SHINING LIGHT ON EUROPEAN BIPV
A SURVEY OF DEPENDENCE AND FRAGMENTATION IN THE EMERGING EUROPEAN VALUE CHAIN FOR BUILDING INTEGRATED PHOTOVOLTAICS

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ABSTRACT: Building integrated photovoltaics (BIPV) is a technology that could support European climate neutrality and energy independence by making buildings sources of renewable energy. BIPV could further support these ambitions if sourced and produced locally. This study provides an overview of the status and import dependency of the European BIPV value chain. The analysis of the upstream value chain showed that the European BIPV industry is highly dependent on non-European countries for the supply of key components, especially the silicon-based cell technology, with 80% of interviewed companies sourcing these cells from China. Other main components are also sourced from manufacturers in China, such as junction boxes (67%) and encapsulants (63%). This dependency is further aggravated by a mismatch between producer requirements and domestic supply of main components. In the downstream value chain, BIPV producers are required to fulfill regulations for both PV products and buildings, which results in time-consuming and complicated processes. It was further identified that a lack of knowledge and specific expertise of BIPV exists among important actors, hindering its development and diffusion.

Keywords: Building integrated photovoltaics (BIPV), Value chain analysis, Technological Innovation Systems, Multi-level Perspective, Energy independence

1 INTRODUCTION

As a result of the Russian full-scale invasion of Ukraine, and the war that followed, the European Union (EU) has decided to accelerate the aim for energy independence and climate neutrality. This has resulted in EU launching the REPowerEU plan, which aims at "rapidly reducing our dependence on Russian fossil fuels by fast forwarding the green transition and joining forces to achieve a more resilient energy system and a true Energy Union" [1, p.1]. The REPowerEU plan contains various strategies and initiatives to further strengthen specific industries and energy sources, such as the EU Solar Energy Strategy. This initiative aims at doubling the European photovoltaic (PV) capacity by 2025, installing 600_{AC} GW by 2030, increasing the supply chain resilience and the domestic production capacity, as well as making rooftop solar mandatory for certain buildings, see Section 2.3 [2]. In addition, the Green Deal Industrial Plan for the Net-Zero Age was launched in 2023 with the goal of making the EU's net-zero industry[1] more competitive as well as supporting the transition towards climate neutrality [3]. The goal of increased value chain resilience is further enhanced by other initiatives that have been developed due to multiple supply chain disruptions in recent years, such as those that resulted from COVID-19 and the Suez Canal obstruction [4].

The European Union (EU) aims for climate neutrality by 2050 and a goal to increase the share of renewable energy has been set [5]. It is estimated that approximately 40% of the EU's energy consumption and 36% of the energy-related greenhouse gases come from buildings [6]. Therefore, it is essential to reduce the emissions and energy consumption related to this sector, for example through adoption of PV. Besides conventional PV modules, alternative PV technologies, such as building integrated photovoltaics (BIPV) are part of the urban capacity additions. The European Commission [7, p.13] has stated that:

"*The potential of this sector remains to be unlocked through uptake by the construction sector and the related economies of scale. EU-wide deployment would require homogeneous certification for the affected products […]*"

Hence, BIPV introduces an opportunity to increase the PV capacity in the built environment and society at large. It is therefore highly relevant to assess the current status of the European BIPV industry to understand what support is necessary to develop a resilient European BIPV industrial value chain and diffuse the technology into society [8].

Therefore, this study analyses the status of the European BIPV industry with a specific focus on the upstream value chain. Through stakeholder interviews and an examination of relationships and policies, the study seeks to uncover prevailing issues, barriers, and gaps in this industry. The research aims to describe the current structure of the European BIPV value chain, and asses its reliance on non-European imports.

1.1 Research Context

BIPV is a type of technology that has two major functions: (i) generate electricity, and (ii) act as a building material for the envelope of buildings. There are multiple definitions of how to classify BIPV. The International Energy Agency Photovoltaic Systems Programme (IEA-PVPS), via Task 15: Enabling Framework for the Development of BIPV, has reviewed several definitions and versions of how to define it, and compiled it into one [9, p.16]. This definition of BIPV is also used in this study:

[1] The Net-Zero Industry Act includes the following technologies: solar photovoltaic and solar thermal technologies, onshore and offshore renewable technologies, battery and storage technologies, heat pumps and geothermal energy technologies, electrolysers and fuel cells, sustainable biogas and methane technologies, carbon capture and stor age (CSS) technologies, and grid technologies [3].

