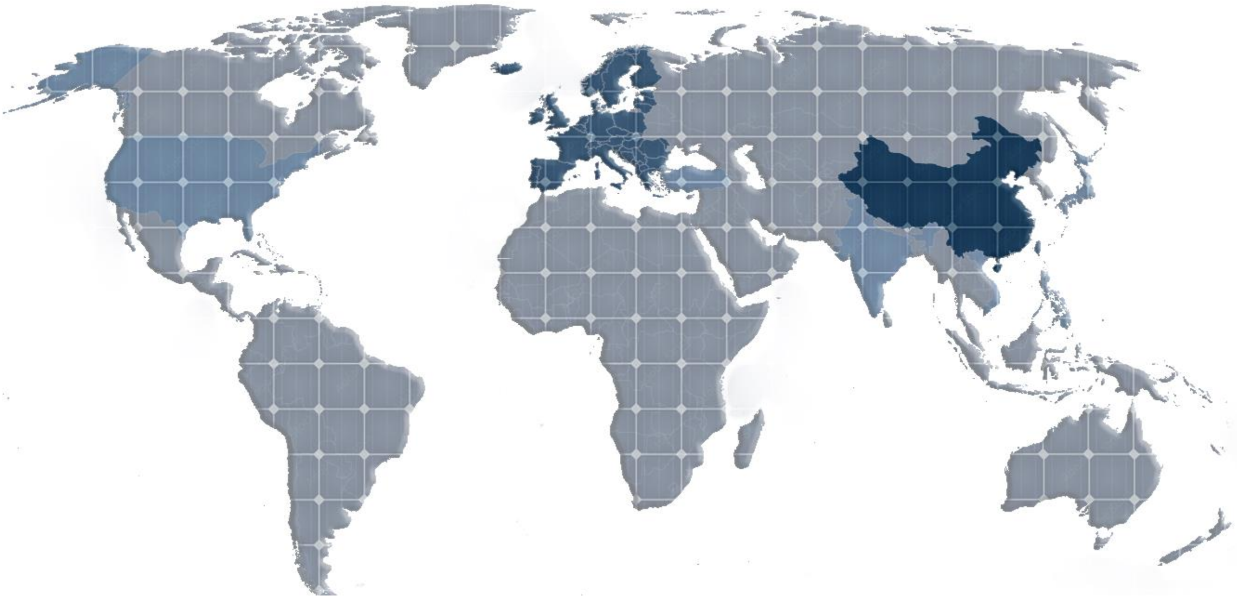

SHINING LIGHT ON EUROPEAN BIPV

A Survey of Dependence and Fragmentation in the Emerging European Value Chain for Building Integrated Photovoltaics

Master's thesis in Industrial Ecology

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Cover:
The cover displays what countries the European BIPV value chain is most dependent on, covered by a PV grid. Darker color indicates a stronger dependency. The figure is adapted from Figure 5.7, on page 30.

Gothenburg, Sweden 2023

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SUMMARY

Derived from the ongoing climate crisis and the Russian invasion of Ukraine, the European Union (EU) aims for climate neutrality as well as energy independence through a green transition. To achieve this, several policies have been proposed and implemented. Some of these policies provide support to the development of renewable energy technologies, such as solar photovoltaics (PV). Building integrated photovoltaics (BIPV) is a particular PV technology that could support this transition by making European buildings sources of renewable energy. Recent disruptions in global value chains have demonstrated the importance of developing domestic European Net-Zero industries for Europe to achieve climate neutrality and energy independence. Therefore, this thesis aims to investigate the status and dependency of the European BIPV industry. This has been done by interviewing domestic producers of BIPV and analyzing the results within the framework of Technological Innovation Systems and Multi-level Perspective Theory. 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. BIPV producers are also required to fulfill regulations for both PV products and building, which results in time-consuming and complicated processes for some of the BIPV producers. It was identified that a lack of knowledge exists in the form of lack of awareness and understanding of the technology, as well as a lack of specific expertise. From the perspective of BIPV producers, this lack of knowledge is true for actors along the value chain such as architects and installers, but also for other actors such as investors and policymakers. The current European policy supports the development of BIPV, however, there are some gaps, such as more specific regulation, that need to be addressed for a more effective green transition and diffusion of this renewable energy technology.

Keywords: Building integrated photovoltaics, BIPV, Value chain analysis, European policy, Technological Innovation Systems, Multi-level Perspective, Climate neutrality, Energy independence

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Gerardo López Pinto y Velasco
Fredrik Özaras

Gothenburg, June 2023

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Introduction

1.1 Background

In the sixth Assessment Report published by the Intergovernmental Panel on Climate Change (IPCC), it is stated that human activities have affected climate change to the degree that it has started to influence the weather, causing more extreme weather events all over the globe (IPCC, 2022). The report also states that the goal of limiting global warming below 1.5°C, and even 2°C, will not be achieved without a far-reaching transition away from fossil-based energy and towards renewable alternatives in the upcoming decades. As the European Union (EU) aims for climate neutrality by 2050, goals to increase the share of renewable energy have been set. For example, the Renewable Energy Directive 2018/2001/EU aims to achieve a level of at least 32% renewable energy by 2030 (European Commission, 2018). It is estimated that approximately 40% of the EU's energy consumption, and 36% the energy-related greenhouse gases, comes from buildings (European Commission, 2021). Therefore, it is essential to reduce the emissions and energy consumption related to this sector, for example through adoption of solar photovoltaics (PV).

As a result of Russia's invasion of Ukraine, and the war that followed, the EU does not only aim for climate neutrality, but also energy independence. This has resulted in that the EU launched 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"* (European Commission, 2022c, p. 1). The REPowerEU plan contains various strategies and initiatives to further strengthen specific industries and energy sources, such as the EU Solar Strategy, and the European Solar Rooftop Initiative. This Initiative aims at doubling the European PV capacity by 2025, and install 600 GW by 2030, increase the supply chain resilience and the domestic production capacity, as well as making rooftop solar mandatory for certain buildings, see Section 2.3 (European Commission, 2022e).

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. For example, the COVID-19 pandemic and the Suez Canal obstruction, highlighted the severe import dependency, and the importance of having a strong domestic value chain that is prepared to provide in times of crisis (Özkanlisoy & Akkartal, 2021). Afterwards, plans such as EU's Green Deal Industrial Plan for a Net-Zero Age were put in place, which aims at achieving a more competitive and resilient European net-zero industry[1], as well as

---

[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 storage (CSS) technologies, and grid technologies (European Commission, 2023c)

supporting the European transition towards climate neutrality (European Commission, 2023a).

According to SolarPower Europe (2022), solar PV is considered one of the more important options for the net-zero industry, it has gathered increasing interest across the European Union in recent years. Proof of this is the 41.1 GW of new capacity installed in the EU in 2022, representing a 47% increase when comparing to the capacity installed in the previous year (SolarPower Europe, 2022). Besides conventional silicon PV modules, alternative PV technologies, such as building integrated photovoltaics (BIPV) are part of the urban capacity additions. The European Commission 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 [. . .]*" (European Commission, 2022b, p.13). Hence, BIPV introduces an opportunity to increase the PV capacity in the built environment and society at large. In addition, since the technology is not yet widely diffused globally, it could be easier to develop a competitive advantage for Europe within the BIPV industry than it is to compete within the conventional PV module industry. It is therefore essential to assess the current status of the European BIPV industry, to understand what support is necessary, and what is needed to further diffuse the technology into society (European Solar PV Industry Alliance, 2022).

1.2 Aim & Scope

The scope of this thesis is thus to investigate the status of the European BIPV industry with a specific focus on the upstream value chain. In addition, in order to assess the support for domestically produced BIPV, this thesis will also evaluate what EU policies and regulation that are in place, to identify current support and gaps.

By interviewing actors (stakeholders) and analyzing relations and policies in the European BIPV value chain, this thesis aims to provide an understanding of what issues, barriers and gaps are present. More specifically, this thesis aims to answer the following questions:

- What is the structure of the European BIPV value chain, and how dependent is it on imports from countries outside of Europe?
- What industry-wide challenges are there to further diffuse BIPV within Europe?
- What policies are currently in place affecting the European BIPV industry, and how could these be adapted to better support European producers of BIPV and what other measures can be implemented to address these challenges?

To understand the current European BIPV landscape in relation to its producers, 23 European producers of BIPV have been interviewed. The goal of these interviews was to acquire knowledge related to the producer's upstream value chain, in other words, what countries they source materials and components from, and what issues they may be facing in relation to this. The interviews also provided an understanding of the producer's perceptions of the industry, BIPV, and further insights to what bottlenecks that may be present, what individual and collective challenges they might be facing, and what the interviewees recognize as important for achieving a more resilient BIPV value chain. In addition, to understand the current status of the European

BIPV industry, the size of the producers is also of interest, especially, their production capacities, revenues and number of employees.

Furthermore, it can be argued that institutional actors, such as the EU, are mobilizing and creating a shift in the energy production landscape and a proof of these are the climate goals set as well as the policy that has been implemented and proposed. To evaluate how this shift influences, and impacts BIPV, Technological Innovation System (TIS) theory is used as a theoretical background to characterize the status of the industry, as well as what actors, networks and institutions that are present. The characterization of the European BIPV industry within the TIS framework allows for a more comprehensive understanding of the industry and its dynamics, which in turn provides insights when proposing actions to strengthen European producers. Multi-Level Perspective (MLP) theory is also used to identify and analyze the European BIPV value chain's context and external dynamics that currently influence the industry.

There are, however, some limitations to the study. First of all, it is not possible to include all the companies that produce BIPV modules in Europe, and a selection have therefore been made in accordance with the data provided. Secondly, the study only considers the upstream value chain with regards to the source of the components. Hence, no consideration is made to where the raw materials are sourced for the components. Lastly, when evaluating the value chain, the volume of imports is disregarded.

2

Research Context

This Chapter provides context for the subjects of study of the thesis. A definition of BIPV is provided and different classifications of this technology are introduced. An explanation of the current status of silicon value chains for PV is provided and an overview of European policies is presented. European policies relevant for BIPV are explained to identify how they can support the development and diffusion of European BIPV.

2.1 BIPV

BIPV is a type of PV that fulfill two goals: (i) generate electricity, and (ii) act as a building material for the envelope of buildings and provides weather protection, thermal insulation, noise protection, daylight illumination and safety. 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 (Berger et al., 2018). This definition of BIPV presented is, therefore, also what will be used in this thesis:

> *"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."*

Berger et al. (2018), p.16

2.1.1 Components of BIPV

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 (Bonomo et al., 2021). Besides the four main components, BIPV laminate and bypass diodes are also used in the module. 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. As a result of the photovoltaic effect that occurs in the semiconductor, a voltage potential is created between the front and back of the PV cell, which in turn drives the electricity through, wiring cables to the junction box, before leaving the module (Bonomo et al., 2021). For a further description of the main components, see Table 2.1.

Table 2.1: The main components of a BIPV module (Bonomo et al., 2021)

Components	Description
PV Cell	The cell is a component that converts the sunlight into electricity by absorbing a share of the incoming photons which excite electrons, causing them to move in the cell. This movement of the electrons generates an electrical current (U.S. Energy Information Administration, 2023).
Encapsulant	The role of the encapsulant is to protect and insulate the PV cells the wiring from the environment, e.g., water and dust.
Front and Back Covers	These comprise the front and the back of the module and provides protection and insulation for the cells against the environment. While the front cover can possess different optical transparency, the back cover is responsible for the attachment to the building. Because of this, the back cover is of special importance when considering performance certifications, such as fire safety.
Junction Box	This component is an enclosure, inside which the circuits are connected.

2.1.2 Classifications of BIPV

Although IEA PVPS has created a definition, there are still aspects that add to the complexity of BIPV. For example, depending on where on the building envelope the BIPV module is intended to be installed, different installation principles, and modules, will be necessary. Based on this, there are different ways to classify BIPV. According to Bonomo et al. (2021), BIPV can be classified with respect to either the application category, system or modules.

Application Category

The application category considers how the system is integrated to the building, by taking into account if the system is installed into the building envelope, the slope of the installation, and if the module is accessible from the inside of the building. According to Bonomo et al. (2021), by combining these three aspects, five different BIPV categories are generated (A-E), which can be used to define the system, see Figure 2.1.

