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Faculty of Business Economics

Master of Management

Master's thesis

Identify the potential challenges for developing solar industry manufacturing capacity in Europe within the EU Green Deal Industrial Plan

Thuy Linh Tieu

Thesis presented in fulfillment of the requirements for the degree of Master of Management, specialization Data Science

SUPERVISOR :
dr. Alessandro MARTULLI

UHASSELT
KNOWLEDGE IN ACTION
www.uhasselt.be
Universiteit Hasselt
Campus Hasselt:
Martelarenlaan 42 | 3500 Hasselt
Campus Diepenbeek:
Agoralaan Gebouw D | 3590 Diepenbeek

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I hope this dissertation offers a meaningful contribution to the field of renewable energy transition from an economic perspective and serves as a foundation for future research in this important area.

Tieu Thuy Linh
Hasselt University
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Executive Summary

The development of renewable energy is considered critical to mitigate climate change, and foster sustainable economic growth. The European Union (EU) has been among the regions that exhibits the most significant commitments to renewable energy transition, evidenced by the establishment of the EU Green Deal Industrial Plan (GDIP) that aims to accomplish optimal levels of resource use and transition towards a green, circular economy. With this initiative, solar energy, as one of the fastest growing renewable energy sources, has been established as one of the key pillars in facilitating the EU's efforts towards the GDIP's goals since it not only offers environmental benefits but also bolsters industrial competitiveness, energy independence, and generates economic opportunities through job growth and cost-effective energy solutions. However, this process meets with numerous challenges in terms of regulations, supply chain, and production economies of scale. It poses a critical research question for this study: **What are the challenges impeding the EU's ability to scale its solar manufacturing capacity under the Green Deal Industrial Plan?** To address this question, a systematic review of EU-level initiatives pertinent to solar PV manufacturing and EU solar manufacturing companies was conducted in this thesis. This was done by utilising the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) framework for the selection of review subjects and the SWOT (Strengths – Weaknesses – Opportunities – Threats) framework for detailed analyses of each subject.

For the analysis of EU-level initiatives, the five chosen subjects are **REPowerEU Plan, Net-Zero Industry Act, Critical Raw Materials Act, Innovation Fund**, and **Horizon Europe**, the first three of which are concerned with policy frameworks and objectives set for the solar sector while the last two of them are related to the funding aspect of the industry. The SWOT analysis of these five initiatives reveals that all these initiatives under the EU GDIP are capable of addressing issues in numerous areas necessary for the fostering of the green energy transition and the solar manufacturing capacity, ranging from the establishment of ambitious energy goals, the overall policy support framework, reduced permit grant wait time, R&D incubation, and operation funding. These initiatives are uniformly able to set ambitious and transparent targets with clear quantification of energy production and deployment for the EU, thus allowing relevant stakeholders namely policymakers, solar companies and investors in the EU to understand the directions and measure their progress against the established goals. Besides, the two funding-focused initiatives have been able to place the right emphasis on innovative technologies to enormously augment the region's

solar manufacturing capacity through improved efficiency and cost effectiveness to increase the competitiveness of Made in EU products on the global landscape. Adding to these beneficial conditions

for these EU initiatives are the rising global momentum for clean energy policies and investments, together with the creation of breakthrough solar technologies in the production process, laying the groundwork for knowledge sharing, positive public and private sector perception of solar energy so that the industry can obtain more support in numerous forms.

However, all these initiatives have their own challenges but the most obvious include the absence of binding enforcement mechanisms and the complex, time-consuming bureaucracy in the EU authorities. This can potentially discourage solar investors and manufacturers in the region to increase the production scale for the EU demand due to high inherent risks of defaults and low returns on investment while on a broader level, EU Member States are left with fragmented guidance and dampened motivation to dedicate themselves to the ambitious targets, hence the issue of fragmented national implementation across nations. These challenges are particularly severe in the context of ambitious solar energy targets that can only be achieved by joint efforts, compounded by supply chain disruptions and macroeconomic uncertainties, cut-throat competition from global solar suppliers namely the US and China with more cutting-edge solar technologies and more generous green energy subsidies.

For the analyses of EU solar manufacturing companies, two representatives are selected: one upstream company **Wacker Chemie AG** – a firm headquartered in Germany focused on silicones and polysilicon – fundamental input materials for the solar PV, and one downstream **company Meyer Burger Technology AG** – a firm headquartered in Switzerland but with major production bases in Germany focused on solar panel assembly and marketing of final solar modules. Both these two representatives exhibit strengths in their excellent levels of solar technologies with top-quality input materials and solar panels, which resonate well with a long-standing strength of Europe in terms of superior research & development (R&D) and help these companies stand higher chances of benefiting from the above analysed with higher local demand and policy support. Nonetheless, the common challenges witnessed in both of these companies are related to the reliance on outside EU suppliers and acute competition with US and Chinese rivals. This stems from the fact that Wacker and Meyer Burger encounter enormous difficulties in keeping up with their competitors' cheap prices and ramping up economies of scale due to the inability to source input materials domestically. Even worse, investigating these two representatives indicates a particular nuanced challenge for EU solar manufacturing companies – the need for vertical integration and multiple revenue streams when Wacker, with its varied product portfolio, can resort to other product lines in times of solar sector crises whereas Meyer Burger, concentrating majorly on solar panel manufacturing, has to face colossal setbacks when unable to address high production costs and compete with global competitors. Downstream companies are especially at higher risks in this aspect since upstream

companies can divert their input materials to other industries while their downstream counterparts usually focus on solar products exclusively, thus less able to diversify their business activities.

With rigorous PRISMA and SWOT analyses of a representative list of EU initiatives and companies in solar PV manufacturing, this study is able to provide a comprehensive picture to allow for a better understanding of the current situation of the sector in the EU. The study pinpoints that EU initiatives for solar manufacturing have established ambitious goals and support frameworks in terms of policy and funding but the gap between policies and reality still remains, hence fragmented national implementation across Member States and EU companies' reliance on old-aged R&D edge without sufficient economies of scale and commercialisation. Therefore, this study proposes several practical recommendations, including securing the full solar PV supply chain and critical materials in Europe with the establishments of input material production sites across Europe, strategic investments and partnerships with a variety of global partners other than just those from China, and priority for material recycling. This should be accompanied by the implementation of criteria for sustainable and locally produced products in solar deployment tenders and public procurement to encourage local product utilisation, the launch of a dedicated solar manufacturing scale-up fund to better support both solar R&D and commercialisation, the introduction of binding requirements for national policy implementation and cross-country collaboration. Also, next-generation, innovative solar technologies that can be easily producible within Europe should be placed high on the agenda to future-proof the EU's long-standing history of R&D advantages and accomplish better economies of scale.