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"A BIPV module is a PV module and a construction product together, designed to be a component of the building. A BIPV product is the smallest (electrically and mechanically) non-divisible photovoltaic unit in a BIPV system which retains building-related functionality. If the BIPV product is dismounted, it would have to be replaced by an appropriate construction product.

A BIPV system is a photovoltaic system in which the PV modules satisfy the definition above for BIPV products. It includes the electrical components needed to connect the PV modules to external AC or DC circuits and the mechanical mounting systems needed to integrate the BIPV products into the building."

IEA Task 15 further lists the main elements that compose a BIPV module, which are the PV cells, encapsulates, front and back covers, and junction boxes [10]. The cells create the core of the module where the energy is generated, while being insulated by the encapsulants, which in turn are protected by the front and back covers; usually made of glass or polymers.

2 METHOD AND THEORY

2.1. Data collection

As suggested by Hellin and Meijer [11], a qualitative approach is preferred when analyzing value chains, such as performing interviews and questionnaires. The companies selected for this study are producers and manufacturers of BIPV modules, research facilities, and policymakers in Europe. During the period between January and May of 2023, 71 companies were contacted and asked to participate in an interview, with the goal of obtaining a description of the current European BIPV industry and value chain. Overall, 2 companies rejected participation in the interview, 46 did not respond to the request, and 23 participated.

By conducting semi-structured interviews with representatives of the BIPV companies, typically Chief Executive Officers, Production Managers, Chief Product Officers and Chief Technology Officers, information about the upstream and downstream value chain was obtained. The duration of the interviews varied between 30 and 60 minutes and was divided into four different sections: (i) general information and background of the company, (ii) value chain and production information, (iii) networks and relations of the company with other companies, institutions, and actors, and (iv) perceived challenges of the company and European BIPV industry. Furthermore, to keep the responses for the interviews anonymous, Europe was divided into different regions: Northern Europe, Central Europe, Western Europe, and Southern Europe, as seen in Figure 1. The system categorization for BIPV was also utilized to classify companies according to the function in the building envelope that their BIPV product performs.

To acquire background information about the European BIPV value chain and EU policies, various databases and websites were the main sources of information. Literature and information regarding how BIPV is currently understood and perceived in Europe was mainly gathered from the BIPVBoost research project and Research Task 15 from the IEA PVPS. A list of European companies producing BIPV was also provided by the ESMC, which was complemented by actors listed in the study of Corti et al. [12].

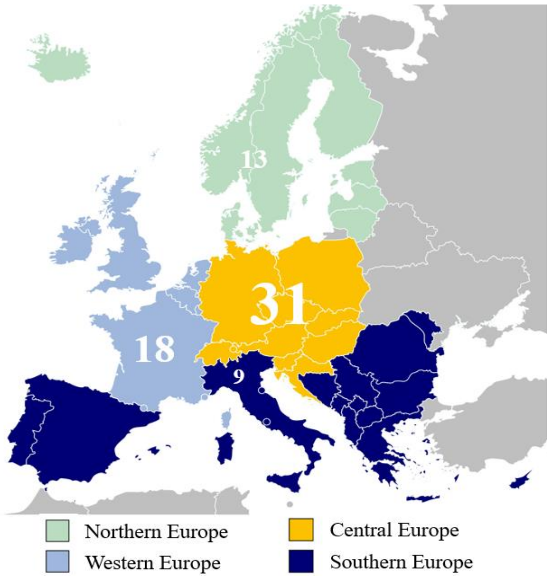

Figure 1: Overview of the location of European BIPV companies by region.