A: Integrated in the roof with slope and not accessible from inside the building.

B: Integrated in the roof with a slope and accessible from inside the building.

C: Vertically integrated to the envelope and not accessible from inside the building.

D: Vertically integrated to the envelope and not accessible from inside the building.

E: Integrated as an additional layer and accessible or not from inside the building.

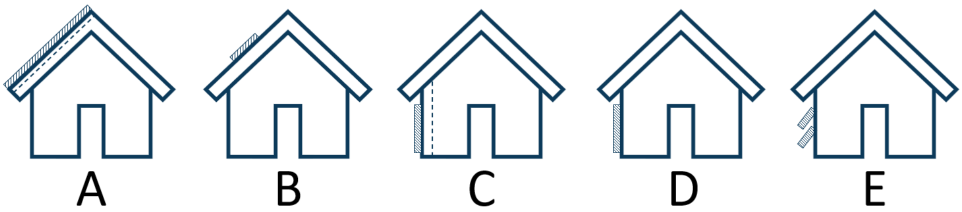

Figure 2.1: System definition categories of BIPV

System Category

The system category refers to the type of function that the installation will fulfill in the building envelope. The building envelope is the part of the building that separates the outside and the inside, and provides protection from the natural elements (Arndold C., 2016). Depending on the system category, different guides and regulations will be applicable. Envelope systems can be divided into several different categories based on different aspects, such as the position in the building and what other functions that the system might fulfill, e.g., shading. IEA PVPS Task 15 has proposed three main classifications for BIPV within this classification (Bonomo et al., 2021):

1. **Roof:** The roof is the top of the building, separating the inside form the outside. Types of roofs include discontinuous roofs, continuous roofs, atriums and skylights.
2. **Façade:** All the surrounding surfaces of the building attached to the main structure, which provide a separation between the inside and outside. Façades can be installed vertically or with a slope, resulting in curtain walls, rainscreens, double skin façades, windows and masonry walls.
3. **External Integrated Devices:** These are external devices that are not in contact with the inside of the building. Examples of these devices are solar shading in buildings, parapets, balustrades, and canopies.

Module Category

According to the module category, multiple classifications can be made based on the type, application, and properties of the module. The IEA PVPS Task 15 suggests categorizing the technology depending on the optical transparency, flatness, mechanical rigidity, size, thermal insulation, and if it is a standard or customized module (Bonomo et al., 2021).

Cell Technology Category

In this thesis we also introduce and include another classification category. The proposed classification sorts BIPV based on the cell technology, i.e., if for example, silicon cells, copper indium gallium selenide (CIGS) cells or perovskite cells are being used.

Silicon is the second most abundant material in Earth's crust, and it is currently the global leading material used for PV cells; over 95% of the modules sold uses this cell technology (U.S.

Department of Energy, n.d.). The maximum conversion efficiency reported for a silicon PV cell is currently 27.6%, which occurred inside a laboratory (NREL, 2022). Outside of laboratories, however, the maximum conversion efficiency recorded is 24.4% (Andreani et al., 2019).

CIGS cells are one of the most used thin-film technologies for solar applications (Honsberg C., Bowden S., 2016). Thin-film cells consist of multiple layers of material, in this case a combination of copper, indium, gallium, and selenide, which is supported by a structure made out of glass, plastic or metal (U.S. Department of Energy, n.d.). In a laboratory, CIGS cells have reached a conversion efficiency of 23.6%. Because of the lower efficiency, compared to silicon cells, the commercial efficiency would not be superior compared to silicon cells (NREL, 2022).

Perovskite cells uses a mixture of organic-inorganic halide perovskite, and are the newest cell type of the three mentioned. The maximum reported efficiency for perovskite cells was 28.6% (Oxford PV, 2023).

2.2 Silicon Value Chains

Since 2011, China has invested ten times more than Europe in PV manufacturing capacity. This has resulted in the manufacturing capacity of solar PV shifting from Europe over to China (International Energy Agency, 2022). Because of this, the current majority of the solar PV panels used within Europe have their origin from China (McKinsey & Company, 2022).

In 2020, 68% of the global production of solar modules occurred in China, amounting to 140 GW (International Energy Agency, 2022; McKinsey & Company, 2022). China is also dominating further up in the value chain, as 95% of the global production of silicon wafer and 76% of silicon cell production occur in the country, which is more than twice the domestic demand. There are, however, still several PV producers throughout the value chain in Europe, but large scale PV manufacturing volumes are missing in most part of the value chain with the exception of Wackers production of polysilicon. Currently, Europe has approximately 9.4 GW of module production capacity, 1.4 GW of cell production capacity, 1.7 GW of ingot and wafer production capacity, and 23.2 GW of polysilicon production capacity (SolarPower Europe, 2023).

Most of the costs for a PV module can be attributed to the materials, and are approximately the same for European and Chinese producers. The production cost in China is, however, almost 35% lower than in Europe (ETIP Photovoltaics, 2023), partly due to the economies of scale the country has achieved (McKinsey & Company, 2022). Another reason is the different cost of electricity, which contributes to almost 40% of the cost difference. However, when exporting to Europe, the lower production costs are somewhat offset by the needed transportation costs.

2.3 European Policies & Regulations

In addition, this thesis also analyzes current European policies to identify how BIPV is supported, and what possible gaps that may be present. In this section, an overview of relevant European policies is presented and their connection and influence for BIPV manufacturing is highlighted.

2.3.1 EU Green Deal

The EU Green Deal was first presented on December 11th, 2019, and is a long-term sustainability goal that all 27 EU Member States has agreed upon (European Commission, 2019). The main goal of the EU Green deal is for Europe to become the first climate neutral continent, have net zero emissions by 2050, reduce the emissions by 55% by 2030, compared to 1990, expand the renewable energy production to 40% by 2030, and increase the energy efficiency. Hence, transitioning and transforming the EU into a resource-efficient, competitive and green economy. To achieve this transformation, funding is required. The total budget for the EU Green Deal is estimated to approximately €1 trillion, where a large share (ca. €600 million) of the funding is allocated from the NextGenerationEU Recovery Plan (European Commission, 2019).

The EU green deal aims to target various sectors, such as energy, buildings and transportation. Therefore, the Green deal is composed by a set of different proposals, such as the Fit for 55 and REPowerEU packages, which further includes other initiatives, e.g., the Green Deal Industrial Plan and the EU Solar Energy Strategy, among others. For an overview of how the initiatives are connected, see Figure 2.2.

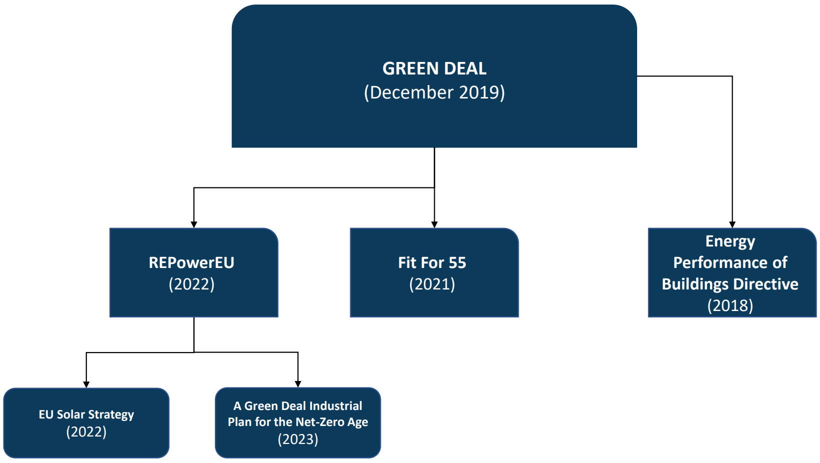

Figure 2.2: Schematic overview of initiatives

2.3.2 Fit for 55

The Fit for 55 Package is a plan that falls under the EU Green Deal, that has the goal to reduce the EU's greenhouse gas (GHG) emissions by at least 55% by 2030, compared to 1990's level, and achieve a climate neutral Union by 2050 (European Commission, 2023b). It is comprised of a set of proposals for the EU legislation that aim at converting the EU's climate goals into law, making them legally binding for all Member States. The package was submitted by the European Council in July 2021 and includes different areas, such as specific policy for the environment, energy, transport and financial aid, among others. The three main objectives of the Fit for 55 package are:

- Ensuring a just and socially fair transition,
- Maintaining and strengthening innovation and competitiveness of the EU industry, while ensuring a leveled playing field in regards to third country economic operators,
- Promote the EU as leading region in the global fight against climate change.

With this package, the European Commission (EC) is creating a new and self-standing emission trading system for buildings and road transport, with the goal of supporting each of the Member States' national targets for emissions reduction (European Commission, 2023b). This comes under the Effort Sharing Regulation which sets binding annual GHG emissions targets for Member States in sectors outside of the scope of the current emission trading scheme. More specifically, some of the areas in the Fit for 55 package that relate to the BIPV technology are renewable energy, energy efficiency, and energy performance of buildings.

The renewable energy section of the package states that at least 40% of all energy must come from renewable sources by 2030 (European Commission, 2023b). This is important since the carbon footprint for the European energy sector currently contributes to 75% of all EU emissions.

The energy efficiency section will make it compulsory to reduce energy consumption (European Commission, 2023b). The goals are to decrease primary consumption by 39% and final consumption by 36%. The key sectors encompassed in this section are buildings, industry and transport. One important aspect included is the renovation of buildings, stating that for each year, 3% of public building floor space will be renovated to improve the energy efficiency.

The Energy Performance of Buildings directive expresses that, buildings are currently responsible for 36% of energy related GHG emissions, and that they account for 40% of final energy consumption (European Commission, 2023b). As of today, 75% of buildings are considered to be energy-inefficient and thus require renovation to increase their energy performance. The Fit for 55 package states that, by 2030, energy performance certificates will be obligatory for new buildings and that all new buildings should be zero-emission buildings. Furthermore, existing buildings should be transformed into zero-emission buildings by 2050. As solar energy installations must be implemented in all new public buildings with a useful floor area of at least 250 m^2 by 2027, in all existing public buildings by 2028 and in all new residential buildings by 2030, it plays an important role for the building energy performance (European Commission, 2022a). According to European Commission (2023b), there will be further EU incentives in place to support all these foreseen renovations in the form of financial subsidies, tax reductions and administrative support.

2.3.3 REPowerEU

REPowerEU is a plan presented by the European Commission on May 18th, 2022, as a response to the invasion of Russia's invasion of Ukraine in February 2022 (European Commission, 2022d). This plan has two main objectives: (i) end the EU dependence on Russian fossil fuels and (ii) address the ongoing climate crisis. The Commission aims to achieve these objectives through energy savings, diversification of energy supplies and an accelerated deployment of renewable energy (European Commission, 2022c). The plan complements the Fit for 55 package by raising the targets for energy efficiency to 13%, and renewable energy to 45%, by legal amendments. It is expected for the REPowerEU to increase the speed of the European transition to clean energy, which in turn will result in both a reduction of the energy prices and the global demand for fossil fuels. Solar power plays an important role in this plan as it has the objective of doubling the installed solar PV capacity in Europe by 2025 and install 600 GW_{AC} (which corresponds to approximately 750 GW_{DC}) by 2030. To achieve this, the plan has defined a specific EU Solar Strategy, see section 2.3.4 below.

Regarding the size of the investment related to REPowerEU, it adds €210 billion between 2022 and 2027 on top of the investment to realize the Fit for 55 goals. The Recovery and Resilience Facility (RRF) is core for the implementation of the REPowerEU plan and overall, close to €270 billion funds will be distributed to the Member States along with a request that the Member States revise and update their national RPP so that they are better aligned with the goals of REPowerEU. Both REPowerEU and Fit for 55 is foreseen to save €80 billion in gas, €12 billion in oil and €1.7 billion in coal per year by 2030. The total amount to be saved is approximately €655.9 billion (European Commission, 2022c).