This study also has several critical considerations that are of paramount importance for evaluation and future research. Firstly, the analysis relies exclusively on publicly available information for policy documents, company and industry reports as of early 2025 but market trends, micro and macroeconomic circumstances experience constant changes over time, combined with the fact that confidential information within the EU level or solar manufacturing companies may present different information. Hence, the results from this study's analysis may not be applicable when the above information is presented. Also, the SWOT analysis, though structured and easily interpretable, may inadvertently simplify the interconnected dynamics between EU-level and firm-level strategies, as well as with global supply chains and outside-EU competitors. Thirdly, the case study selection just focuses on two representatives Wacker Chemie AG and Meyer Burger Technology AG so while able to capture the upside and downside in essential segments of the solar supply chain, the analysis may fail to take into account the diversity of challenges faced by solar SMEs and new entrants in the market. These limitations represent potential directions for future research in order to better demonstrate the beneficial and adverse factors facing the solar PV manufacturing within the EU and provide pragmatic solutions to address those challenges.

Abstract

This study examines the European Union' strategic initiatives and representative companies in the field of solar manufacturing under the Green Deal Industrial Plan, focusing on five initiatives REPowerEU Plan, the Net-Zero Industry Act, the Critical Raw Materials Act, the Innovation Fund, and Horizon Europe, and two companies Wacker Chemie AG and Meyer Burger Technology AG. Using the PRISMA framework and SWOT analysis, the study pinpoints common strengths namely policy ambition and financial innovation support but also several challenges such as fragmented national policy implementation, supply chain vulnerabilities, and increasing global competition. This study proposes targeted policy recommendations to improve regional competitiveness, from resilience-based solar procurement, binding national requirements, and coordinated capital support for innovation and operation.

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List Of Abbreviations

Abbreviation	**Definition**
CRM	Critical Raw Materials
ETS	Emissions Trading System
EU	European Union
GDIP	Green Deal Industrial Plan
GHG	Greenhouse Gas
PV	Solar Photovoltaic
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
R&D	Research & Development
REEs	Rare earth elements

Chapter 1: Introduction

The development of renewable energy is critical in mitigating climate change, as it offers a pathway to reduce greenhouse gas emissions and promote sustainable economic growth. Renewable energy sources, such as wind and solar, are central to addressing the environmental impact of fossil fuels and ensuring long-term energy security. In the European Union (EU), renewable energy accounted for approximately 45.3% of gross electricity consumption in 2023, reflecting the region's commitment to diversifying its energy portfolio and advancing its climate goals (Eurostat, 2024). The crux of the EU's renewable energy strategy is the Green Deal Industrial Plan (GDIP), which aims to optimize resource use and transition towards a clean, circular economy. The main focus of the GDIP is the transformation of energy production and consumption patterns, a vital step not only for reducing greenhouse gas emissions but also for enhancing energy security and economic resilience across the EU. Through investments in renewable energy and the promotion of energy efficiency, the GDIP aims to mitigate climate change, restore biodiversity, and lower pollution levels continent-wide. As Ossewaarde and Ossewaarde-Lowtoo (2020) emphasize, the GDIP presents a transformative opportunity to build a sustainable, inclusive, and competitive European economy, ensuring resilience in an evolving global market.

Solar energy, as one of the fastest-growing renewable energy sources in the EU, plays a pivotal role in the Green Deal's objectives. Solar energy not only provides environmental benefits but also strengthens industrial competitiveness, enhances energy independence, and creates economic opportunities through job growth and cost-effective energy solutions. In 2022, solar power generation in the EU reached approximately 220 TWh, equivalent to powering around 70 million average European households for a year and contributing about 5% of the EU's total electricity consumption (Jäger-Waldau, 2023). This significant increase underscores the potential of solar energy to play an integral part in achieving the EU's climate objectives and enhancing energy security (Dolge, 2023). Furthermore, solar energy serves as a cornerstone of the EU's transition to clean energy, providing a scalable and reliable means to generate affordable renewable energy (Madsen & Hansen, 2019). The GDIP recognizes this potential and emphasizes the importance of expanding solar manufacturing capacity to achieve climate neutrality and foster sustainable economic growth.

However, realizing this potential is contingent on addressing systemic barriers that impede the growth of the EU's solar industry. One of the most significant barriers lies within the EU's regulatory landscape, which significantly influences the solar manufacturing sector. Malinauskaitė and Erdem (2023) argue that reconciling market competitiveness with sustainability goals requires legislative adjustments that promote green innovation while maintaining fair competition. Legislative reforms are vital to foster investments in technologies and practices that align with the EU's climate ambitions. Additionally, targeted research and innovation (R&I) funding can help overcome financial constraints and enhance productivity, as emphasized by Fragkiadakis et al. (2020). Addressing these regulatory challenges is a crucial step toward developing a resilient solar manufacturing industry capable of supporting the EU's ambitious climate targets. The economic implications of scaling solar manufacturing capacity further compound these challenges. While investments in R&I for low-carbon technologies can enhance EU productivity and competitiveness (Fragkiadakis et al., 2020), high initial costs for establishing manufacturing facilities and limited economic incentives pose significant hurdles. Therefore, the EU must adopt a strategic approach to investment and funding, ensuring that early-stage financial constraints are alleviated to unlock long-term growth potential.

This study addresses a central research question: **What are the challenges impeding the EU's ability to scale its solar manufacturing capacity under the Green Deal Industrial Plan?** By focusing on critical segments such as polysilicon and module production, the research seeks to uncover economic and regulatory barriers that hinder the development of a resilient solar manufacturing industry in the EU. The study examines cost structures, regulatory delays, and policy effectiveness in mitigating supply chain vulnerabilities, providing actionable insights to inform strategic recommendations. The findings will offer not only a deeper understanding of the challenges but also practical recommendations for policymakers to establish a sustainable and competitive solar manufacturing industry. These recommendations aim to guide governments in making informed decisions to enhance energy independence, address current barriers, and prepare for future crises in the renewable energy sector.

Chapter 2: Literature Review

1. Introduction

1.1. Overview of the PV production supply chain:

The imperative to transition toward sustainable energy systems has intensified in recent years, driven by the escalating climate crisis, growing concerns about energy security, and the recognition that future economic prosperity depends on decarbonizing global energy production (Jacobson & Delucchi, 2011; IEA, 2023b). The urgency to reduce greenhouse gas (GHG) emissions and their detrimental impacts on the global climate, along with the need to secure a reliable and affordable energy supply, has compelled nations worldwide to explore and invest in diverse renewable energy sources (World Economic Forum, 2021).