2.2. Multi-Level Perspective theory

Transitions can be understood as changes from one socio-technical system to another [13]. A socio-technical system is a system that provides a specific function for society [14]. Since transitions influence patterns, behaviors, regulation and even infrastructure, they involve multiple elements and engage with both technologies and society simultaneously. This co-evolution of technology and society can be seen as system innovations [15]. To understand what influences the transition to a new technological system, attention needs to be placed on both the internal mechanisms and interactions within the system, as well as on the externalities and the context in which the system develops. An approach to study these system transitions and technology evolutions, and their diffusion and adoption within society, is to utilize the multi-level perspective (MLP). The MLP provides a framework to study the transition of innovations through the interaction of technology and society [15].

The MLP presents a nested hierarchy composed of three levels: (i) micro-level, (ii) meso-level, and (iii) macro-level [13]. The micro-level is represented by niches. Technologies at this level do not compete with already established technologies as they are not mature nor efficient enough, which results in high uncertainty. Technologies in niches are formed through trial and error in a protected space [15]. The next level in the hierarchy is the meso-level, represented by the regime [13]. The regime can be understood as a set of established rules, patterns, and behaviors agreed upon by actors in society around a technology [16]. Technologies in this level are mature and stable, and the innovation that occurs at this level is of a slow and incremental nature, as opposed to the radical innovation from the micro-level niches. The last level of the hierarchy is the macro-level, which is represented by the landscape. The landscape is the broad context of society, including spaces and materials, such as infrastructure [15, p.684]. As the highest level of the MLP, the landscape is hard to change and cannot be directly influenced by actors.

The nested hierarchy of these levels originates from the constant interaction and embedment between them, which results in the levels influencing and affecting each other. More specifically, changes in the regime come from pressure applied by the landscape. This pressure can be of a material-, political-, perception-, or behavioral nature. When an opportunity opens in the landscape level, and pressure is put in the regime, technologies in the niche level can seize this pressure and gain more diffusion and acceptance [13].

The MLP framework was used to analyze the broader context in which the BIPV system is developing by identifying what other systems that interact with the industry and how this occurs.

3 RESULTS

3.1. European BIPV industry analysis

According to the system categorization of BIPV, it was identified that 54 of the analyzed companies produce roof BIPV, 39 façades and 35 external integrated devices (EID). However, some of the companies also produce multiple categories, or all of them.

The data gathered to describe the size of the industry (number of employees, turnover, and production capacity) does not consider all 71 companies, only those for which the data was available. The companies producing BIPV in Europe differ greatly in size, as can be seen in Figures 2–4. The largest company has 810 employees, while the smallest producer only has three. The average number of employees is 84 employees, while the median is 30 employees. However, it should be noted that some of the larger companies also produce regular modules, and that not all reported employees necessary work within the BIPV branch of these companies. The size difference is also reflected in the turnover, as seen in Figure 3. The lowest turnover of any company in 2021 was €4 250, the company with the highest turnover reached €46 800 000. The average and median turnover for the year amounts to €8 287 732 and €1 572 438, respectively. However, note that some of the companies exclusively produce BIPV while others offer it as part of a broader product catalog.

The production capacity of the companies varied greatly, as can be seen in Figure 4. The producers measure their capacity using different units; some companies measure it in megawatts per annum (MW/a), while others measure it in square meters per annum (m^2/a). This stems from the dual nature of BIPV, as some companies view their product as a PV system while others view it as a construction material. To get a uniform compilation, the manufacturing capacities reported in m^2/a were converted by the authors to MW/a by the average W/m^2 ratio of the company's BIPV products disclosed in their datasheets. In terms of MW, the largest capacity was found to be 200 MW/a, while the company with the lowest capacity produces 1.4 MW/a. The total combined yearly capacity of the 27 reporting companies was 1 313 MW/a, which on average gives a capacity of 49 MW/a and a median capacity of 30 MW/a per company. However, these figures do not include all the 71 identified BIPV companies, just the 27 companies that disclosed manufacturing capacities in the survey. In addition, it is important to stress that due to fluctuations in demand, some of the companies mentioned that they often produce only at a share of their maximum production capacity.