Once the amendment REF Regulations take effect, it will include an increase of the RRF financial envelope by:

- €20 billion in new grants to that Member States will be requested to include in their REPowerEU chapters. These grants will be financed through the sale of Emissions Trading System allowances.
- €5.4 billion of funds from the Brexit Adjustment Reserve that Member States will be able to voluntarily transfer to the RRF to finance REPowerEU measures. This comes on top of the existing transfer possibilities of 5% from the cohesion policy funds (up to €17 billion).
- These new grant possibilities come in addition to the remaining €225 billion of RRF loans that Member States can use for REPowerEU purposes.

2.3.4 EU Solar Energy Strategy

The EU Solar Energy Strategy was introduced in May 2022 and is mainly a part of the two incentives *the European Green Deal* and *REPowerEU*, and it is indirectly related to the Fit for 55 package. The EU Solar Energy Strategy has the core goal of reducing the EU´s dependency on foreign fossil fuels, expand the European solar energy capacity to 320 GW_{AC} by 2025, and to reach 600 GW_{AC} by 2030 (European Commission, 2022b). The strategy aims to promote electricity production from PV in the European Union, as well as support European manufacturers to expand the domestic manufacturing base. By 2021, the European PV capacity reached 136 GW, contributing to approximately 5% to the EU electricity mixture, as well as producing electricity below the current European wholesale price; making it a liable investment, and the most accessible sustainable energy source available (European Commission, 2022b).

To reach the EU Solar Energy Strategy targets of 600 GW_{AC} PV installed, the EU will need to, on average, install 70 GW_{DC} per year until 2030 on average. Furthermore, by making households electricity prosumers[1], instead of just consumers, they can be more protected from high volatile energy prices(European Commission, 2022b). The shift from consumers to prosumers will require support and policies, such as feed-in tariffs, investments subsides and exemptions from certain taxes. To further strengthen the EU solar market, it is estimated that €26 billion will be needed by 2027, where most is assumed to come from private investors.

The EU Solar Strategy identifies current challenges and barriers related to the solar energy sector and suggests four initiatives to overcome them (European Commission, 2022b). The four initiatives suggested in the strategy are:

1. **The European Solar Rooftop Initiative**: The aim of the European Solar Rooftop Initiative is to promote a utilization of rooftops for solar energy (European Commission, 2022b). The initiative proposes to gradually make it mandatory to install solar energy into buildings, starting with new public and commercial buildings by 2026, that are over 250 m^2, and then later residential buildings by 2029. The initiative also includes a goal to make all new buildings "solar ready", i.e., designed to maximize the solar radiation and make the installation of solar power easier. Moreover, to ease the installation process, the EU aims to limit the permitting time to maximum 3 months. The initiative further discusses how to support BIPV for both renovations and new buildings, however, in which way is yet to be decided.

2. **Making permitting procedures shorter and simpler:** The aim is to make the permitting process easier, which will be done by a legislative proposal, a recommendation, and a guidance plan (European Commission, 2022b).

3. **The EU large-scale skills partnership:** Skilled workforce has been identified as a current bottleneck to further expand the solar energy sector in the Union (European Commission, 2022b). The EU large-scale skills partnership initiative therefore aims to promote and expand labor with the necessary skills that are needed in the solar energy sector.

4. **The EU Solar PV Industry Alliance:** The alliance was created in October 2022 and consists of the European Commission, research institutes, industrial actor, and associations (European Commission, 2022b). The goal of the alliance is to act as a support forum to ensure investment opportunities, and necessary policy support, to further develop a stronger domestic solar industry, focusing on the entire and value chain.

There is also a proposition to include PV modules, inverters and system sold within the Union in both the Ecodesign Regulation ,and the Energy Labelling Regulation (European Commission, 2022b). In addition, the EU will provide European consumers a guarantee that the product is produced with respect to human and labor rights. The EU Solar strategy also aims to use EU policies to make a more diversified value chain and promote resilience in relation to raw materials; mainly based on resource accessibility, sustainability and circular economy. Hence, it is in EU´s interest to strengthen and redeem domestic sourcing of materials and PV production.

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[1] A prosumer is an individual who both consumes and produces electricity.

2.3.5 A Green Deal Industrial Plan for the Net-Zero Age

The Green Deal Industrial Plan for the Net-Zero Age, also referred to just as The Green Deal Industrial Plan, was released in February 2023 and aims at making the EU's net-zero industry more competitive as well as supporting the transition towards climate neutrality (European Commission, 2023a). These net-zero industries include solar PV 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 storage (CSS) technologies, and grid technologies. The goal is to facilitate industrial capacity for clean technologies in the Union based on four pillars:

1. Predictable, coherent and simplified regulatory environment,
2. Faster access to finance,
3. Enhancing of European skills in key net-zero technologies,
4. Open trade for resilient supply chains.

The plan comes from the ongoing transition of the world to a more sustainable society as new technology is being developed to tackle climate change and reduce the emissions of greenhouse gases (European Commission, 2023a). Net-zero technologies are the cornerstones to make this happen and the demand for this type of products is set to increase. The EU wants to capitalize on the accelerating market by being leading in research and development, but also in the manufacturing and deployment of these technologies. The manner in which this plan aims at achieving these objectives is by supporting the development and implementation of net-zero technologies in European industry (European Commission, 2023a).

One key point of this plan is to create attractive conditions for the development of net-zero technologies, as well as to improve the domestic production capacity of these in Europe. This in turn will bring resilience and independence to the European energy sector and value chain.

2.3.6 The Energy Performance of Building Directive

The Energy Performance of Building Directive (2010/31/EU) and the Energy Efficiency Directive (2012/27/EU) both aims at improving the energy performance of buildings within the Union (European Commission, 2021). Since the implementation of the two directives, buildings have reduced their energy consumption by 50%, compared to a standardized building from the 1980s.

Both the Energy Performance of Building Directive and Energy Efficiency Directive were amended in 2018 and 2019, respectively. The purpose was to promote technological improvements and increasing the renovation rate of buildings (European Commission, 2021). As followed, the European Commission presented the Renovation wave strategy as part of the European Green Deal; containing measures to regulate, finance and enable renovations of buildings. The strategy focuses on 3 main areas: (i) tackling energy poverty and worst-performing buildings, (ii) public buildings and social infrastructure, and (iii) decarbonizing heating and cooling (European Commission, 2020).

In end of 2021, the European Commission proposed a revision of the Energy Performance of Building Directive (European Commission, 2021). The revision contains a more ambitious framework for the building sector and suggest that Europe can achieve zero-emissions and a fully decarbonized building stock by 2050. In addition, the revision raised the target of decreasing the emissions from building with 60% by 2030, compared to 2015. It also introduces minimum energy performance and long-term renovation strategies.

The amended Energy Performance of Building Directive (2018/844/EC) further introduced the requirement that all new buildings built after 2020 must be nearly zero-energy buildings (NZEB) (European Commission, 2021). A nearly zero-energy building means that the building must have a very efficient energy performance and that the needed energy should mostly be covered by renewable energy sources generated on-site, or near the building (European Commission, 2020). In December of 2021, the European Commission proposed to revise the directive further, and introduced zero-emissions buildings (ZEB), to make all buildings energy efficient, stipulating that the needed energy must be generated from only renewable sources, without on-site carbon emissions from fossil fuels. The proposition includes all new buildings owned, or occupied, by public authorities by 2027, and all new buildings by 2030.

3

Theory

In this Chapter the theoretical background used to study the European BIPV value chain is introduced. In order to explain the internal and external dynamics of the system relevant theory from the Technological Innovation System and the Multi-level Perspective is first introduced. Afterwards, Value Chain theory is presented to provide context of the approach used in this thesis.

3.1 Technological Innovation System

The Technological Innovation System (TIS) framework provides a model of how innovation is developed and diffused in society, as well as a methodology for how to study the changes that occur (Bergek, Jacobsson & Sandén, 2008). Here, technology, actors, networks, and institutions are all important components of the system (Bergek, Jacobsson and Sandén, 2008; Bergek, 2002; Galli and Teubal, 1997). Jacobsson and Bergek (2004) further suggests that it is essential for a technological system to allow for the following five functions to be served:

1. Allows for creation and diffusion of new knowledge,
2. Guides technology users and suppliers with regard to the growth potential of a new technology and specific design approaches,
3. Allows a creation of positive external economies,
4. Open trade for resilient supply chains,
5. Allows market formation.

3.1.1 Components of the Technological Innovation System

Artifacts and knowledge are both included in the technology (Bergek, Jacobsson & Sandén, 2008). *Artifacts* refer to hardware and software, such as products, design tools, machinery, and digital protocols. *Knowledge* can in turn be shared or located via various channels, such as between the actors of the technological system or embedded within the *artifacts* of the system. Asheim and Isaksen (1996) further suggest that the *knowledge* may come from research-based sources, or from the experience that the actors have gathered themselves.

Actors include all firms and organizations that are active throughout the value chain, as well as all others who may have an influence or interest in the innovation process (Bergek, Jacobsson & Sandén, 2008). In relation to this thesis, *actors* include all producers of BIPV, miners and producers of the metals needed, cell producers, manufacturers of the machines needed to produce the modules, architects, installers of the modules. In other words, everyone who is involved in the life cycle of the product, from raw material extraction to the end user. Moreover, in this thesis the identified *actors* are classified according to their influence and interest in the European BIPV industry, adapted from Corti et al. (2020). *Actors* are classified according to their importance to BIPV producers as well. The *actors* are of great importance for the legitimacy of the TIS, and their involvement and interactions, such as knowledge sharing, are equally important for this (Carroll, 1997).

Networks connect segments and components into a system (Bergek, Jacobsson & Sandén, 2008). The formation of *networks*, which creates a linkage between actors do not appear automatically; the *actors* of the system need to create and encourage the relationship between each other for it to be possible. According to Bergek, Jacobsson and Sandén (2008), there are two types of *networks* that are of particular significance: *learning networks* and *policy networks.* On the one hand, *learning networks* refer to the linkage between suppliers and users, companies and their competitors, and universities that may be of relevance to the industry. Hence, this type of linkage is rather important to be able to share and transfer knowledge (F. Geels & Raven, 2006). On the other hand, *policy networks* use the shared or different beliefs between the *actors* to influence both policies and the political agenda (Bergek, Jacobsson & Sandén, 2008).

Institutions regulate the interaction among *actors*, as well as the interaction between *actors* and the technology in the technological system. This regulation may either be done via *hard regulations*, i.e., controlled by a juridical system, or by *norms* and *cognitive rules*, which are controlled by social systems (Bergek, Jacobsson & Sandén, 2008). Institutional changes are therefore a key process for new technologies, as this is how they advance and develop (Bergek, Jacobsson, Carlsson et al., 2008). Hence, the competition between different technologies (and firms) is not only to gain market segments and increase their revenue, but also to gain influence over the institutions.

x

3.1.2 Technological Development Phases

The components mentioned may be both individual and specific for different systems, but they do not have to be. This is especially true for emerging TIS, since its components have not yet been developed, which leads to a dependency, and overlap, to more established systems (Bergek, Jacobsson and Sandén, 2008; Bergek, 2002; Galli and Teubal, 1997).

A newly formed system starts with a *formative phase* (Jacobsson & Bergek, 2004). This phase is characterized by uncertainty for entrepreneurial actors, investors, and policy makers regarding the technology. There also exists uncertainty regarding the market the technology will act on and the regulations that will apply to it. These uncertainties could create hindrances for new markets to form (Kemp et al., 1998). Additionally, the process of forming the components is a cumulative process of incremental changes, and thus, the formative phase may last for quite some time (Bergek, Jacobsson, Carlsson et al., 2008).

Except for the uncertainties mentioned by Kemp et al. (1998), the *formative phase* is further disadvantaged by hindrances regarding the development of the technology (Jacobsson & Bergek, 2004). For example, there is often a cost disadvantage for new technologies compared to already established ones, as well as blockages by the current technological system for promotion and development of beneficial institutional frameworks. Therefore, the *formative phase* is highly dependent on niche markets, i.e., markets where the new technology is superior. The niche market may act as a protected space for the new technology, allow it to grow, develop, and increase in performance (Erickson & Maitland, 1989). Nevertheless, new technologies are not necessarily limited to one niche market. As the technology diffuses, new niches may be explored (Jacobsson & Bergek, 2004). The niche market does not, however, only act as support to reduce the price and increase the performance of the technology, it also supports and allows the development of all parts and components of the system throughout the value chain.