Within the diverse array of renewable energy options, solar energy emerges as a particularly abundant and promising resource for the global clean energy sector (IRENA, 2019). Unlike localized resources such as geothermal or region-specific resources such as wind, solar energy resources are plentiful across the world, and this makes it a very attractive alternative (Turner, 1999). That wide accessibility distinguishes it from other renewable sources. Solar energy is now one of the primary sources of clean energy and offers a promising source of economic, social and environmental growth as opposed to traditional sources (Zhang et al., 2021). As time continues to move forward, it is expected to increase the use of sustainable technologies.

At the heart of solar energy systems is the photovoltaic (PV) process, where sunlight interacts with a semiconductor material, creating an electric current. PV technology presents a proven and increasingly cost-competitive pathway for harnessing solar radiation directly into electricity, offering a versatile and scalable solution to meet diverse energy demands (Krishnan et al., 2023; NREL, n.d.). Semiconductor materials are the key, with silicon being the most commercially successful semiconductor. Two main technologies currently dominate global solar PV markets and supply chains: crystalline silicon (c-Si) modules account for over 95% of global production while cadmium telluride (CdTe) thin-film PV technology makes up the remaining (IEA, 2022).

- **Crystalline silicon**: While there are various semi-conductors, silicon has been regarded as an excellent one. Monocrystalline Silicon, multicrystalline silicon, which have been used as the base for making solar cells and are different in the arrangement of their silicon. As technology improves, better methods of arranging those silicones will continue to be made for more sustainable power. The excellence of silicon for solar cells can be attributed to its superior efficiency to convert sun rays into electricity, at above 20% under real-world conditions, its durability and its dwindling costs over time, making it an affordable and efficient choice for solar cells (Shukla, 2024).

- **Thin Film**: CdTe, CIGS, and A-Si all make up the structure and composition for thin film solar cells, but GaAs and other various cell types may occur. While silicon accounts for 95% of the solar market, there are various reasons scientists may be making different compositions.

  The essence of solar PV manufacturing is a complex production process comprising multiple primary components: polysilicon, ingots, and modules for silicon-based production while for thin-film production, the manufacturing process commences with refining cadmium and tellurium into ultra-thin layers, which are coated on a thin glass base with other conductive and protective coatings (IEA, 2022). Despite rapid advancements in technical innovation, contemporary mainstream solar photovoltaic systems often exhibit a consistent structure and component configuration as follows:

- **Polysilicon Production:** The initial stage concentrates on the production of high-purity polysilicon, a crucial material for solar cells. The Siemens process or Fluid Bed Reactor are the core chemical reactions to produce the material by refining metallurgical-grade silicon (electrolysis, thermal energy, process emissions).
- **Ingot and Wafer Manufacturing:** To generate the individual sheets for the solar cells, molten polysilicon is then cast into ingots through many processes and methods. China today dominates global solar PV wafer fabrication
- **Cell Manufacturing:** These building blocks for solar power are created by the layering of various chemicals onto the surface of the silicon wafers and is usually done with semiconductor fabrication to create a p-n junction(NREL, n.d.).
- **Module Assembly:** Solar power modules are manufactured by the connection of solar cells between layers of glass and polymers to create a long-lasting product. [IEA, 2022f] By its nature, encapsulation plays a vital part in the reliability and durability of these panels for outdoor deployment.
- **Panel assembly:** modules are assembled to PV panel unit
- **Array:** complete PV power-generating unit
- **Inverter:** inverters convert the DC to AC so it can be used.

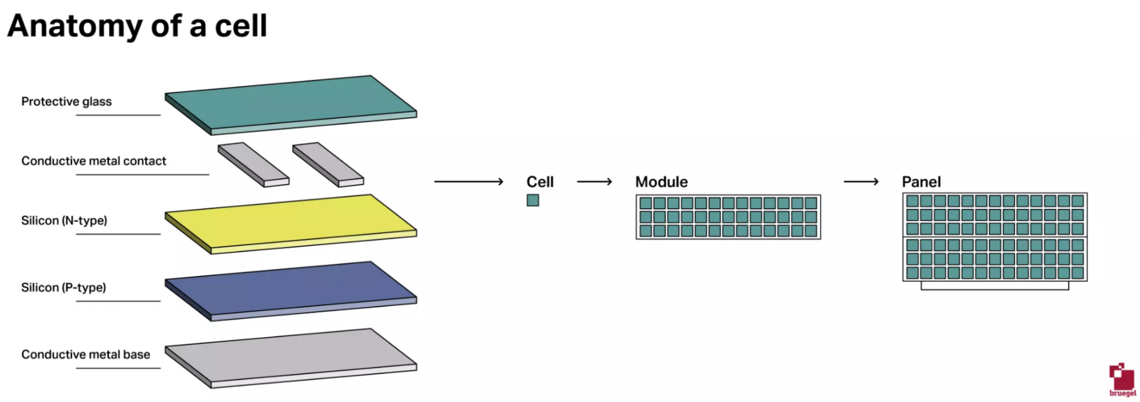


Figure 1. Anatomy of a PV cell, module and panel.

Source: Jugé et al. (2025)

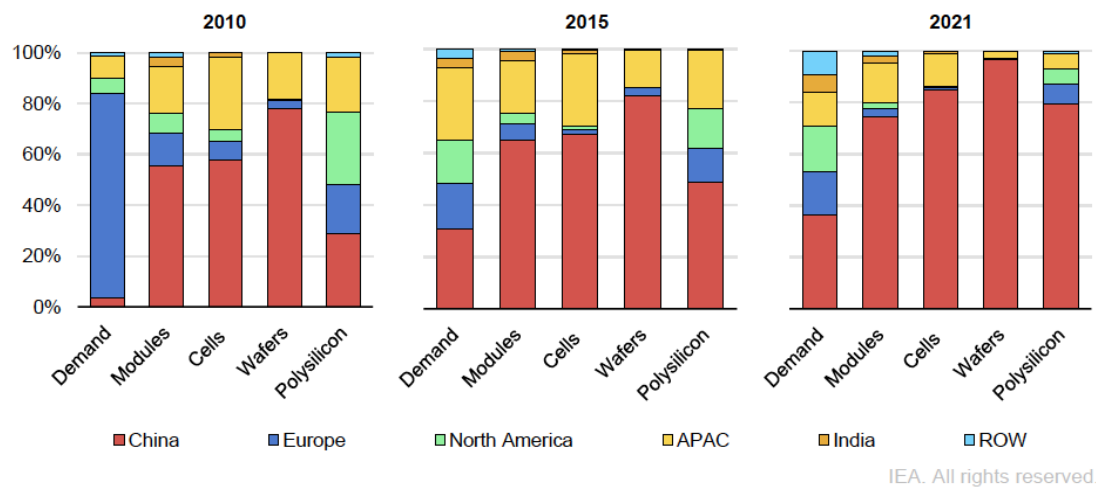
2. Global solar manufacturing industry and EU position

2.1. Global landscape

The increasing imperative to address climate change and attain energy security has established solar energy as a crucial element in worldwide energy transitions. Solar photovoltaics (PV), the technology that directly transforms solar energy into electricity, are fundamental to this shift. Photovoltaic (PV) systems are acknowledged as among the most scalable and economically viable renewable energy technologies currently available, essential for capturing solar energy (IEA, 2022). The photovoltaic manufacturing process, encompassing the manufacture of polysilicon, wafers, cells, and modules, is fundamental to the solar energy sector. An advanced and competitive photovoltaic manufacturing industry is essential for securing the EU's energy autonomy and achieving overarching climatic and economic objectives (SolarPower Europe, 2023). The EU Green Deal Industrial Plan (GDIP) emphasizes the advancement and use of solar energy technology, especially photovoltaic systems, as essential for attaining climate neutrality by 2050.