3.2. Value chain of silicon based BIPV

Silicon based BIPV is the conventional cell technology. Out of 71 contacted companies, 51 used

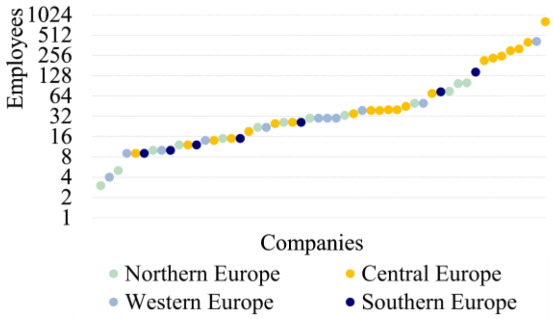

Figure 2: Number of employees per company of the 52 companies' data was acquired for.

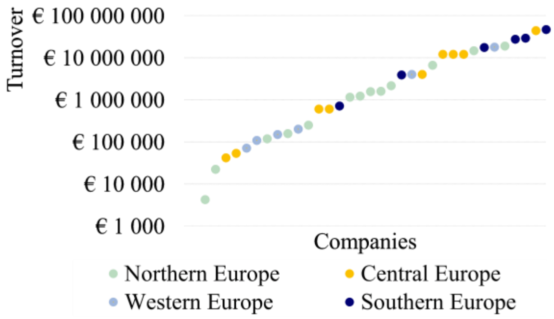

Figure 3: Turnover in 2021 per company of the 34 companies' data was acquired for.

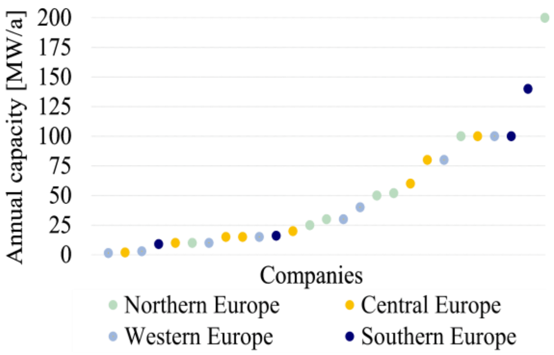

Figure 4: Yearly BIPV manufacturing capacity of the 27 companies' that were willing to share data.

silicon as their cell technology, whereof 16 were interviewed. It was revealed that 80% of interviewed companies source their silicon cells from China. Responding companies indicated that 67% and 63% of the sourcing of junction boxes and encapsulants, respectively, also were from China. Glass (for the front and back covers) dependence on China is lower, with only 27% mentioning it. Taiwan is also a significant silicon cell source; 38% of producers utilize it, while 44% use both China and Taiwan.

Notably, producers in Northern Europe also source silicon cells from the United States and the Philippines.

Regarding the other components, European silicon based BIPV producers acquire glass primarily from European countries (36%), such as Belgium, Germany, Italy, Spain and the Netherlands, as well as Türkiye, Vietnam, and India. junction boxes are primarily sourced from China (67%), while the secondary source for this component is European countries (unspecified). In addition, some interviewees also mentioned that they used to source junction boxes from Germany, but since the supplier closed its operations, this was no longer an option.

Encapsulants mostly come from non-European countries, namely China (63%) and Taiwan (13%), with 25% from Europe. Other components such as back sheets, wires, and foil vary in origin. The most mentioned suppliers were China and unspecified European countries. In addition, one also mentioned India as a supplier.

3.3. Value chain of CIGS- & perovskite-based BIPV

CIGS is the second most common cell technology used amongst the contacted companies, as nine out of 73 use this technology, whereof 3 were interviewed. Two of the contacted companies use perovskite cells, whereof one agreed to participate in this study.

The materials and components used in CIGS based BIPV differ from the ones used in silicon based BIPV, and the companies that participated did not share the origin in much detail. One company manufactures CIGS cells in-house, sourcing materials from Europe and Asia. The other two import the cells from the United States, however, one plans to change to a French supplier within 2–5 years. Regarding the other components, one producer mentioned challenges sourcing solar graded glass from Europe, the remaining sourced 50% from Europe and 50% from China. All firms source junction boxes and encapsulants from China. In addition, one evaluates a shift to a European supplier due to supply chain issues and expiration concerns regarding the encapsulants.

Lastly, the company that uses perovskite disclosed that their suppliers are mainly located in Europe, whereas the metal used is sourced from the UK but could be mined somewhere else. Although they did not specify which parts, the producer did mention that some specific parts were obtained from Japanese suppliers as well.

