, purchasing power and disposable income were relatively average, however economic growth was found to be lower.				
10	Flourishing housing market	1.81	1	2	3	3	3
			In Germany, Switzerland and the UK, house prices are increasing again. In France house prices were found to be slowly deceasing over the last few years, but are still higher than 2010 levels. In the Netherlands, recovery seems to slowly be taking place, however house prices are still significantly lower than 2010 levels.				
11	Part of Eurozone (EMU), indicating no risk of losses due to currency changes	1.19	5	5	5	1	2
			The Netherlands, France and Germany are in the European Union and all have the Euro as a currency. The UK is part of the EU, but not part of the EMU. Switzerland is not in the EU and neither in the EMU.				
12	High degree of trust in government, indicating a politically stable environment	2.29	3	2	3	5	2
			The Swiss have the highest trust in their government, i.e. 80%. In the Netherlands and Germany, respectively 51% and 50% trusts their government. For France and the UK, these numbers respectively are 19% and 37%.				
13	Clear renewable energy strategy and targets	2.48	2	3	5	4	3
			Germany is very clear and ambitious in their renewable energy strategy. Switzerland closely follows this example. France and the UK are less ambitious, but the targets are clearly defined in a renewable energy act. The Netherlands has a relatively clear and ambitious strategy, however these objectives are not defined in the form of a mandatory act.				
14	Clear policy on energy performance of buildings	2.48	4	4	4	4	4
			All countries have translated the European Building Performance Directive into their national strategies. However, not much difference in types of targets and level of ambitiousness can be found between them.				
15	Availability of feed-in tariff schemes (or other specific financial support)	2.05	3	5	4	5	3
			France and Switzerland have feed-in tariffs and support schemes specifically for BIPV. Germany also offers well-regulated feed-in tariffs for PV, but does not offer specific incentives for BIPV. The feed-in tariffs of the UK are also not specifically for BIPV and the Netherlands does not offer feed-in tariffs, but has a net metering principle. Less future security is provided for consumers in the last two countries.				

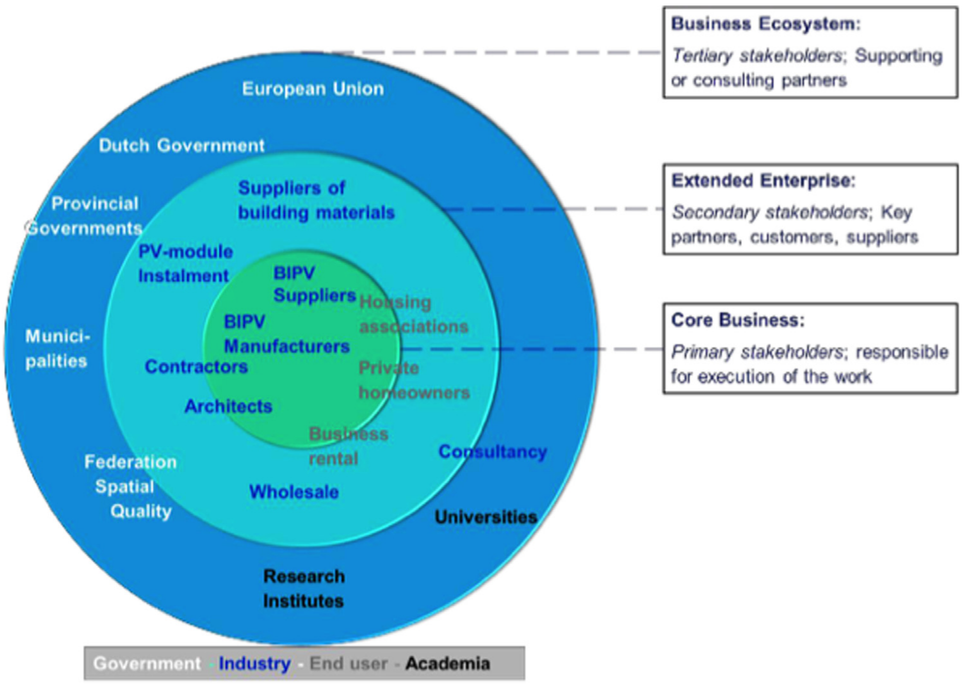

Fig. 4. Stakeholder map for the BIPV ecosystem.