The global solar photovoltaic (PV) industry is predominantly characterized by the dominance of Asian manufacturers, particularly China. China’s solar manufacturing capacity in all stages has occupied 80% of the world’s grand total levels (IEA, 2022) and is expected to retain this figure in its polysilicon, cell, wafer, module production for the period of 2023-2026 (Wood Mackenzie, 2023). Among the top 10 world’s largest solar manufacturing companies until first half 2024 (Wood Mackenzie, 2025), Chinese-owned firms occupy 7 spots out of the top 10 with only the exception of India, Canada and Singapore making their entry here. The extensive manufacturing capacity of China even goes to the extent that it exceeds its own rate of PV deployment which only accounts for 36% of the worldwide PV deployment levels in all production stages (IEA, 2022), leading to the issue of over-capacity and PV price reductions. China has even lately announced policies to curb over-capacity ranging from decreasing export tax rebates, establishing production guidelines and capital ratios to ensure effective manufacturing allocation, avert oversupply and improve sticky low prices (Howe, 2024).

Another notable area that represents a significant proportion of global PV manufacturing capacity is the Asia and Pacific (APAC) region. As of 2023 share of PV polysilicon, wafer, call and module production (IEA, 2024d), besides China's complete dominance, the APAC region constantly has representatives in the global share namely India, Vietnam, South Korea and Malaysia, indicating this region's considerable role in the worldwide supply chain of solar manufacturing. Therefore, this situation leaves little share in production capacity for Europe (Figure 2) despite being the region with a long-standing heavy emphasis on decarbonization. Figure 2 shows that despite having a rather strong demand, Europe's production shares in all four kinds of PV solar manufacturing appear either negligibly small or even barely visible as time progressed from 2010 to 2021, so an over-concentration of solar PV supply certainly exists.



Notes: APAC = Asia-Pacific region excluding India. ROW = rest of world.

Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation and PV InfoLink.

Figure 2. Solar PV manufacturing capacity by country and region, 2010 - 2021

Source: IEA (2022)

The rationales for such overconcentration are numerous, the chief of which lies in China's ability to elicit "high margins for polysilicon, technology upgrades and for developing local manufacturing in overseas markets" (Wood Mackenzie, 2023). China is able to lead in producing raw materials for solar PV such as silicon PV, thin-film PV, and especially rare earth elements (REEs) such as gallium, indium and tellurium - critical materials for producing solar PV because China hold a relative monopoly over the production of these materials by producing all these materials itself or sourcing Chinese firms in this production process in other markets such as Malaysia and Vietnam (Chadly et al., 2024). This has allowed China to manufacture solar PV at a low cost when being capable of implementing vertically integrated supply chains with all production activities within its border and even gained profits from exporting these crucial raw materials, particularly REEs, to markets with huge demands like Europe and the US. Combined with the Chinese government's favourable policies such as subsidies, tax breaks and low-interest loans for PV enterprises (Bai et al., 2024), China has been adept at taking advantage of economies of scale and governmental support to ramp up the manufacturing of solar PV and export these products to other markets in the globe. The results are that despite efforts to generate local solar PV elsewhere, the price of a module produced in China is still 50% lower than in Europe and 65% lower than in the US (Wood Mackenzie, 2023), which is particularly important in a free-market economy where businesses compete on costs. This excessively low costs are even worsened by the over-capacity in China already analysed above, creating a mismatch between supply and demand and lowering the Chinese solar PV prices even further. As a result, with Europe's higher manufacturing costs in terms of factory location, material exports, labour wages and salaries, and bureaucratic processes, the EU's solar manufacturing sector has little incentives to operate within the region due to higher costs and, consequently, the inability to compete with cheap products from China.

However, this geographical concentration of raw materials for solar PV manufacturing has certainly become a breeding ground for several supply chain vulnerabilities. When the supply of production materials revolves around one single source - China with no less than 60% of global capacity for the majority of mass-produced clean energy technologies (IEA, 2023), it introduces a single point of failure where any kind of disruptions to this source of materials can leave fatal consequences for the importer/manufacturer. Therefore, if China wants to control the manufacturing and export of REEs and solar PV, given the overcapacity issue with solar PV production and low prices in this country, China can establish policies that disrupt the manufacturing activity in the EU or affect the pricing in the solar market. Also, based on the history of geopolitical relationships between the EU and their allies like the US with China and the country's assertive diplomatic tactics tied to REEs to punish other countries (Burgers & Romaniuk, 2023), the constantly looming threats of trade war and tariffs can pose an enormous threat to the prices of raw materials for solar PV production and the certainty of this industry in the EU. Hence, the global landscape of solar PV manufacturing is a market of extreme concentration surrounding Asia with China for the most part, as well as the emerging APAC region, indicating high-risk supply chain vulnerabilities to any market dependent on China, including the EU.

2.2. The EU Solar Industry Overview

Owing to its affordable price, flexibility and environmental cleanliness, solar energy is the top competitive source for electricity generation in many areas of the EU. The total solar generation capacity of the EU has risen significantly, from 164.19 GW in 2021 to 259.99 GW in 2023 (European Commission, 2023f) – a rise of nearly 60% over 2 years to decrease the region's reliance on fossil fuels. When breaking down the capacity for solar PV manufacturing by each component in Europe, most of the production concentrates around polysilicon and modules with 24 GW for the former and 22 GW for the latter as cells and wafers are not Europe's strength (IEA, 2024c). In terms of member state distribution of manufacturing, as of the latest figures in February 2025, there are 166 solar manufacturing companies in the EU, 61 of which are located in Germany (SolarPower Europe, 2025) and account for nearly 37% of the total number. Germany is also where nearly a large proportion of modules and nearly all of cell and polysilicon production are concentrated, thus making this country the main hub of solar manufacturing in the EU. Other notable countries in the region are France with 21 companies and producing 4.4 GW of solar modules, Italy with 19 companies and producing 2.1 GW of solar modules, and Spain with 19 companies as well but focusing mostly on solar inverters (SolarPower Europe, 2025) .