In summary, it can be concluded that the European BIPV value chain is strongly dependent on China, and Figure 5 illustrates the situation.

Figure 5: Visual representation of the countries that contribute to the upstream European BIPV value chain. Darker color indicates a stronger concentration of supply.

3.4. Upstream Challenges of European BIPV

A challenge that was mentioned throughout the interviews was the inability to source materials from Europe. This is not only due to a lack of suppliers in Europe, but also because few European suppliers can provide the quantity required by producers. There is, however, a very strong interest from European BIPV producers to source all materials and components from Europe, since it would decrease the risk of value chain disruptions, bring shorter lead times, and improve the environmental footprint of their products. Moreover, a clear mismatch was identified between European BIPV producers and possible European suppliers of materials and components. The two main drivers of this mismatch are: (i) that some of the materials and components are of a specific nature and cannot be found in Europe; and, (ii) that the prices offered by European suppliers are often not competitive with the international market, especially since the required volumes are too small to allow for economies of scale.

Another challenge mentioned by multiple interviewees was the limited control that they have when procuring materials, specifically silicon cells. It was stated that they perceive that the quality of the cells received does not match what was ordered, which could be due to more relaxed laboratory standards in China. At the same time, options are limited since the silicon cell supply is currently rather concentrated to a few countries.

3.5. Downstream Challenges of European BIPV

One identified downstream challenge is the general lack of awareness of BIPV in Europe. This was mentioned in connection with various actors, including installers, architects and policymakers. During all interviews, independently of the size of the producer, it was mentioned that policymakers and governmental entities lack awareness and understanding of BIPV, and therefore fail to regulate it properly. Firstly, BIPV must comply with both the PV and building regulations which differ throughout Europe. Secondly, there is no standardized regulation for BIPV in Europe and it is unclear for some actors if it legally should be treated as a PV system, a building material, or both. This misconception is further confirmed by the fact that some producers perceive BIPV mainly as either a PV system or a building material.

Multiple companies further expressed a general lack of knowledge of the architectural sector, especially those who do not have a relationship with architectural firms. This is important because architects are a primary actor, with a high influence for the diffusion of BIPV in Europe. The lack of awareness can further be seen in other aspects. For example, throughout the interviews, it has been mentioned that it is rather difficult to secure funding to further expand the production capacity. The interviewees further express that this obstacle may be due to a lack of understanding about the technology from investors, and that it may be considered too risky to invest in. Because of this, two companies have been pushed to close their production in Europe and move to China or the United States, where better support mechanisms exist for the technology, such as the Inflation Reduction Act in the United States.

Lastly, numerous producers noted the challenge of sourcing skilled installers. Some manage this by performing installations in-house or through close connections with the construction industry. In specific instances, BIPV project costs surge significantly due to installers and subcontractors, rendering the end price overly costly for customers. An interviewee even highlighted a potential tenfold price increase.

3.6 The niche of European BIPV

To summarize, the function that the socio-technical system of BIPV aims to provide is that of transforming energy-passive construction infrastructure, such as buildings, into active energy sources. Because of this, it can be interpreted that the two regimes that the BIPV socio-technical system interacts with are the electricity generation regime, including conventional PV, and the building regime. During the interviews, European BIPV was recurrently characterized as a niche, partly due to its specific function. In addition, BIPV is neither mature enough to compete directly with common construction

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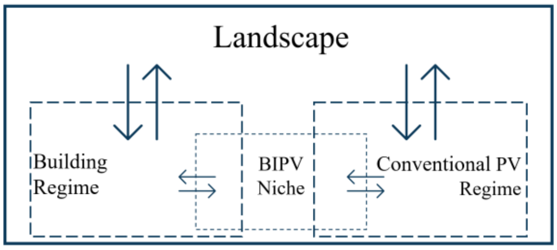

Figure 6: MLP characterization of the European BIPV industry.

materials, nor with more widespread PV systems, or any other energy source in general. It can therefore be argued that European BIPV found itself in the niche level of the MLP, as depicted in Figure 6. However, many of the interviewees responded that their goal with BIPV is not to compete against more diffused energy sources, but instead to serve a customer with specific needs, for which energy generation and aesthetics play an equally important role.