After all the components have been created and put in place, the technological system shifts from the *formative phase* to the *growth phase* (Carlsson and Jacobsson, 1997). Here, the system may react to externalities and institutional changes in a way that allows the system to evolve and grow. Eventually, the evolution of the technological system allows it to become self-sustaining. This, combined with other positive feedback mechanisms within the system further allows it to shift towards the *mature phase*, characterized by a steady and rigid structure (Bergek, Jacobsson & Sandén, 2008).

3.2 Multi-Level Perspective

Transitions can be understood as changes from one socio-technical system to another, such as the transition from sailing ships to steam ships (F. W. Geels, 2002). These *transitions* do not only involve technologies, but also the society. Since *transitions* influence patterns, behaviors, regulation and even infrastructure, they involve multiple elements and engage with both technologies and society simultaneously. This indicates that there is a co-evolution of technology and society, which can be seen as *system innovations* (F. W. Geels, 2005).

In order to understand what influences the *transition* to a new technological system, attention needs to be placed not only in the internal mechanisms and interactions within the system, as proposed in Section 3.1, but also in the more established external systems that interact with it, as well as the context within which the technological system develops. Therefore, a suitable approach to study system transitions and the evolution of different technologies, as well as their diffusion and adoption, is the multi-level perspective (MLP). The MLP proposes a framework to study the transitions of innovations through the interaction of technology and society (F. W. Geels, 2005). This happens within the context of a *socio-technical system* (STS), which is a system that provides a specific function for society (Bergek, Jacobsson & Sandén, 2008). The MLP presents a nested hierarchy composed of three levels: (i) the micro-level, (ii) the meso-level, and (iii) the macro-level (F. W. Geels, 2002).

The *micro-level*, at which radical innovation is spawned, 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, through a learning process (F. W. Geels, 2005). The next level in the hierarchy is the *meso-level*, represented by the *regime* (F. W. Geels, 2002). The *regime* can be understood as the set of established rules, patterns, and behaviors agreed upon by actors in society around a technology (Rip & Kemp, 1998). These rules can be aggregated in three different groups: *cognitive*, *regulative* and *normative* (F. W. Geels, 2004). Technologies in this level are mature and stable, and at this level, the state of things is maintained. 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; in words of Geels, it involves all "the material aspects of society" (F. W. Geels, 2005, p.684). As the highest level of the MLP, the *landscape* is hard to change and cannot be directly influenced by actors.

The MLP presents a nested hierarchy of these levels, which originates from the constant interaction and embedment between the levels. This interaction results in the levels influencing and affecting each other, as depicted in Figure 3.1. 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 (F. W. Geels, 2002). However, established technologies in the *regime* level can also influence changes in the *landscape* level.

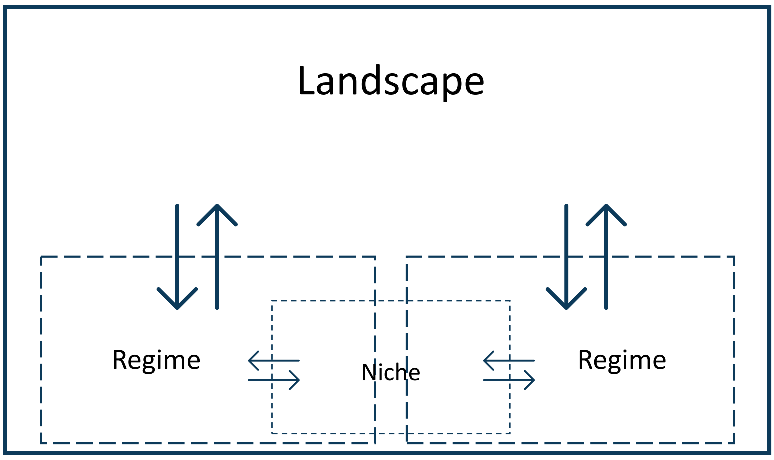

Figure 3.1: Hierarchical levels of the MLP based on F. W. Geels (2002)

3.3 Value Chain

According to Andersson et al. (2021), emerging technological systems may be conceived as a bundle of value chains. The concept of a “value chain” was first introduced by Porter (1985) and is used to describe all the steps and activities needed to produce a product or service, as well as distribute it to consumers, and dispose after usage (Zamora, 2016). It can therefore be seen as a system, compiled by subsystems, where each input, process and output deliver value (Linkov et al., 2020). The activities within the value chain can either be seen as upstream activities or downstream activities. The upstream value chain is commonly closer to activities that use natural resources and inputs, and thus produces primary commodities and virgin materials (Singer & Donoso, 2008). The downstream value chain contains instead activities that add value via manufacturing, customization or services, where the outflow is a final commodity. In this Thesis, however, we will refer to the upstream system as the activities that occur before the production of the modules, and the downstream as all activities that occur after the production, see Figure 3.2.

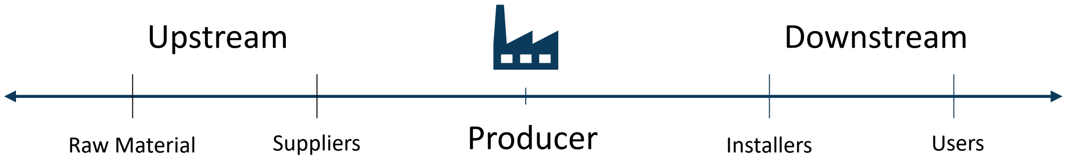

Figure 3.2: Visual representation of the components in a value chain

Value chain theory aims to understand where the value is created (Fearne et al., 2012). Hence, a value chain analysis may be used to identify important activities, such as different production steps, how actors interact within the value chain, and its strengths and shortcomings (Porter, 1985; Zamora, 2016). Value chain analysis may therefore be used to evaluate specific systems within companies, as well as both entire industries and clusters of industries (Zamora, 2016). As more activities of the value chain are being scattered around the globe, where multiple countries and continents are involved, more "global value chains" (GVC) are created. For these, international linkages become important, such as those in which knowledge is shared, since the domestic knowledge may be deemed too limiting (Lall, 1997).

According to Zamora (2016), value chains may be classified with regards to what the driver is, meaning which what actors have the most influence, either the producer or buyer. Buyer-driven chains are more common in labor-intensive industries, e.g., consumer goods industries that are heavily dependent on retailers, merchandisers, and trading companies, such as toys, garments, and consumer electronics. Producer-driven chains are instead characterized by capital intensive and technology-oriented industries, such as electrical machinery, automobiles, and semiconductors. However, independently of what the driver is, every creation and capture of value requires an investment, and are thus also expected to add value to the product or service (Zamora, 2016). Furthermore, since the producer driven value chains are usually characterized by a capital and technology-intensive production, where economic of scale is close to a necessity, they tend to have more barriers of entry than the buyer driven ones (Rodrigue, 2020).

4
Methodology

The following chapter contains a methodological overview of the thesis. It begins with describing how literature and information were compiled. Thereafter, the chapter presents how the companies of the study were selected and how relevant information about them was obtained. As some of the companies were interviewed, the chapter explains how these interviews were conducted and analyzed.

4.1 Acquisition of Information

To acquire background information about the European BIPV value chain, various databases and websites were the main source of information. First, to obtain information about current European regulations and policies, such as information about the Green Deal and REPowerEU plan, the European Commission website[1] was the main source of information. Here, official documents, press releases, and available online information were used.

Secondly, literature and information regarding how BIPV is currently understood and perceived in Europe was mainly gathered from the on BIPVBoost research project[2] and Research Task 15[3] from the IEA PVPS. Furthermore, web-based search engines and electronic bibliographical databases were used to gather and compile information about theory of Value Chains, Technological Innovation Systems, and the Multi-level Perspective. In order to gain a deeper understanding of the theoretical concepts used in this thesis, snowballing and reverse snowballing were also utilized.

This thesis was written in collaboration with the European Solar Manufacturing Council (ESMC), which is an organization representing the interest of the European PV manufacturing industry. ESMC provided a list of European companies producing BIPV. A study by Corti et al. (2020) from the Becquerel Institute in Brussels was further used as a reference to add more companies to the final list of European BIPV producers. By interviewing actors within the companies, information about the upstream and downstream value chain was obtained. The interviews also provided information about the challenges that the industry faces, what the key networks and stakeholders are, and what support that is perceived as required to strengthen the industry in Europe.

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[1] https://commission.europa.eu/

[2] https://bipvboost.eu/

[3] https://iea-pvps.org/research-tasks/enabling-framework-for-the-development-of-bipv/

4.2 Preparation of Interviews

As suggested by Hellin and Meijer (2006), a quantitative approach is preferred when analyzing value chains, such as performing interviews and questionnaires. The companies selected for this thesis consist of producers and manufacturers of BIPV modules, research facilities, and policymakers. During the period between January 2023 and March 2023, 71 companies were contacted and asked to participate in an interview, with the goal to obtain a description of the current European BIPV industry and value chain, from the perspective of multiple producers. Overall, 2 companies rejected to participate in the interview, 46 did not respond to the request, and 23 chose to participate. Except for gathering information by conducting interviews, some general information about the companies was also obtained by revising the company's websites and national company registries.

The main channels to establish contact with the companies were LinkedIn[4], the companies' websites and email. In these channels, founders, Chief Executive Officers, Production Managers, Chief Product Officers and Chief Technology Officers were mainly targeted. For an overview of where the contacted companies were located, see Figure 4.1. Furthermore, in Appendix A, a list of the 71 contacted companies, where they are located, and what they produce, is provided.

Figure 4.1: Overview of the location of European BIPV companies

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[4] https://www.linkedin.com/

The duration of the interviews varied between 30 and 60 minutes and was divided into four different sections. The first section contained questions related to general information about their role in the company and the company, such as the background of the company, what they produce, number of production sites, among others. The next section contained questions related to the value chain and production, e.g., where the production site(s) are located, where the materials and components are sourced from, if they have any challenges within the production, and if they see any bottlenecks in the value chain. The third section of the interview had the goal to get an understanding of the networks of the company, where questions related to partner relationships, funding, and financial support were asked. The last section of the interview included questions related to challenges, such as if they saw any hindrances and barriers to expand, what support would be needed to overcome them, and if there were any specific policies that they would like to see introduced or changed.

4.2.1 Compiling & Analyzing the Result

To compile comparable results from the interviews, the provided information was categorized in accordance with the five different rubrics presented in Table 4.1. The compilation was done by examining the interview notes, as well as going through recordings. To minimize the risk of conformity bias, each author of the thesis started with reviewing the interviews individually. Afterwards, the reviews were compared and merged into one result per interview. When each interview had been merged into one reviewed version, the information from every rubric of all interviews was condensed and aggregated into a final result. To keep the responses from the interviews anonymous, as well as to aggregate the information, Europe was divided into different regions; Northern Europe, Central Europe, Western Europe and Southern Europe.

Additionally, the TIS and MLP theory was used as frameworks to characterize the current status of development and diffusion of the European BIPV industry. The TIS was used to describe the system and its components from an internal perspective. This was done by identifying the technologies and actors involved, as well as the relationships between them. The MLP was used to analyze the broader context in which the system is developing by identifying what other systems interact with the industry as well as the nature of the interactions and how these come to be.

Table 4.1: Rubrics used to compile and structure the result from the interviews

Rubric	Description
General Information	General information about the company and person that was interviewed, such as the company's history, location, when it was founded, generated revenue between 2019 and 2021, number of employees, production capacity and market segment.
Value Chain	Information about components and materials used in the production. This was further categorized in relation to what type of PV system that was being used, i.e., if it was silicon-, CIGS- or perovskite-based cells. Furthermore, information regarding bottlenecks in the value chain, as well as other issues related to the value chain were also summarized here.
Networks	Information about how the company interacts with different actors throughout the value chain. This rubric also included what actors the company perceived as most important, and why they perceived them as such.
Challenges	Information about current challenges that the company faces, excluding the ones that were related to the value. More specifically, the rubric included what barriers there are to further develop and grow the company, expand into new markets, and challenges related to the technology and BIPV itself.
Wants/Needs	Information about what the company needed, or wanted, to easier overcome the challenges and barriers that had been previously presented.