However, when it comes to the global market share, the situation is rather bleak for the EU when the already small market share in 2021 even dwindled further in 2024. The shares for wafer and cell manufacturing in both 2021 and 2024 were either 1% or close to 0% whereas those of polysilicon and modules - Europe’s apparent strength, were 8% and 3% in 2021, declining to 2% for both types in 2024 (IEA, 2024c) despite the increases in production capacity. This highlights the EU’s struggle to compete with other global solar manufacturing competitors, especially those in China and other Asian nations, and consolidates the EU’s position as just a small player in the global production landscape of this industry.

The growth projections for the EU’s solar industry expects to observe a two-digit growth rate for the time frame between 2024 and 2028 but the figures are anticipated not to be as high as that in 2023 and likely to stay in the low two-digit threshold due to the overwhelming production quantities compared to installers’ ability and the slowdown in the demand for rooftop solar in several member state countries (SolarPower Europe, 2024e). SolarPower Europe (2024a) generated predictions for the solar market of the EU based on 3 scenarios: low, medium, and high. To be specific, the medium scenario is based on the current state of play of the market to predict the most probable direction. In contrast, the low scenario assumes the freeze of current policy support, as well as the presence of unexpected issues like increased interest rates and financial recession whereas the high scenario presumes the optimal conditions favoured by policies, financial situation and other aspects. that Figure 3 displays that the predicted annual solar PV market would already diminish in the low scenario or just improve a bit in the medium one in 2024, which would continue until 2028. The medium and high scenarios understandably suggest a growth in annual additional solar PV manufacturing but the remarkable pre-2023 growth rate could not be sustained and even the low scenario would exhibit a downtrend, indicating a downturn in deployment trends in the EU.

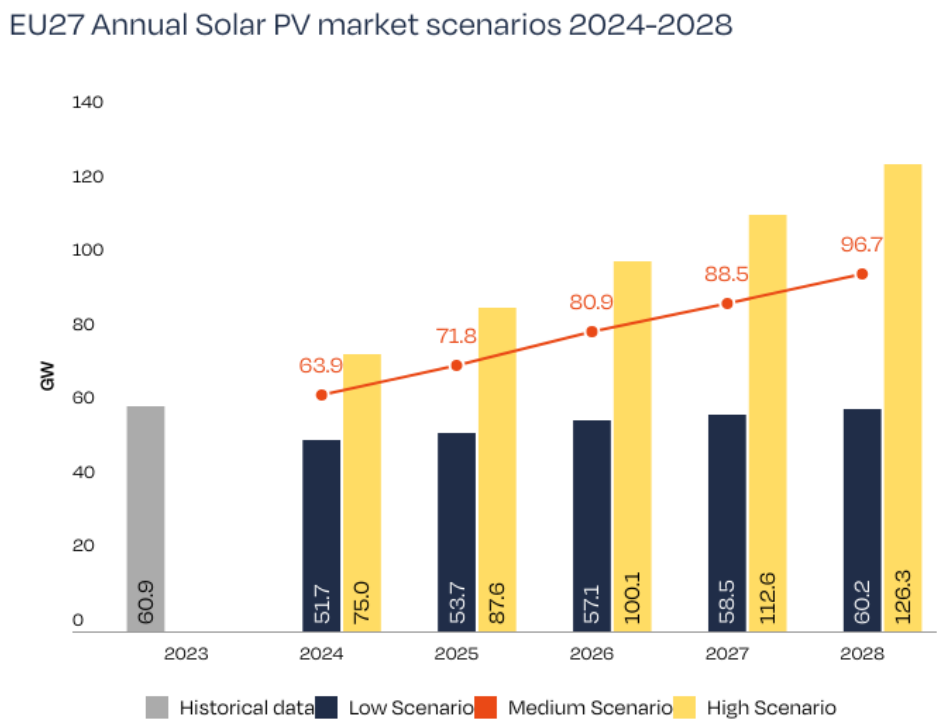


Figure 3. EU27 Annual Solar PV market scenarios 2024-2028

Source: SolarPower Europe (2024e)

The deceleration in the solar deployment pattern of the EU can be ascribed to the waning interests and urgency of solar development in the region as the energy crisis in Europe caused by the Russia-Ukraine conflict has occurred for a period of time long enough for the EU energy suppliers and households to adjust to and for the citizens' electricity bills to normalise (SolarPower Europe, 2024a). Therefore, the demand to accelerate solar energy has taken a dip when citizens and businesses are not as interested in switching to solar energy as before. Adding to this difficulty is the inability of the EU electricity grid systems to improve flexibility, scalability and compatibility upon the solar energy transition due to Europe's electrification rate, which stayed at 23% from 2020 until 2025 since most of the system still has to depend on combustion fuels (Laio, 2025). This induces bottlenecks in the EU grids and hinders the construction of bankable and scalable solar PV plants. Even in the apparently solar energy haven of the EU - the Netherlands, a country with the highest PV watts per person in the world at 1,044 watts per capita, the decreasing solar capacity addition is also a current complication due to the industry's uncertainty (Laio, 2025) in the face of its ambitious solar policies and objectives. In other words, the EU has been experiencing a downturn in solar deployment with its decreasing additional solar capacity year by year, which makes the EU market appear even grimmer for both solar production and consumption as opposed to other global competitors in America and Asia, as well as risking missing the solar target by 2030 (Laio, 2025).

Nevertheless, the EU also has several EU-level policy frameworks and initiatives that support solar manufacturing in the region. The most outstanding representative among these is the REPowerEU Plan, introduced in May 2022 that aims to gradually eliminate the reliance on Russian fossil fuels (European Commission, 2022b). The main set of actions in this initiative entails energy savings, diversification of energy supplies, acceleration of clean energy transition and smart combination of investments and reforms. These pillars are expected to structurally change the way the EU energy system operates with a strong emphasis on joint efforts coming from EU member states' regulatory and infrastructure upgrades, as well as measures from both the demand and supply side to guarantee that the manufacturing capacity can meet with the demand resulting from the conversion to clean energy (European Commission, 2022a). With this initiative, solar energy as the most competitive and popular green power source can receive huge financial and legal boosts so that the demand and the solar manufacturing can grow faster.