From the interviews, it can further be interpreted that the European BIPV industry is still going through a learning phase since there is still knowledge being developed that is essential to end the formative phase. This knowledge includes certification requirements and processes, as well as ways of working among actors, such as the sourcing and supply of materials and the approach taken when designing, developing and installing BIPV projects. Furthermore, from the perspective of BIPV producers, a lack of awareness from some important actors has been mentioned on multiple occasions, which suggests that more knowledge still needs to be developed.

From the interviews, it also can be inferred that European BIPV lacks a protected space to develop knowledge. One reason for this is that BIPV is usually categorized together with more conventional PV solutions, such as roof mounted modules and large-scale solar parks, which results in tension between the PV regime and the BIPV niche. This lack of differentiation and protected spaces hinders BIPV from developing its own standards and ways of working, and instead, the standards of the PV regime are applied to BIPV. Another reason mentioned in multiple interviews for the lack of protected spaces in the BIPV niche is the limited financing and incentives to invest in the industry.

Finally, the landscape in which the BIPV niche and the mentioned regimes interact involves the current energy supply infrastructure and the building infrastructure in Europe, as well as the current environmental, political and societal context. All these factors that shape the landscape put pressure on the regimes to transition into new ways of generating energy and constructing buildings. These factors also add pressure on Europe to become more energy-independent from foreign fossil fuels. An evident way in which this pressure is manifesting in the regimes is through the policies and regulations proposed by the EU, mentioned in the introduction. The interaction between the levels in the nested hierarchy presented is mainly driven by actors with different roles, responsibilities, influence, and interests, as seen in Figure 7, adapted from Corti et al. [12]. Furthermore, the actors are categorized according to their relationship with European BIPV producers, and are listed in Table I.

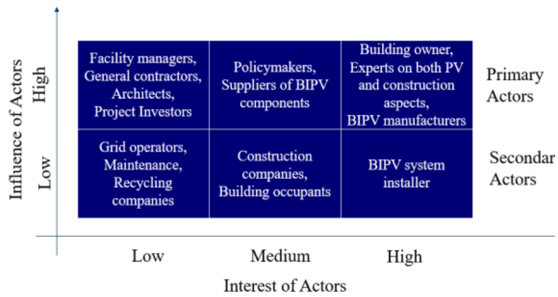

Figure 7: Classification of actors regarding their influence and interest of BIPV, based on Corti et al. [12].

4 DISCUSSON

The results from the value chain analysis indicate that the European BIPV industry relies heavily on foreign suppliers. The dominant country of origin, however, varies depending on cell technology. Silicon-based BIPV, which dominates the market, gets most key components from

Table I: Classification of actors within the European BIPV Industry.

Actors	Category & Definition
Research institutes, universities, R&D, PV and BIPV industry associations, and consortiums	**Knowledge Development and Sharing:** These actors are of importance because they support with research and development of BIPV. These developments could result in BIPV becoming more attractive due to higher efficiencies, new materials, or new forms to adapt the technology into the building.
Laboratories, governments, certification institutes	**Testing and Certification:** The actors in this group provide guidance and frameworks for certification of BIPV products so that the modules can be installed into buildings across Europe.
Governments, private investors, banks, and other companies	**Funding and Financing:** This group of actors are important to the producers of BIPV from an economical and financial perspective, as they provide financial support for companies to operate and expand.
Architects, installers, façade and roof companies, builders, distributors, construction companies, and developers	**Planning and Installation:** The actors in this group are of utmost importance for a successful implementation of a BIPV project. Each of them has a specific role throughout the process and collaborate closely among each other, and with the producers of BIPV.
Policymakers and entrepreneurs	**Industry development and support:** These actors have the ability to influence the development and diffusion of BIPV among all actors. They support with the legitimation of the technology, which can present itself in the form of legislation favoring BIPV, special demonstration of the technology, and sharing of BIPV success stories.
Companies, owners of buildings, and government	**Final customer:** These are the actors that purchase the BIPV products and for whom the BIPV project is performed.
Suppliers, international partnerships, sales and technical consultancy	**Other:** The actors in this category have different ways to support and collaborate with producers of BIPV. For example, they could include suppliers, or they may provide market knowledge, special partnerships for collaboration, or access to a wider range of contacts in other industries

manufacturers in China. CIGS cells, on the other hand, are sourced from suppliers in the United States or Europe. The strong dependency on foreign suppliers, especially Chinese, is due to the economies of scale and low cost achieved by these producers, which creates barriers for other producers to enter the market. Interviews do, however, indicate a preference for European suppliers if large enough quantities were available. Hence, there is an unmet demand for European upstream BIPV components and materials.