5
Results

In this Chapter, the interviews are used as base to characterize the European BIPV industry within the TIS and MPL frameworks. This is done to understand its current status of development and diffusion. Particularly, the TIS is used to identify internal dynamics of the industry, whereas the MLP is used to analyze external dynamics that currently influence the European BIPV industry.

5.1 The Niche of European BIPV

Using the TIS theory presented in Section 3.1 as an analytical framework, the main technological *artifacts* of the European BIPV technological system are identified as the PV modules that fall under the BIPV definition stated in Section 2.1. However, other identified *artifacts* include all the machines used for the production, testing, and installation of the modules. These modules, as mentioned before, have two main functions: (i) they generate electricity and, (ii) serve as part of the building envelope in multiple ways.

Knowledge includes all the expertise involved in the processes from the extraction of the raw materials, the manufacturing of the BIPV components, manufacturing and design of the modules, and the installation. Furthermore, due to the dual function that BIPV fulfills, knowledge and know-how between the solar PV industry and the building construction industry must be shared in order to successfully implement this PV solution. These two industries must collaborate closely to further develop knowledge specific to BIPV. This specific *knowledge* comes as a result from the merging of relevant best practices from both industries.

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. Due to the dual nature of BIPV, as both electricity generator and a construction material, it can be interpreted that the two *regimes* that the BIPV socio-technical system interacts with are both the electricity generation regime, including conventional PV (PV deployed in land and PV installed as an addition to buildings), and the building construction regime.

During the interviews, European BIPV was recurrently characterized as a niche, due to its specific function. It can therefore be argued that European BIPV founds itself in the niche level of the MLP. This is further supported by the fact that the technology is not mature enough to compete directly on the same level with common construction materials, nor with more widespread PV energy systems, or any other energy source in general. However, many of the interviewees responded that their goal with BIPV is not to compete against more diffused energy sources, but instead aim 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*, as presented in Section 3.1.2. 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 a project. Furthermore, from the perspective of BIPV producers, a lack of awareness from some important actors has been mentioned on multiple occasions, which shows that more knowledge still needs to be developed. Nevertheless, from the interviews, it can be inferred that European BIPV lacks protected spaces to develop *knowledge*, with one of the reasons being that it is usually categorized together with other PV solutions, such as mounted modules and large-scale solar parks, wwhich 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 those of the PV regime are instead applied to BIPV. However, some companies have more standardized processes and ways of working than others. As mentioned in multiple interviews, another reason for the lack of protected spaces in the BIPV niche is the lack of financing and incentives to invest in the industry. Figure 5.1 presents the BIPV niche in the context of the MLP.

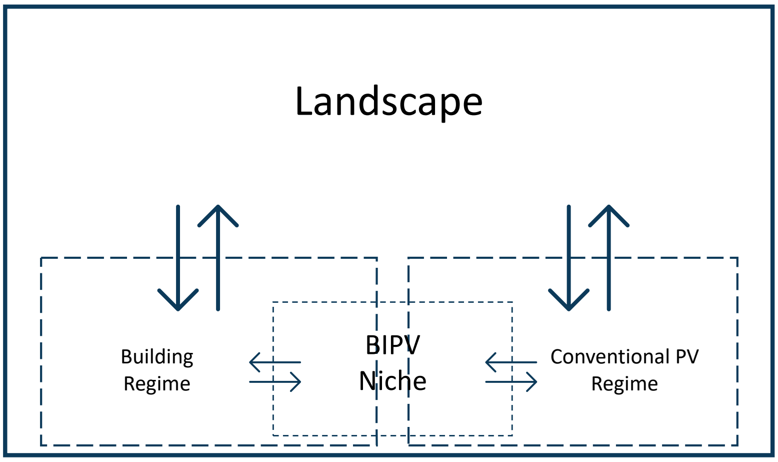


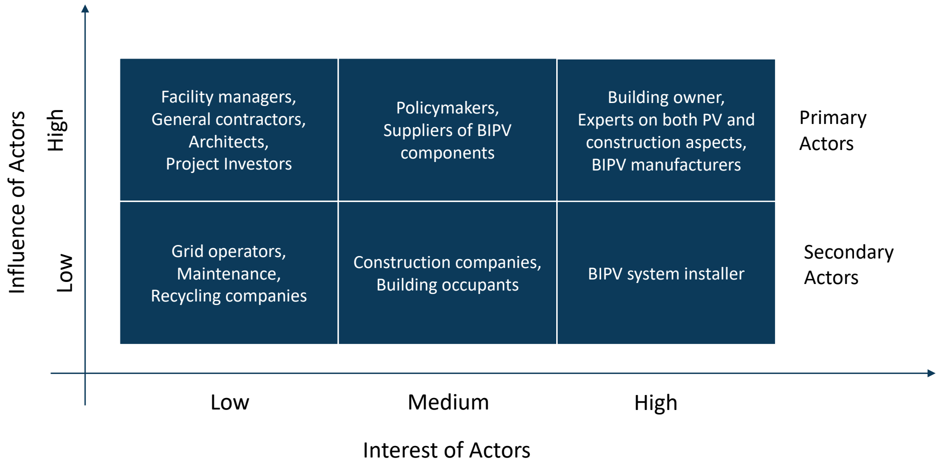
Figure 5.1: MLP characterization of the European BIPV industry

Finally, the broader context in which the BIPV niche and the regimes mentioned above interact, i.e., the landscape, involves the current energy supply infrastructure and the building infrastructure in Europe. It also includes the current environmental, political and societal context, such as the ongoing climate crisis and the global tensions derived from supply chain disruptions, shortages and Russia's invasion of Ukraine. All these factors that shape the landscape are putting pressure on the regimes to transition into new ways of adapting energy generation and the construction of 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 into the regimes is in the form of policies and regulation proposed by the EU, as described in Section 2.3. The interaction between the levels in the nested hierarchy presented is mainly driven by actors with different roles, responsibilities and interests. To understand the dynamics of the socio-technical system, the actors and their networks must be identified.

5.2 Actors in the Technological System

The actors within the BIPV socio-technical system include the producers of silicon and silicon wafers, cell producers, manufacturers of the machinery needed for refining the materials and producing the modules, suppliers of BIPV components, the manufacturers of the BIPV modules, architects, installers of the modules, the end user and owners of the buildings, the grid and electricity providers within the different geographical regions, financing bodies and the relevant authorities that provide the certification and regulation standards for the modules to be approved for installation, as well as research centers and universities where research projects relevant for the artifact are performed. Depending on the knowledge the actors process, their interest, the activity they perform, and proximity to the end user, different degrees of importance and influence may be assumed.

In Figure 5.2, actors are classified according to their level of influence and interest regarding the development of the technology and its implementation, based on the classifications by Corti et al. (2020). The influence that these actors possess depends on their power to provide support for the development of the BIPV technological system, resulting in "primary" and "secondary" actors. In this classification, "primary actors" are those with a high influence and "secondary actors" are those with a low influence. The actors with the highest level of influence and interest are the building owners, the PV experts and experts on construction aspects. Furthermore, the interest relates to the urgency of the actors in developing and supporting the BIPV TIS. The classification presents three levels of interest for actors: low, medium, and high. The level of interest depends on how much an actor would be benefited from the diffusion of BIPV.



	Low	Medium	High	
High	Facility managers, General contractors, Architects, Project Investors	Policymakers, Suppliers of BIPV components	Building owner, Experts on both PV and construction aspects, BIPV manufacturers	Primary Actors
Low	Grid operators, Maintenance, Recycling companies	Construction companies, Building occupants	BIPV system installer	Secondary Actors

Figure 5.2: Classification of actors regarding their influence and interest of BIPV, based on Corti et al. (2020)

When asking the companies who their most important partners and stakeholders are, the most mentioned actors were the governments (local and European), investors and banks, research centers, institutes and universities, construction-related companies, such as roof and façade producers, architects, and installers. Other important actors that were less mentioned were PV and BIPV industry associations, final customer, suppliers (other upstream businesses), and laboratories.

Important factors for the successful development and diffusion of any technology are the networks and relationships among the actors within the TIS. In the case of European BIPV, and from the perspective of the BIPV producers, the key networks and actors were identified in the interviews as presented in Table 5.1.

Table 5.1: 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

Overall, some of the actors were mentioned in different occasions by the companies, which reveals their importance and the relevance of that relation for the BIPV producers. Despite some actors being mentioned by different companies, it does not mean that the relationship with that actor is the same for all companies. For example, the relationship with the government or the European Union, is of importance for some companies in the context of testing and certification as well as research of BIPV modules, while for other producers this relationship was important due to financing and development support. Some other actors, especially those grouped under "Planning and Installation" were important for less varying reasons. For example, they have a closer relationship and involvement in the processes related to the downstream value chain, and it could be noted that their interest and influence on the diffusion of BIPV are either medium or high, as shown in Figure 5.2.

5.3 European BIPV Industry Analysis

The previous section describes the networks of the socio-technical system from the perspective of the European BIPV producers. In this section, the industry is analyzed by describing the producers and their activities. Value chains for different cell technologies are presented, as well as challenges related to the up- and downstream value chains of the producers. As stated in Section 4.2.1, the responses from the interviews are kept anonymous. Therefore, to obtain an aggregated perspective of the European BIPV industry, Europe has been divided into the following regions: Northern Europe, Central Europe, Western Europe and Southern Europe. The countries composing each of these regions, and the number of companies included in these, can be seen in Figure 5.3.

A total of 71 European BIPV companies have been analyzed in this thesis, and can be found in Appendix A. 31 of these companies are located in Central Europe, which makes it the region where most of the companies are located. 18 companies can be found in Western Europe and 13 in Northern Europe. The region with the least companies was Southern Europe, containing only 9 known companies. By taking the system categorization from Section 2.1.2, it was identified that 54 of the companies produce roof BIPV, 39 façades and 35 external integrated devices (EID). However, some of the companies also produce multiple of the categories, or all of them. The data gathered for describing the size of the industry (number of employees, revenue and production capacity) does not consider all 71 companies, but only those for which the data was available.

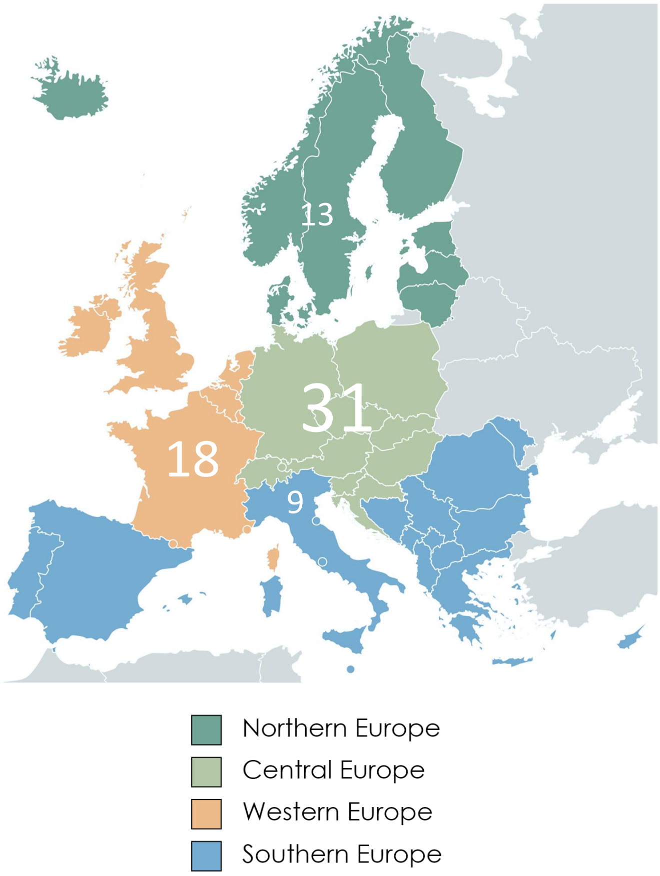


Figure 5.3: Overview of the location of European BIPV companies by region

The companies producing BIPV in Europe differ greatly in size, as can be seen in Figures 5.4 - 5.6. The largest company has 810 employees, while the smallest producer only has three. Although the average number of employees is 84 employees, the median is 30 employees.