Also, as part of the efforts to put REPowerEU into practice, the EU established the EU Solar Energy Strategy in May 2022 that outlines the objectives to enhance solar PV capacity to almost 600 GW by 2030 (European Parliament, 2022). The primary pillars of this strategy involves European Solar Rooftops Initiative to tap into the unused potential of rooftops for the creation of solar-ready buildings, EU large-scale skills partnership to tackle the skills gap in the human resources for renewable energy industry, EU Solar PV Industry Alliance to create mutual platforms for various stakeholders' legal and technical collaboration (European Commission, 2023f), as well as the Commission's permitting package with legislative guidelines and recommendations (European Parliament, 2022). Furthermore, to bolster collaboration within the region, the EU. the member states and around 100 industry representatives signed the European Solar Charter on April 15, 2024, to highlight a list of voluntary actions in the legal, political and R&D areas to strengthen the resilience and competitiveness of EU-made solar manufacturing and reduce reliance on external sources (European Commission, 2024a). All these EU-level policy frameworks make significant contributions to supporting the growth of EU solar manufacturing and lay a firm groundwork for future development of the region as a resilient and competitive solar manufacturer on the global map.

In spite of the emergence of numerous supportive policy frameworks, EU-level trade policies regarding solar PV production still remains a heated debate because there are still conflicting interests and perspectives as to what kinds of tariffs and trade restrictions should be applied to imported solar materials and products. In the draft Clean Industry Deal by the EU, anti-dumping and anti-subsidy duties and tariffs are anticipated to be adopted more in 2025 and the following years to guard against cheap imports from other countries, in particular China, and protect EU-made products (Abnett & Payne, 2025) but this certainly meets with some opposition from industry groups as it can risk even slowing the growth of solar manufacturing and backfiring on the EU's solar targets (Abnett & Blenkinsop, 2023) as untimely, poorly implemented tariffs and trade defence measures can induce sudden drops in available solar PV capacity and deployment as history already demonstrated in the 2023-2019 period (SolarPower Europe, 2024d). As a result, trade policies related to the protection and re-shoring of EU solar manufacturing remain in the investigation stages without clearly defined guidelines and effective time marks.

3. Key Challenges for Solar Manufacturing Capacity in the EU

The strive to ameliorate solar manufacturing capacity in the EU encounters a multitude of challenges in all aspects, which will be discussed from the standpoints of economic and market barriers, technological barriers, policy and regulatory barriers.

3.1. Economic and Market Challenges

The most prominent types of barriers for solar manufacturing capacity improvements in the EU are related to the economy and market, chief among which are high capital costs coupled with investment risks. Establishing solar PV manufacturing in the EU requires colossal amounts of capital in all kinds of tasks, ranging from sourcing sufficiently skilled labour force, going through administrative bureaucracy with the authorities, constructing factories, sorting out the necessary raw materials, finding partners and conducting maintenance for the factory site and products. One notable factor contributing to the high costs of producing solar PV products in Europe is the high energy cost, which is two times greater than their rivals in China, and three times greater than those in the US (SolarPower Europe, n.d.-a). In an energy-intensive sector like this, energy costs can play a crucial role in deciding the investment costs and pricing strategies for the final product, which can be seen in Figure 4 as below. Figure 4 demonstrates that Europe has the highest total production costs for mono PERC c-Si solar components - a critical part in solar cells, the reason for which lies in the striking differences in the energy cost compared to other preeminent global competitors.

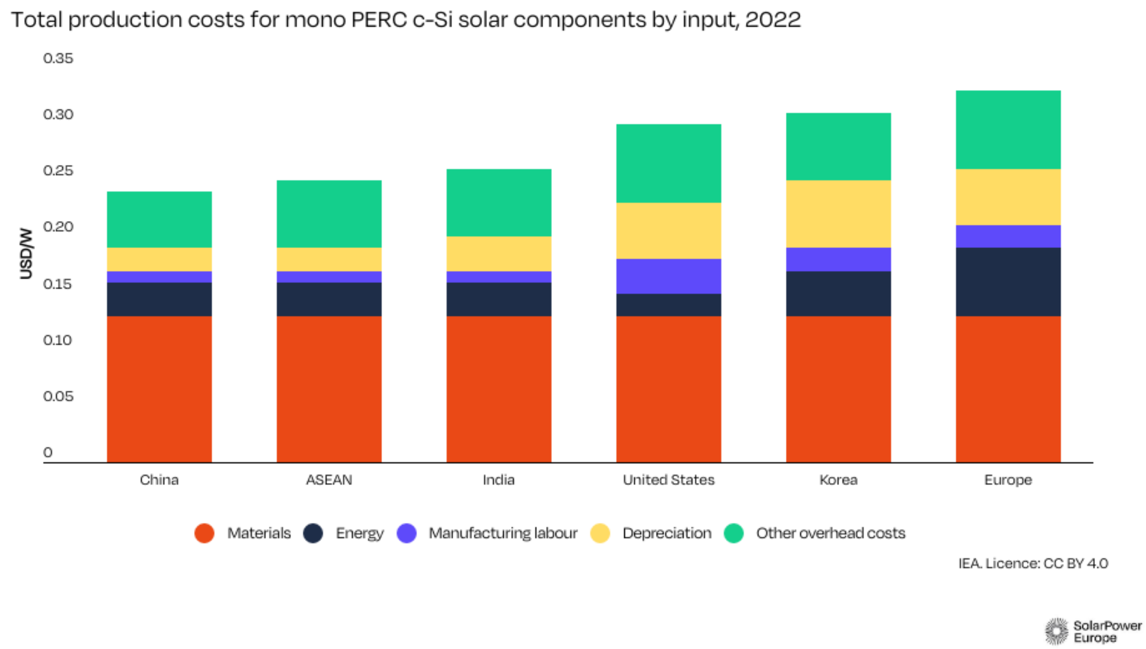


Figure 4. Total Production Costs for mono PERC c-Si solar components by cost input and region, 2022

Source: SolarPower Europe (n.d.-a)

Also, high technology costs are found to be an important rationale behind the high costs involved in the solar production process and even the major barrier to its development in the EU compared to traditional power plants and other renewable energy forms (Río et al., 2018). Another significant factor that comes into play in the high capital costs of solar manufacturing in the EU is the generally higher level of wages in EU countries, particularly compared to global competitors like China and other Asian countries where costs of labour are cheaper. This is particularly discernible in countries located in higher latitudes where higher wages lead to higher levelized cost of energy (LCOE) with the exception of Latvia where lower wages make solar PV production profitable to a certain extent (Lugo-Laguna et al., 2021). With all these components contributing to capital costs, together with enormous upfront capital expenditures (Kallio & Chen, 2023), investing in solar manufacturing in the EU is fraught with huge financial burdens, as well as uncertain investment risks. This is particularly the case considering the fact that current affairs of the industry in the region are not as bright as in the previous periods, making returns on investment volatile and deterring prospective investors and manufacturers.