The European BIPV niche exists at the intersection of the conventional PV and building regimes. The expertise of these two regimes needs to be combined when implementing BIPV. This fusion could yield a distinct BIPV expertise and more well-defined roles and responsibilities for involved actors. Due to the diverging perceptions of BIPV as either a PV system or a building material, an industry-wide agreement on a definition of BIPV and EU-wide BIPV standards would likely facilitate implementation and certification processes. However, this would also make it easier for foreign producers to enter the European market, which could result in more competition and a weaker domestic value chain. Furthermore, a market niche, protected by policy, would enable the accumulation of knowledge and practical experience required for future competitiveness with conventional roof mounted PV modules as well as conventional building materials.

One limitation of this study is its relatively small sample size of participating manufacturers. Out of 71 contacted companies, only 23 (31%) engaged in the study, leading to a somewhat narrow scope. Among the 48 remaining companies, two declined, and the rest did not respond. Furthermore, of the 71 companies included, 51 utilized the silicon cell technology, nine employed CIGS cells, and two utilized perovskite cells. The study is therefore somewhat angled towards producers of silicon-based BIPV and their perception of the European BIPV market. However, silicon cells are the most used cell technology in the PV market, which makes the sample of producers in this study representative of the market.

Despite this bias, the geographically varied participants provide a comprehensive perspective, offering well-representative findings of European BIPV perceptions. Future studies regarding the European BIPV industry would benefit from a broader range of cell technologies and more European producers. Including the processes further up in the value chain, especially module components and raw material production, would add insight. Further investigations could potentially also delve into actor network dynamics within the industry.

There are, however, some limitations to the study. Firstly, due to practical constraints, not all European BIPV module manufacturers are included; the selection is based primarily on data from the European Solar Manufacturing Council (ESMC). Secondly, the study examines the upstream value chain in terms of component sourcing — restricted to the specific components of PV cells, junction boxes, front and back covers, and encapsulants — disregarding the origin of raw materials. Lastly, import volumes are not factored into the value chain evaluation.

5 CONCLUSIONS

The silicon cell technology is the most dominant technology used in European BIPV modules. Overall, most key components used in the module, such as silicon cells, junction boxes and encapsulants originate mainly from China, whereas glass is the only key component that is mainly sourced from European countries. Other cell technologies used in European BIPV are, for example, CIGS and perovskite cells. Although most of the producers of these technologies rely on imports, there are companies who either produce the cells themselves, source them from European producers, or will, in the near future, source them from European suppliers. Nevertheless, since the CIGS and perovskite BIPV segment is significantly smaller than the silicon one, there is an overall large import dependency. While many producers currently import components, interviewees demonstrated a preference for domestically sourced components. However, due to the mismatch between producer requirements and domestic supply, it is usually not possible to meet this demand. Policy packages, like the Green Deal Industrial Plan for the Net Zero Age, could potentially stimulate growth of domestic production capacity and expertise, via faster access to funding and a simplified regulatory environment.

The downstream value chain involves diverse actors, including investors, policymakers, architects, and installers. Interviews reveal a lack of BIPV awareness, which increases the perceived investment risks, pushing producers to expand in the United States and China. Measures to enhance general knowledge about BIPV is therefore key in order for the European BIPV industry to develop and expand. Certification poses another challenge. BIPV producers need to comply with both PV regulations and varying regional building regulations. Standardized EU-wide BIPV regulations could simplify certification. Nevertheless, this could also facilitate the entry of foreign producers into the European market, potentially leading to increased competition and a less resilient domestic value chain.

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