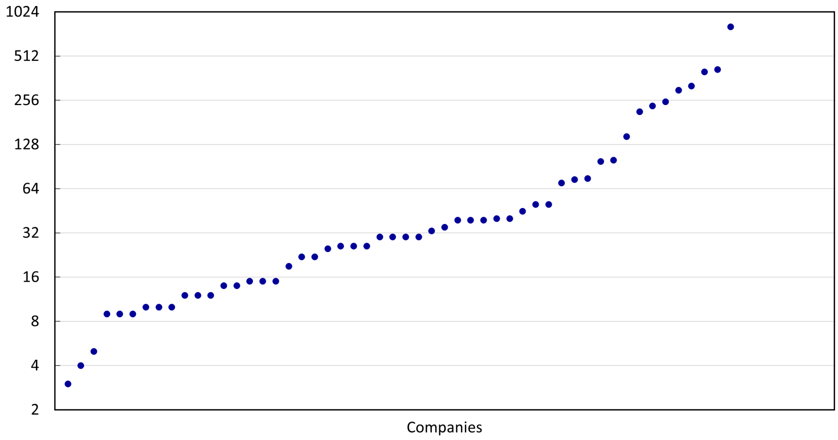


Figure 5.4: Number of employees per company of the 52 companies' data was acquired for

The size difference is also reflected in the revenues, as seen in Figure 5.5. While the lowest revenue of any company in 2021 was €4 250, the company with the highest revenue reached €46

800 000. The average and median revenue for the year amounts to €8 287 732 and €1 572 438, respectively.

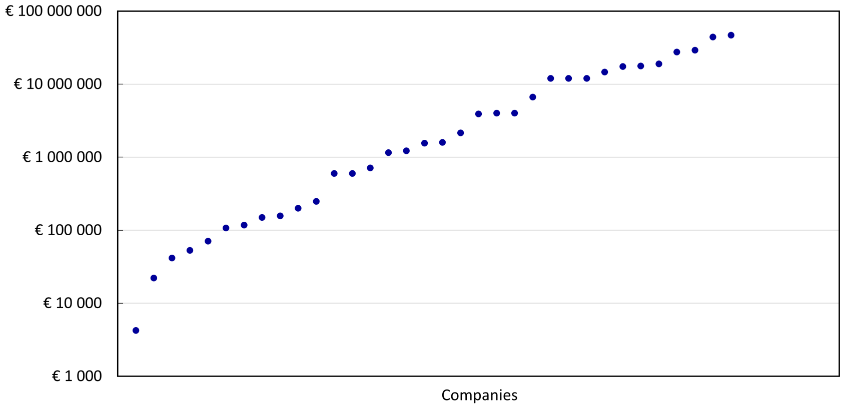


Figure 5.5: Revenue in 2021 per company of the 34 companies' data was acquired for

The production capacity of the companies varied greatly, as can be seen in Figure 5.6. Although, the producers measure their capacity different in units; some companies measure their production capacity 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 more as a construction material. In terms of MW, the largest capacity was found to be 400 MW/a, while the company with the lowest capacity can produce 2 MW/a. On average the companies manage a capacity of 100 MW/a, and a median capacity of 40 MW/a. Regarding m^2, the largest capacity was 300 000 m^2/a while the lowest is 10 000 m^2/a. The average capacity was 121 000 m^2/a, while the median capacity was 60 000 m^2/a. However, some of the companies mentioned that they often produce only at a share of their maximum capacity potential. The reason for this was a fluctuation in demand for BIPV. For the companies that measure their capacities in MW, the total combined yearly capacity was 1 693 MW/a, while for the companies who measure in m^2 the total combined yearly capacity reached 605 800 m^2.

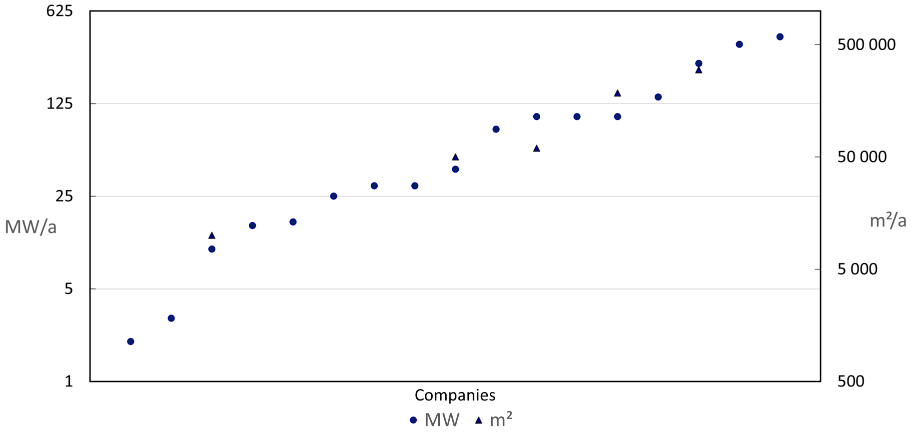


Figure 5.6: Yearly production capacity of the 22 companies' that were willing to share data

To describe the current value chain of European BIPV, the upstream value chain has been classified and categorized by type of cell technology used: silicon cells, CIGS cells, or perovskite cells. However, with regards to the challenges and opportunities in the downstream value chain, the results are considered to be more coherent, thereby, it has been determined that such categorization is unnecessary.

Furthermore, the value chain characterization will start by describing the upstream value chain for silicon BIPV, describing the origin of the components used. Then, the same is made for CIGS- and perovskite based BIPV. It is, however, important to notice that the information gathered about each company's value chain, and the components and materials used, was not consistent, and the number of answers regarding each material and component may thereby vary. Nevertheless, to provide an aggregated overview of all the cell technologies, and their dependency of different countries, Figure 5.7 shows a color graded map of where the dependence is more concentrated; darker color indicates a stronger dependency. As can be seen, China is the country that Europe is most reliant on when considering all components of the European BIPV value chain.

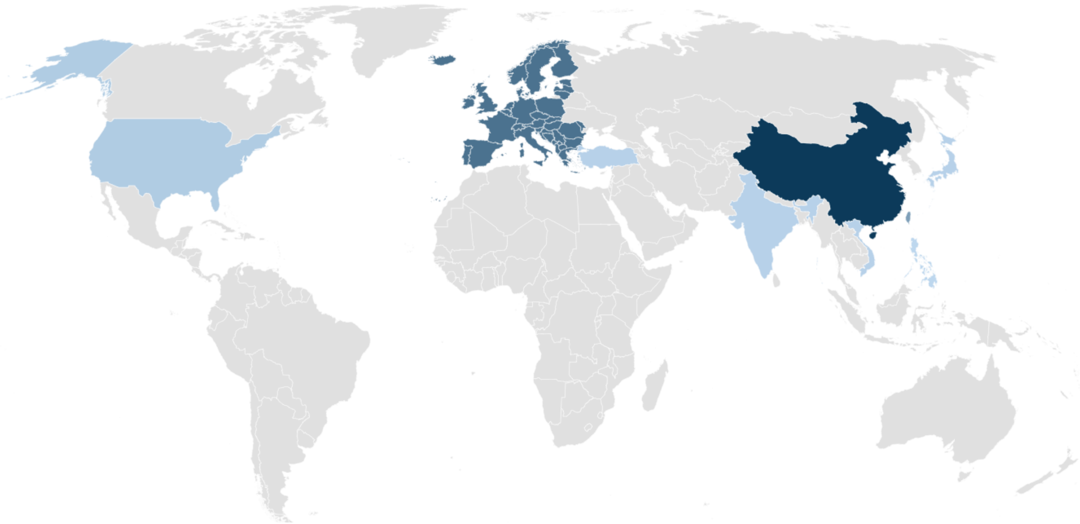


Figure 5.7: Visual representation of the countries that contribute to the European BIPV value chain

5.3.1 The value Chain of Silicon Based BIPV

As mentioned in Section 2.1.2, silicon is the second most abundant material in the Earth's crust, and the most common cell technology used for solar PV globally. Regarding BIPV, the same trend can be seen as well. Of the 71 contacted companies, 51 used silicon as their cell technology, and from the 23 interviewed companies, 16 used silicon cells.

Figure 5.7 shows that the aggregated European BIPV value chain is strongly dependent on China, which is also the case for silicon BIPV. From the interviews, China was mentioned as a supplier for 80% of the silicon cells. Furthermore, with regards to junction boxes and encapsulants, 67% and 63%, of the responding companies, respectively, stated that they source these components from China as well. Glass, however, is not as dependent on China as the rest of the key components; only 27% of the of the provided statements mentioned that they source the glass from China. Taiwan is also a rather important source of silicon cells, as 38% of the producers mentioned that they source their cells from Taiwan, whereas 44% use both China and

Taiwan as suppliers. Furthermore, producer in Northern Europe sources silicon cells from other countries as well, such as the USA and Philippines.

The glass used by silicon-based BIPV producers is mainly acquired from European countries, as 36% of the companies stated that they source it from either Belgium, Germany, Italy, Spain, or the Netherlands. Apart from Europe and China, other suppliers that were mentioned were located in Turkey, which provides 18% of the companies with glass, and in Vietnam and India, each providing to 9% of the producers.

As previously stated, 67% of the responding companies stated that they obtain their junction boxes from China. Except for one who sourced it from Taiwan, the remaining (all located in Northern Europe) reported sourcing it from a European country, although not specifying from which one. In addition, one producer who is also located in Northern Europe, and is currently sourcing their junction boxes from China, stated that they used to buy this component from Germany, but since the supplier closed its operations, this was no longer an option

The encapsulants used are sourced mainly from non-European countries. China and Taiwan provide 63% and 13%, respectively, of the silicon based BIPV producers with encapsulants. Only 25% of the provided answers (all from producers in Southern Europe) stated that they obtain it from a European Country, e.g., Spain.

Other components mentioned during the interviews were backsheets, wires and foil. The backsheets were only mentioned to be sourced from China, although only two companies could provide the origin for this component. The origin of the wires varies, as China, Finland, India , and Taiwan were mentioned as suppliers. However, the producer who mentioned Finland also said that they would soon shift to China as well, due to a specific product demand. Lastly, the origin of the foil also varies. From the interviewees who mentioned foil, China and Europe (not specified which country) were the most common countries, whereas India was also mentioned by one.

5.3.2 The 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 cell technology. Out of these nine companies, three agreed to participate in the study. Moreover, two of the contacted companies use perovskite cells, whereas 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. Therefore, it was only possible to obtain information about the cells, junction boxes and encapsulants. One of the companies produces the CIGS cells themselves. However, the materials used for the cells are sourced from either Europe or Asia. The other two companies currently acquire their cells from the USA, whereas one of them is planning to change to a producer located in France within 2-5 years.

Although one of the companies stated that solar graded glass is hard to obtain in Europe, they did source 50% of it from Europe, whereas the remaining 50% comes from China. As for junction boxes and encapsulants, all answers stated that they source it from China. However, due to supply chain issues of encapsulants, and because expiration is a factor to value in, one of the companies is currently evaluating the feasibility of changing to a European supplier instead.

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 not specified which parts, the producer did mention that some specific parts were obtained from a Japanese supplier.

5.3.3 Upstream Challenges of European BIPV

One challenge, or issue, that was mentioned throughout the interviews, was that although the producers wanted to source the materials from Europe it is not currently possible. This is not only due to 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 due to shorter transportation distances. Moreover, during the interviews, 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 inquired volumes are too small to allow for economies of scale.

Another challenge mentioned by multiple interviewees is the lack of control that they have when purchasing and sourcing materials, specifically silicon cells. Some interviewees stated that they perceive that the quality of the cells they receive does not match what they ordered, which is mainly due to more relaxed laboratory standards in China. At the same time, they do not have any other options since the silicon cell market is currently rather concentrated to a few countries.