The next noteworthy barrier in the market aspect is the lack of economies of scale compared to global competitors. One of the pivotal reasons why Chinese firms are able to scale up their solar manufacturing at a low price is the significant economies of scale China possesses with its efficient automation, supply chains and mass production of raw materials and finished solar products. This is because China is able to produce raw materials and critical REEs for solar PV cells within its border or have local companies source it abroad so the country can scale up the production assembly and manufacture solar PV cells at a lower cost per product, thus able to keep their product prices one-third less than that made by the EU (Mendonça, 2023). This Chinese strength is an area where the EU struggles to replicate because the manufacturing scale is smaller than in China due to dependency on imports for production energy sources and raw materials from China and other countries (Kallio & Chen, 2023; Guarascio et al., 2024). This vulnerability in materials is especially acute for such EU countries as Austria, the Czech Republic, Denmark, Slovakia and even Germany - the largest solar manufacturer in the region (Andersen et al., 2024). As a result, EU solar manufacturers cannot scale up their production line in a cost-effective manner due to import dependency unless struck with innovative, disruptive production technologies. However, according to a report from McKenzie, European firms will only be able to achieve success if they can grow fast enough to accomplish large scale but still retain great capital and operational quality as gaining adequate scale can close the initial cost gap of approximately 4c/W with Chinese organisations (Bettoli et al., 2022). Therefore, this introduces a paradox of the need to improve the production scale to gain revenues and capital, which, however, requires enormous capital in order to scale up. This possibly creates a vicious cycle of investment capital and scalability, necessitating huge initial capital costs to increase the extent of the manufacturing process and research ground-breaking, cost-effective solar technologies.

The series of economic and market challenges even extends to the workforce and skills gap in the EU in the current context. As of the end of 2023, the solar industry has employed 826,272 full-time equivalent workers in the EU, around 44% of which are direct jobs and 87% of the total jobs revolve around the deployment phase (SolarPower Europe, 2024b).

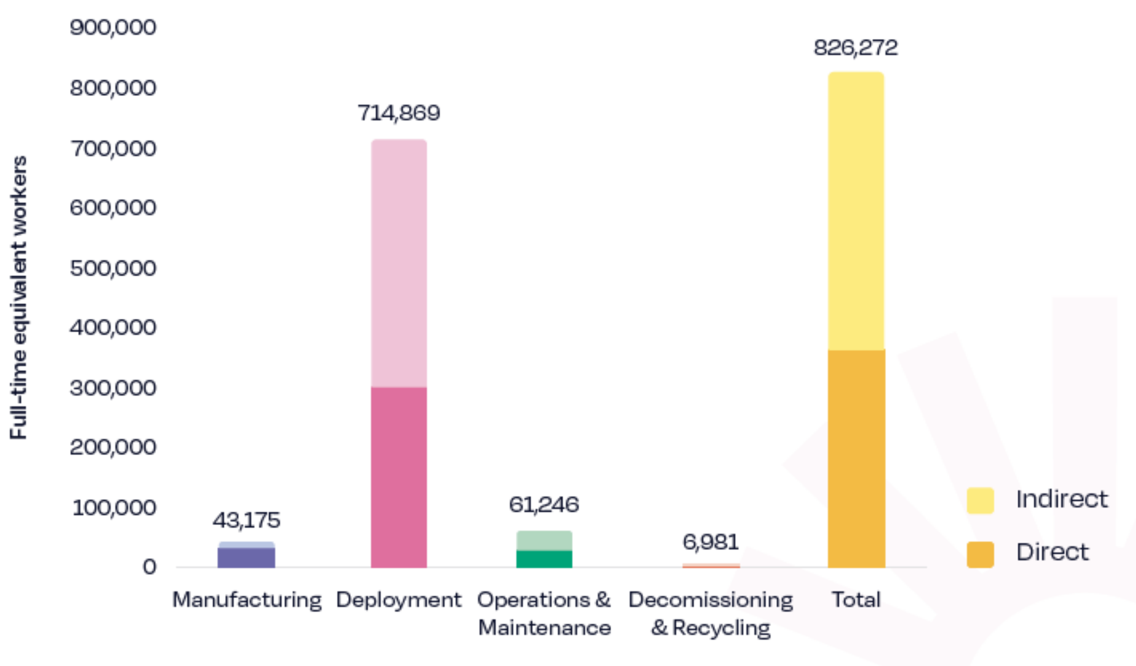


Figure 5. EU-27 Solar Job Market & Total Solar Job Breakdowns in 2023

Source: SolarPower Europe (2024b)

This figure is expected to rise to 1 million jobs by the end of 2025 (SolarPower Europe, 2024b) so guaranteeing the match between the industry's demand and the workforce's skills and qualifications is of paramount importance. Nonetheless, the EU has witnessed increasing imbalance between the growing solar sector and the size of skilled personnel for the industry across the value chains (Mendonça, 2023; InnoEnergy, 2024), especially in terms of academic, industrial and entrepreneurial skills (Amalu et al., 2023). There is even insufficient data on the quantities of solar workers trained and available in each country due to the lack of frequent country-wide reports (SolarPower Europe, 2024c), which may even cause obstacles to the EU's efforts to address the skill shortages. The list of critical solar jobs includes design engineers, electrical engineers, construction workers such as roofers, and manufacturing workers. This is further compounded by the lack of standardised European training courses and certifications and the differences and non-recognition of national certifications of each member state (InnoEnergy, 2024), thus creating difficulties for the solar workers in re-training and tuition fees when moving across borders for employment. Furthermore, as digitisation is a trend across different industries, the solar sector included, job demand is not just confined to technical solar roles but even extended to critical digital roles such as machine learning, data analytics and software programming (InnoEnergy, 2024), so the employment gap in the solar manufacturing industry in the EU is even more apparent.

3.2. Technological Challenges

Innovation in solar technologies plays an integral part in the acceleration of solar manufacturing capacity. As the capital required for initial investments, operation and maintenance is still exceptionally high for concentrating solar power, technical, technological and innovative techniques for solar manufacturing must be tackled (Ferruzzi et al., 2023). Kiefer and Río (2020) also found that R&D and proven solar technologies are among the top drivers and barriers to the EU's goal of solar manufacturing capacity. If the EU is able to establish innovative solar PV production techniques or to be more specific, achieve better cell efficiencies and power per module (Bettoli et al., 2022), it can lead to reduced demands for input materials (Koese et al., 2022), thus able to address the import dependency for raw materials from China and several supply chain vulnerabilities as outlined in previous sections. The EU already has a strong historical base for research and development (VOÏTA, 2024) but maintaining this competitive advantage in the current solar industry landscape is no easy feat as the EU can run the risks of resting on its laurel without striving further for more innovation, considering China has been constantly pouring money into R&D in this field (IEA, 2022).