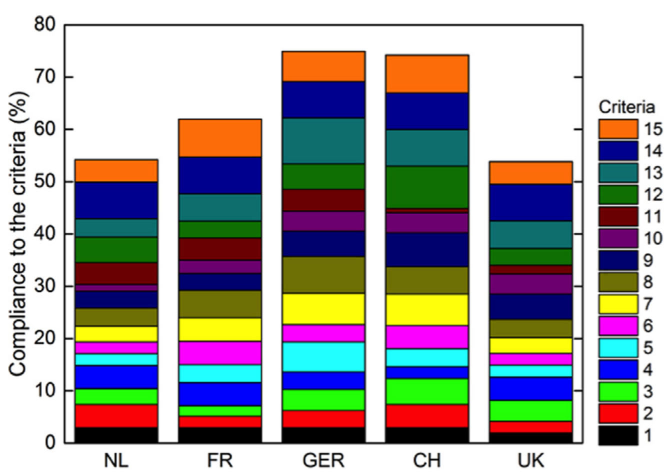

Fig. 5. Multicriteria analysis of the focus countries, providing a quantitative comparison of their relative compliance to 15 criteria that influence BIPV implementation.

recommended to conduct a more in-depth research on the DESTEP factors.

Policy measures have been reviewed mainly at the federal/national level. For all renewable energy measures, including BIPV, it is expected that regulations at the regional or even municipal level are abundant and can be influential. Especially since many countries are subdivided in smaller regulatory provinces, further detailed research on such more locally oriented incentive schemes is recommended to parties who are interested to start business activities.

Lastly, a few things can be pointed out on the MCDA. First of all, the number of respondents to the online survey was 21. More respondents would have led to more reliable results with less noise. However the opinions of respondents appeared to be well in line, so the low number of respondents is not expected to impact the results to a large extent. Secondly, the relative scoring of the focus countries on the fifteen criteria has been done based on qualitative information gathered throughout the research. This could have led to biased scores, potentially influencing the outcomes of the MCDA. Finally, the MCDA showed that energy policy and building performance policy are main drivers for BIPV implementation. This study also identified the need for new innovative business models for BIPV, to provide the possibility to survive as an individual industry, without governmental support or mandatory regimes. One possibility could be to vertically integrate the roles of different stakeholders, as shown in Fig. 6, to increase efficiency and competiveness. If these business models find their way in the near future, this would alter the criteria that business developers regard as important and therefore change the outcomes of this analysis.

5. Conclusion

This research continued on the Dutch roadmap for BIPV by placing the outcomes in an international context. The purpose of this research was twofold, to assess which countries show interesting opportunities for Dutch BIPV companies and to determine what the Netherlands can learn from the situation for BIPV in other countries.

Based on the fifteen criteria that were weighted by the preferences of Dutch BIPV stakeholders and evaluated for the focus countries in the MCDA, Switzerland and Germany show the most interesting opportunities for Dutch BIPV companies. Main drivers in this are their clear renewable energy targets and strategies. Both countries offer interesting support schemes for PV, Switzerland even provides legislation and incentive schemes specifically for BIPV. Companies indicated that political stability and a high level of trust in the government could be an important factor, on which Switzerland scores very high worldwide. Also, the level of environmental concern in society appears to be higher in both Switzerland and Germany, thus providing opportunities for BIPV implementation. It has to be stated that this research merely provides an insight based on a limited amount of selection criteria on which the alternatives were scored relative to each other. Individual companies will need to reflect on their personal values, assets, and strategies, which could lead to different outcomes. The information provided in this paper can provide guidance in this.

In addition, the situation for BIPV in the Netherlands was compared to the other focus countries. The Netherlands was found to stand out in the following points:

Table 6
Lessons and recommendations for the (Dutch) BIPV sector.