5.3.4 Downstream Challenges of European BIPV

When asking about the challenges that the companies are currently facing, most refer to challenges that appear in the downstream part of the value chain, i.e., after the module has been produced. One such challenge is the general lack of awareness of BIPV in Europe, which was mentioned in connection with various actors, including installers, architects and policymakers.

Firstly, in relation to installers, several producers expressed that there is a difficulty for obtaining qualified installers, which further hinders the diffusion of BIPV. Although, it was not mentioned as an issue by all producers. This could be because some provide the installation themselves and others have stronger relations with the building sector. For some producers another issue is that the final cost of a BIPV project increases considerably due to installers and subcontractors, resulting in the final price becoming too expensive for the final customer. One interviewee stated:

> *"In the beginning our offer was around €200 000, but then due to sub-contractors, and sub-sub-contractors, and by the fact that it looks like glass but is not, they put on a large margin. So, in the end, the cost reached around €2 million."*

Secondly, multiple companies further expressed a general lack of knowledge in the architectural sector, especially those who do not have a relationship with architectural firms. As previously mentioned in Section 5.2, we propose, in accordance with Corti et al. (2020), that architects are a primary actor, with a high influence.

Lastly, during all interviews, independently on 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. For example, BIPV must comply with both the PV regulations and building regulations which both differ throughout Europe, but also throughout local regions in countries; there is no standardized regulation for BIPV in Europe and it is unclear for some actors if it is a PV system, building material or both. This misconception is further confirmed by the fact that some companies view BIPV solely as either a PV system or a building material. From the companies for which the production capacity was available, 17 measure their production capacity in megawatts, whereas six measure it in square meters. From this, it can be interpreted that they perceive BIPV differently, and thus acts on different markets.

The lack of awareness can further be seen in other aspects. 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 because of a lack of understanding from investors, and that it may be considered too risky. Because of this, two companies have been pushed to close their production in Europe and move it to China or the US, where better support mechanisms exist for the technology, such as the Inflation Reduction Act (IRA). Additionally, when asked about future production expansion, two companies expressed that they were currently looking into shifting their production to China, mainly due to the lower production costs.

5.3.5 What the Industry Wants

From the previously introduced challenges, the interviewees further expressed what they believe is necessary to overcome the challenges, as well as what they believe is required to create a stronger domestic BIPV industry. Firstly, it was mentioned that it is necessary to create more knowledge and awareness of BIPV, as the lack of it is what creates most (if not all) challenges in the downstream value chain; although no one expressed how this knowledge and awareness should be created. However, two actors specifically mentioned where more understanding is needed: architects and governmental entities. Moreover, with an expanded knowledge of the BIPV sector, this could further result in a more harmonized standard for BIPV in Europe, which is currently non-existent.

Secondly, to create a stronger domestic value chain, the producers said that they require long-term support. The continuous changes in regulations and funding programs make it harder to create a long-term plan for production. Here, it was mentioned that the current European import tariffs hinder producers, as they only target components, and not the modules. For example, glass is subjected to import tariffs, while finalized modules are not. From a cost perspective it therefore becomes more attractive to buy foreign modules than to produce it locally in Europe, hence, creating a disadvantage for European producers. Moreover, to have the same requirements regarding environmental impacts and working conditions for imported goods is further believed to strengthen the competitiveness of European production. Additionally, Europe needs to create a strong domestic value chain that contains all steps, not only the production, as this otherwise only pushes the issue further up in the value chain; the dependency on non-European countries is the same.

Finally, the current regulations for building aesthetics in some European regions heavily benefit roof mounted PV, and some producers therefore expressed that it is necessary to implement the same aesthetics requirements for both roof mounted PV and BIPV.

6

Discussion

In this section, the strengths and shortcomings of the thesis are presented and the results of the analysis of the European BIPV industry are discussed. Further, the strengths and weaknesses of the presented European policies are described. Lastly, BIPV-specific regulations and opportunities are also proposed in order to address the discussed weaknesses of the presented European-policies.

6.1 Strengths & Shortcomings of the Study

The results of this thesis provide information about the current European BIPV value chain. The focus is on the upstream part but also certain aspects of the downstream part is addressed. It takes into consideration the different actors, cell technologies, and policies. However, the sample size of contacted producers is limited, especially for CIGS- and perovskite-based BIPV. The total number of companies included in this thesis was 71, whereas 51 uses a silicon cell technology, nine used CIGS cells, and two used perovskite cells. The study is therefore somewhat angled towards producers of silicon-based BIPV and their perception of the European BIPV market.

However, as previously mentioned, silicon cells is the most used cell technology in the PV market, which makes the division of producers in this study, based on cell technology, far more diverse than the global average. Nevertheless, two of the producers included in this study uses the Cadmium telluride (CdTe) cell technology, and one uses organic cells. For these three, no interviews have been conducted, and no data about their value chain is thus available. The companies who were included in this study, and participated in the interviews are, however, located in different European regions. The results are therefore considered to be of good representation regarding how the different countries in Europe perceive the domestic BIPV value chain.

Furthermore, although 71 companies were contacted, only 23 (31%) chose to participate in the study. This evidently leads to a rather narrow sample size, and biased results could therefore be expected, especially regarding those cell technologies who are not silicon-based. The results of this thesis would therefore benefit from a larger sample size of contacted and interviewed companies. However, of the remaining 48 companies, two declined and the rest did not respond when contacted. Therefore, it may be interpreted that there was a lack of interest to participate in the study, which results in that their perspective and knowledge cannot be included.

To obtain information about the individual companies' value chains, the interviews were the main source of information, whereas to obtain general information about the companies, such as revenue and number of employees, the companies' website and national company registries were the main source of information. However, the governmental registries varied a lot. Information about companies in Northern Europe, Germany, Greece, the UK, Lithuania, Estonia, and Poland was publicly available, without any payment required. Whereas information about companies located in the Netherlands, Belgium, Austria, Switzerland, France, Italy, Spain, and Romania was not easily available. Either the information was not publicly available, or a national identification number of the country was needed. Moreover, depending on the country, the publicly available information about the companies also varied, as smaller companies in e.g., Germany, are not obliged to share their revenues. Hence, the result section where the revenues, number of employees, and production capacity is presented, does not take into consideration all the companies included in the study. Some regions might therefore be unevenly represented.

Furthermore, it is important to note that all interviews are subjective, due to the nature of the conversation; all questions that have been asked might not have been interpreted in the same way by all interviewees. Additionally, due to the structural coherence and progression of each interview, the follow up questions varied as well. Which in turn leads to some more elaborated answers than others.

6.2 Comments on BIPV industry in Europe

The dependence of the European BIPV industry on non-European countries is discussed with the perspective of the respective cell technology used by the producers. Furthermore, the importance of the knowledge development for the diffusion of the technology is presented as well as its relation to the actors identified.

6.2.1 PV Cell Technology Matters

The results from the value chain analysis indicate that the reliance on different countries varies depending on the cell technology used. CIGS based BIPV is not as dependent on non-European suppliers to the same extent as silicon-based BIPV is. The sample size of CIGS producers is, however, a lot smaller than the one for silicon producers, which could affect the robustness of the findings. Nevertheless, the results for the silicon-based BIPV reveal that China is the most dominant supplier for most of the key components, including the silicon cells, junction boxes and encapsulants. It can therefore be argued that the current European BIPV value chain is heavily dependent on one single country, namely China. This dependency exist not only for silicon-based BIPV, but for most PV (McKinsey & Company, 2022). As presented in Section 2.2, most of the upstream value chain for silicon PV is highly dependent on China.

A similar argument can be made for CIGS-based BIPV, as most of the producers mentioned non-European suppliers for their components. One key difference is that the cells used in CIGS-based BIPV do not originate from China, but instead from the USA and Europe. Consequently, although these value chains have some dependency on non-European countries, they seem to be less dependent than the silicon-based one. However, it is worth mentioning that this thesis does not take volumes into consideration when evaluating the dependency, only where the components and materials are sourced from. Therefore, the company that sourced their silicon cells from the USA and Philippines could, theoretically, import more than what is currently sourced from China. Nevertheless, this does not change the fact that the current European BIPV industry is heavily dependent on foreign producers, only which country it is the most dependent on. Furthermore, although the current value chains are dependent on foreign producers, the interviews also indicate that there is a desire to rely more on locally produced materials and components. However, due to the current mismatch, as presented in Section 5.3.3, this is not possible. This clearly indicates that there is a strong need to strengthen the domestic upstream BIPV value chain, with a special emphasis on developing and expanding the production of components and materials.

The strong dependency on foreign producers, especially China, is partly derived from the economies of scale achieved in the country, which has been accomplished by support from the Chinese government to the domestic PV manufacturing value chain for more than a decade. As suggested in Section 3.3, this further creates barriers for other producers to enter the market. Hence, more investments may be crucial to reach a European economy of scale, which could be considered essential if the European upstream value chain should become competitive.

6.2.2 Catalyzing BIPV with Knowledge

The most important actors, from the perspective of BIPV producers, are those that provide knowledge about certifications and standards, financing, research, and support with the implementation of BIPV projects. Based on this, it may be proposed that focus should be put in these relationships in order for the European BIPV industry, and especially the manufacturing, to develop and expand.

As the niche of European BIPV interacts with the two regimes: the Conventional PV regime and the Building regime, as mentioned in Section 5.1, it is suggested that the industry relies heavily in expertise from both the PV industry and the building industry, and the combination of these is an important factor for a successful implementation and diffusion of BIPV in Europe. The combined knowledge of these industries might result in a specific BIPV expertise, as well as more defined roles and responsibilities for the different actors involved throughout the value chain. This specific expertise could be developed in protected spaces for the BIPV niche. The development of the expertise would depend on both the degree of interest and influence of the actors (Figure 5.2), as well the interactions among them. Without specific efforts from the actors, the knowledge will likely not be developed. This is especially important for those actors in the Planning and Installation group from Table 5.1, which are directly involved in the planning and installation of BIPV and are of great importance from the perspective of the BIPV producer.

Due to the different perceptions of BIPV as either a PV system or a building material, an industry-wide agreement on a definition of BIPV could be a good starting point to bring consensus to the industry. This could serve as an important step in the development of knowledge within the industry and with this, the technology could become clearer to both actors within the system and outsiders, thus supporting its diffusion. The idea behind this is that if the technology is defined universally and easy to understand, it might be simpler for all actors to interpret and adopt it.

6.3 BIPV Policies

This section comments on the policies proposed by the EU and that are introduced in Section 2.3. First, the strengths of the policies that are relevant for BIPV are highlighted and then their shortcomings are commented on. Additionally, proposals for policies and regulations specific for BIPV are presented.

6.3.1 Strengths of EU Policies

As presented in Section 2.3, the European Union has shown a clear and strong interest in transitioning towards a low carbon economy, supporting the development of domestic production for key net-zero technologies, and cutting the dependency on foreign energy. To achieve this, several policies have been put forward. The starting point is the EU Green Deal, which sets the base target and framework from which other policies part from.

For instance, the Fit for 55 package aims for Europe to become the first climate neutral continent by 2050 and reduce domestic greenhouse gas emissions by 55% by 2030. Some areas included in this package that are relevant for BIPV are renewable energy, energy efficiency and the energy performance for buildings. BIPV could therefore be perceived as an attractive option for the reduction of emissions by buildings, especially for new buildings. The package also supports the installation of solar energy in buildings by stating that solar energy must be installed on all new public and non-residential buildings with a useful floor area larger than 250m^2 by 2027, for all existing public buildings in 2028 and for all new residential buildings by 2030. This requirement will increase the demand for PV in the build environment. However, since no policies are currently exclusively targeting BIPV, and since conventional PV is generally cheaper and more established, the policy will most likely be more beneficial for conventional PV, than for BIPV.

The REPowerEU plan is another important policy from which European BIPV could benefit from, as it proposes a solar energy strategy to increase the European solar energy capacity. The EU Solar Energy Strategy included in this plan is aimed at all types of solar energy. BIPV could benefit particularly from the European Solar Rooftop Initiative included in the strategy, as well as from the shortening of the permitting procedures for solar deployment. Additionally, the EU large-scale skills partnership has the potential of supporting the development of knowledge for European BIPV if relevant actors are included; the BIPV industry could benefit from this if actors with medium and high interest are included in multidisciplinary skill development and knowledge-sharing programs, such as those presented in Figure 5.2.