Responsible parties	Lessons and recommendations
Government	
European and national governments	Governmental regulations and financial incentive schemes need to provide security for the future, and reflect the higher cost of BIPV systems compared to regular PV. Harmonisation of building codes with energy performance requirements and aesthetics is necessary for BIPV to gain ground.
CENELEC and IEC, EU and national governments	General standardization and certification for BIPV needs to be developed, as well as a generally accepted definition. Legislation needs to provide a clear distinction from PV.
Industry	
Manufacturers, suppliers and construction industry	Given the shifting regulatory regimes, business models are required that survive without the need of subsidies or that optimally capture subsidies offered in the current regime.
Suppliers, wholesale, construction industry, architects	BIPV needs to follow requirements and developments in the construction sector. This means among others that prices should be expressed per m^2 and not per Wp, aesthetics and materials comply with current standards and the added value of BIPV is understood.
Manufacturers, construction industry	In manufacturing, further automation of processes and digitalization of information needs to be adopted. This should simplify the integration process.
Existing PV industry associations, BIPV industry	An industry association specifically for BIPV needs to be developed at an international level, bringing together BIPV stakeholders to find complementary products and activities and collectively prepare market approaches.
Manufacturers, suppliers, media	The advantages and possibilities of BIPV and outcomes of projects need to be clearly communicated to the public, the government and the construction industry.
Academia	
Universities; educational institutions	Education specifically for BIPV needs to be provided at all stakeholder levels, e.g. construction, design and technological development.
Research institutes	Internationally coordinated research and development is already happening, but knowledge sharing remains important in this new and dynamic sector.

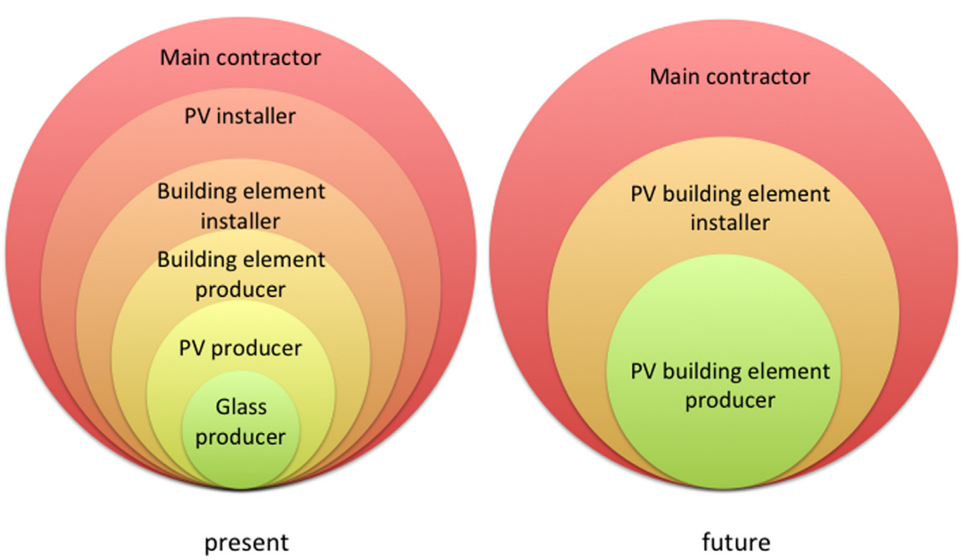

Fig. 6. New business model of vertical integration of present stakeholder roles to future roles to increase efficiency and improve competitiveness.

- Interesting support schemes are provided to stimulate SMEs to collaborate in the field of innovation, sustainability and renewable energy, e.g. IPC [56], SIB [57] and PIB [58].
- All homes require an energy label and this information is openly accessible.
- Most municipalities have a Design Review Committee (Federatie Ruimtelijke Kwaliteit), showing that aesthetics in the built environment is valued high.
- The Dutch research institutes (SEAC, Solliance and Hogeschool Zuyd) conduct valuable research on BIPV, making pioneering at an international level possible.

The main lessons for the (Dutch) BIPV sector that can be drawn from the comparative review were summarized in Table 6. The recommendations are clustered according to the Triple Helix to provide information on the main responsible parties. Some of these were found to have an international character. The information that was provided throughout this research and the conclusions that were drawn should be taken into account by the government, academia and the BIPV industry when further designing the BIPV (export) strategy for the Netherlands. It has become clear that the BIPV sector crosses national boundaries, and should therefore be reviewed and developed from an international perspective.

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