The Green Deal Industrial Plan can directly support the development of the European BIPV production capacity, as its aim is for Europe to build and increase its capacity in relevant key technologies that support the achievement of the European climate goals. This plan could be used to close the gap between the cutting-edge technology research and development done in Europe and production of these technologies.

The Energy Performance Building Directive could be taken as an opportunity to deploy BIPV in buildings that require renovation as well as in new building projects. The aim is that buildings in

Europe become nearly zero-energy buildings, meaning that most of the energy that they demand comes from renewable energy sources, resulting in a decarbonized European building stock by 2050. BIPV could seize this opportunity and turn energy-passive areas of these buildings into energy sources. Due to the adaptability of BIPV, these areas could be either roofs, façades or other parts of the building envelope.

6.3.2 Weaknesses of EU Policies

The goals the EU has set in relation to the transition towards clean energy sources are quite ambitious and this is reflected by the policies implemented and proposed. However, these policies do come with some shortcomings. It has been mentioned by some of the BIPV producers that the EU policy mechanisms are rather complex and hard to understand, which hinders the possibility for a smooth implementation. Another shortcoming that adds upon the complexity of the European policies is that, while ambitious and relevant, the policies sometimes lack an implementation plan, i.e., how to reach the targets. Additionally, the coordination between EU and Member States could be complex, as different Member States could implement the policies in different ways and paces, as well as have different interests and preparedness in regard to the transition towards an emission-free energy sector.

The Member States' different ways of working and regulating of the generate a disadvantage to BIPV when compared to conventional PV. An example of this is related to aesthetic regulations in some regions. During the interviews, it has been mentioned that since BIPV is part of the building envelope, some European regions have stricter aesthetics standards for these modules to follow when a building is being constructed. These aesthetic standards do not apply to conventional PV modules, despite often times being perceived as less aesthetically pleasing than BIPV. However, it must be underlined that this is only an issue for some countries and only in some regions.

Regarding standards and certifications, BIPV products must comply with both PV and building requirements. This is perceived differently by different BIPV producers in Europe. For some, this presents no difficulty, while other producers sometimes find it difficult and time consuming, especially regarding the building requirements. A European-wide regulation, or framework, for minimum requirements of BIPV could be a potential solution for this. A guideline like this could provide minimum requirements aimed specifically at BIPV that include both PV and buildings aspects. Member States could then add specific requirements to it depending on their national regulation. This could make it easier for producers to certify their products regardless of their target market within Europe. However, a guideline like this could be hard to create and it could potentially make it easier for non-European producers to enter the European BIPV market. One way to protect European-made BIPV would be to propose stricter quality regulations, as it is sometimes perceived by BIPV producers that European quality for modules is higher than that of non-European countries, despite the fact that both European and foreign modules must fulfill the same quality requirements. This perceived difference in module quality could stem from a variation of performance of the quality tests at the laboratories; stricter quality standards for modules could provide less variation in laboratory performance.

Existing policy regarding import tariffs create another disadvantage for European BIPV producers, and European PV producers at large. Currently, some of the components needed for the modules, e.g., glass, are subjected to import tariffs, while importing the finalized modules does not include any tariff on neither the whole product nor the specific components. Buying foreign modules can therefore be more attractive from a cost perspective, which, in turn, evidently hinders European manufacturing of modules. Implementation of policy regarding these tariffs could result in making European suppliers more attractive to producers from an economic perspective.

6.3.3 Make European BIPV Shine and Thrive

In order for the niche of European BIPV to take advantage of the pressure put on the regime by the landscape through policies, the gap between these policies and the needs of the industry must be narrowed.

As BIPV presents itself as a good option to contribute to the climate and energy independence goals of Europe, a EU manual that explains clearly how to take advantage of these policies and incentives could prove to be useful for all relevant actors involved in the BIPV industry, especially producers and investors. This could tackle the current complexity of the policies perceived by some of the actors and could be seen as a starting point close the gap between needs and the opportunities presented.

As mentioned in Section 6.3.2, a European-wide regulation for minimum requirement for BIPV could prove useful to set the base of what certificates and regulations producers must follow. This would make it easier and possibly faster for BIPV producers to offer their products on any European market, consequently supporting the diffusion of the technology in Europe. The EU-wide regulation should be based on a universal definition of BIPV agreed upon by the actors within the industry. The combination of the universal definition with the regulation would also allow for an easier understand of what the technology is among internal and external actors.

Although a universal EU regulation for BIPV could make it easier for non-European competitors to enter the market, stricter quality regulations for BIPV and import tariffs could protect the European industry. An example is the policy on CO_2 import taxes for products manufactured outside EU that has been discussed to be implemented (ETIP Photovoltaics, 2023). The current import tariffs that target components and not PV modules could also be revised to not only protect European manufacturers of the components but also the producers of the final product. However, the implementation of an import tariff on modules would increase their overall price, which could result in PV becoming a less attractive and thus potentially affecting the accomplishment of the EU Solar Strategy goals of 600 GW_{AC} in 2030. Because of this, specific policies must be implemented to develop the domestic value chains to the level that they reach economies of scale, and the Green Deal Industrial Plan for the Net-Zero Age is a good initial framework to support this development.

7

Conclusion

The silicon cell technology is the most dominant technology used in European BIPV modules. Overall, the 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 mostly sourced from European countries. Hence, the European silicon BIPV producers are highly dependent on imports, especially from China. Other cell technologies used in European BIPV are, for example, CIGS and perovskite cells, where CIGS is the more common of the two. Although most of the producers of these technologies for BIPV 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, the results clearly indicate that it would be beneficial to strengthen the BIPV domestic upstream value chain, to ensure a resilient industry that is less dependent on imports.

Furthermore, although the majority of the producers currently imports most of their components, there is a strong interest to source them from Europe. However, due to the specific requirements of the producers, and higher domestic prices, a mismatch between the producers and suppliers of materials and components exists. Hence it is currently not an option for many of the producers even if the will is strong. This mismatch could be counteracted by implementing policies that aim at expanding the domestic production capacity of material and components, such as those included in the Green Deal Industrial Plan for the Net-Zero Age, i.e., faster access to funding, a simplified regulatory environment, and enhanced expertise for all actors within the European BIPV industry.

The downstream value chain contains different actors, who are all of importance for the development and diffusion of European BIPV, such as investors, policymakers, architects, and installers. It has been identified from the interviews that there is a widespread lack of knowledge and awareness regarding BIPV, which further creates challenges when developing and diffusing the technology. More specifically, the lack of awareness of BIPV makes it more difficult to secure funding. Some interviewees mentioned that the investor's lack of awareness and understanding of BIPV results in an impression that the European industry is too risky to invest in. Because of this, barriers are created that do not only hinder the development of European BIPV, and its domestic value chain, but also pushes producers to expand elsewhere, such as in the US and China.

Moreover, except for a lack of knowledge, another recurring challenge stated by the interviewees is the that in order to certify BIPV, and be able to sell and install them, producers have to comply with both PV regulations and building regulations. Although the PV regulations are consistent throughout the EU, the building regulations vary depending on the region. This creates a time-consuming and complicated certification process which makes it harder for some producers to expand into new markets. Therefore, an EU-wide dedicated and standardized regulation for BIPV could ease and simplify the certification process. However, a simplified process 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.

Future studies regarding the European BIPV industry would benefit from focusing on processes further up in the value chain, namely in the production of the components for the modules and the raw materials used. A greater diversity of cell technologies, as well as a larger sample of European producers, would also be beneficial for a more robust study of this topic. Further studies of this industry could also focus deeper on the dynamics of the networks between the actors. This thesis has proposed policies of interest, however more detailed policy instruments and mechanisms, as well as how to implement them, could provide useful information to strengthen the domestic value chain of BIPV.

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A

Appendix: Companies Included in the Thesis

A.1 Companies in Northern Europe

	Name	Country	Category
1.	Dansk Solenergi Aps	Denmark	Roof, façade
2.	InfinityPV ApS	Denmark	N/A
3.	Ennogie	Denmark	Roof
4.	Virte Solar	Finland	Roof
5.	Innos AS	Norway	Façade
6.	Tarpon Solar AS	Norway	EID
7.	Midsummer AB	Sweden	Roof
8.	Solarstone	Estonia	Roof tiles, EID
9.	Roofit Solar Energy OÜ	Estonia	Roof
10.	Intelligent Solar	Lithuania	Roof, façade
11.	Metsolar	Lithuania	Roof, façade
12.	SoliTek Cells JSC	Lithuania	Roof, EID
13.	ViaSolis	Lithuania	Roof, façade, EID

A.2 Companies in Central Europe

	Name	Country	Category
1.	Antec Solar GmbH	Germany	Façade, EID
2.	Grenzebach Envelon GmbH	Germany	Façade
3.	Sunovation Produktion GmbH	Germany	Façade, EID
4.	Autarq	Germany	Roof
5.	Meyer Burger GmbH	Germany/Switzerland	Roof
6.	Heliatek	Germany	Roof, façade, EID
7.	Sunset Energietechnik GmbH	Germany	Roof
8.	Galaxy Energy	Germany	Roof, façade, EID
9.	SolteQ	Germany	Roof
10.	ASCA GmbH	Germany	Roof, façade, EID
11.	AVANCIS GmbH	Germany	Roof, façade, EID
12.	Sonnenkraft GmbH	Germany/Austria	Roof, façade, EID
13.	Aleo solar GmbH	Germany	Roof
14.	SOLARWATT Innovation GmbH	Germany	Roof, façade, EID
15.	Ertex Solartechnik GmbH	Austria	Roof, façade, EID
16.	MGT-esys GmbH	Austria	Roof, façade, EID
17.	Kioto Photovoltaics GmbH	Switzerland	-
18.	Flisom AG	Switzerland	Roof, façade
19.	Glas Trösch Group	Switzerland	N/A
20.	SunStyle AG	Switzerland	Roof
21.	KROMATIX	Switzerland	Façade
22.	3S Solar Plus AG	Switzerland	Roof, façade, EID
23.	Gasser Ceramic	Switzerland	Roof
24.	Solaronix	Switzerland	Roof, façade, EID
25.	Sunage	Switzerland	Roof, façade
27.	solaxess	Switzerland	Façade
28.	Megasol Energie AG	Switzerland	Roof, façade, EID
29.	ML System S. A.	Poland	Roof, façade, EID
30.	Saule Technologies	Poland	Façade, EID
31.	Terran Rooftile Manufacturer Ltd.	Hungary	Roof

A.3 Companies in Western Europe

	Name	Country	Category
1.	ActivSkeen	France	Roof, façade, EID
2.	Novéa Énergies	France	EID
3.	Solar Cloth System	France	EID
4.	S'Tile	France	Roof, façade
5.	Systovi	France	Roof, façade, EID
6.	SoyPV	France	N/A
7.	New ISSOL s.a./n.v.	Belgium	Roof, façade, EID
8.	Smartroof n.v.	Belgium	Roof
9.	New Soltech n.v./s.a.	Belgium	Roof, façade, EID
10.	Exasun BV	Netherlands	Roof
11.	HyET Solar	Netherlands	Roof
12.	Kameleon Solar	Netherlands	Roof, façade, EID
13.	Solinso	Netherlands	Roof
14.	Solarix	Netherlands	Roof, façade, EID
15.	Power Roll Ltd.	United Kingdom	Roof, façade, EID
16.	Verditek PLC.	United Kingdom	Roof, façade, EID
17.	Viridian Solar Ltd	United Kingdom	Roof
18.	BIPVco	United Kingdom	Roof

A.4 Companies in Southern Europe

	Name	Country	Category
1.	Organic Electronic Technologies P.C.	Greece	Roof, façade, EID
2.	GRUPPO STG S.R.L.S.	Italy	Roof, façade, EID
3.	Solbian S.r.l.	Italy	Roof, façade, EID
4.	Solarday	Italy	Roof, façade
5.	TEGOLA CANADESE - S.R.L	Italy	Roof
6.	Industrie Cotto Possagno	Italy	Roof
7.	Suners Solar	Italy	EID
9.	Onyx Solar	Spain	Roof, façade, EID

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