Additionally, even though the EU has a history in solar R&D and long-standing solar companies, it is found that large companies with older stock of innovation in the EU are more likely to be stuck in the old-age, outdated technological paths while newer firms are able to innovate more, particular in the face of the "China shock" impact (Andres, 2024). However, this creates a contradiction because large, long-standing firms are more capable of innovation by having better capital and human resources whereas smaller-scale, newer companies do not have the same robust resources for R&D, which necessitates external funding from state governments or the European Commission. However, public R&D funding is a pressing issue among EU member states as the level of government R&D funding and support varies widely from one nation to another (Grafström et al., 2020; Gasser et al., 2022) and the European Commission also make mere promises for funding in the form of paper policies and announcements without definite information on funding allocation, targets and outcomes (European Commission, 2024b). This underscores the uncertainty and vast heterogeneity in the levels of R&D support for innovating solar technologies in the region and potentially puts a damper on future investments in technological R&D for the sector.

Another technological constraint lies in the restraint of carbon footprint and the improvements in recycling over the product life cycle of solar PV. To improve the efficiency of solar technologies, material reuse, recycling and recovery (Michas et al., 2018; Udayakumar et al., 2021; Nyffenegger et al., 2024). Even though the EU has already been able to accomplish the greatest 'energy return on energy invested' (EROI) and 'net energy return on carbon invested' (EROC) values in the long term compared to the US and China (Liu & van den Bergh, 2020), proving efficient returns on investment in EU's solar PV manufacturing, further cost effectiveness can be achieved by investing in the four strategy pillars of a circular solar PV framework, which includes "(1) reinserting by-products, (2) digitizing the VC, (3) preparing PV modules for reuse, and (4) recycling and material recovery" (Nyffenegger et al., 2024) so that the solar PV manufacturing procedures can be truly circular and environmentally friendly with as little carbon footprint as possible, besides realising a portion of cost savings thanks to material recycling and process digitisation. Besides, technology transfers and patenting are of equal consequence as smooth transfers and patenting of solar technologies can ensure greater sharing and applications of innovation across the region but in EU, green patents only occupy a small share of total, especially due to the descension of solar patents after the solar boom between 2005 and 2013 (Vysoka et al., 2021). Both of these aspects can act as a robust groundwork for future commercialisation of different solar manufacturing stages at the EU level and as a stimulation for cross-border, cross-industry collaboration between stakeholders.

3.3. Policy and Regulatory Challenges

Navigation in the complex policy and regulatory frameworks of the EU represents another conundrum. Kiefer and Río (2020) demonstrates that for the region, effective policy frameworks act as one of the most or even the most critical drivers and barriers for solar manufacturing capacity at both expert and investor levels. Paradoxically, in the context of efforts to reduce import dependency, EU countries with more regulated electricity markets and higher energy import dependence (Grafström et al., 2020), implying the need for regulations and import control policies in the EU market dynamics. However, despite the presence of several policy frameworks advocating for solar production acceleration, there exists a lack of consistent public support framework from the authorities for funding of operating costs (OPEX) and initial capital investment (CAPEX), leading to the widening gap in cost competitiveness compared to China (European Solar PV Industry Alliance, 2023).

Also, the discrepancies between the levels of government and European Commission support in each member state are also staggering. Firstly, while Eastern European countries receive rather limited or inconsistent assistance and are not able to implement strong solar policies, other more developed countries have better established frameworks to advocate for solar energy transition such as Germany with the Easter Package reform that introduces clearly defined solar capacity goals of 400 GW by 2040 and financial stimulations namely feed-in tariffs for installations up to 1 MW and bonuses for feed-in (Gleiss Lutz, 2022). Spain is another striking example of energy transition strategies since it has established a transparent aim of achieving 81% of total energy from renewable sources by 2030 and introduced industrial "super clusters" to scale up solar energy and optimise resource logistics (World Economic Forum, 2025). Considering the fact that Germany and Spain are already countries with high levels of solar production, this only serves to expand the policy gap between EU member states. In addition, the cross-country gap can be discerned in the level of EU support for countries since Belgium and Spain obtained 63% and 46% respectively of their total public R&D aids for renewable technologies from the European Commission but the figures for France and Finland are merely 18% and 15% (Gasser et al., 2022) - an extremely wide distance between nations.

The inconsistency and fragmentation in the EU's solar industry are reflected in the permitting procedures for solar manufacturing. Industrial permitting process in the EU is infamous for its lengthy and highly complicated nature (Piotrowski & Gislén, 2024). Even for solar manufacturing projects that fall under special categories of projects of common interests, the permitting process, depending on each country's regulatory regime, can last a maximum of 3.5 years, extendable by 9 months in exceptional situations, with two stages of pre-application and statutory permit granting (European Commission, 2023d), which is a significantly prolonged process as there are some examples of efficient countries such as the Netherlands with a 3-month decision-making deadline for special projects (SolarPower Europe, 2023). This procedure is complicated further with the presence of different systems regulating the solar manufacturing sector: "energy planning, climate governance planning, spatial planning onshore and at sea, natural resources planning" and in energy planning, there are energy system planning and energy infrastructure planning while the level of authorities for permitting submissions also varies between countries (Banet & Donati, 2024). The consequences of such lengthy and bureaucratic permitting procedures are large proportions of stuck projects as 81% of renewable energy projects in the EU, including solar manufacturing and other kinds, are in numerous permitting stages, as well as the substantial costs of delays, at a duration of 2 years and cost of 25,000 euros for 380 KW of rooftop solar installations (Piotrowski & Gislén, 2024).

The EU also experiences complications resulting from complex financing regulations and access to funding. To safeguard fair competition, the State Aid rules mean that national governments have extremely limited ability to subsidise the solar industry (European Commission, n.d.-b) to avoid distortive advantages. As a result, the solar manufacturing industry has to rely on EU-scale funding namely the Innovation Funding, whose history is teeming with administrative complexities and delays with the gap between submission to funding grants reaching over 12 months (SolarPower Europe, n.d.-a). Some solar flagship projects such as Enel's 3Sun have been able to secure €118 million in EU grants but those cases are solely exceptional as the Innovation Funding mostly concentrates on innovative proposals and hence does not suit a moderately mature solar-PV sector (Bettoli et al., 2022). Therefore, the impact of these types of upfront grants are rather humble and prevents solar manufacturing capacity projects from truly materialising. The issue goes further to the extent that it introduces uncertainty in terms of long-term commitments. Historically, the funding from the European Commission was stable for most countries but countries like Norway, the Netherlands, Belgium and Portugal saw their R&D funding increase after 2012 but then failed to double the public R&D support between 2015 and 2020 despite their commitments (Gasser et al., 2022).Today, most of the policies and funding support remain on paper due to lengthy bureaucracy. With the uncertain financing policies and funding sources, Kallio & Chen (2023) references the long-term financial health and sustainability of the solar PV field as one third of solar PV manufacturing capacity runs the risk of bankruptcy at either medium or high levels in the EU due to strong reliance on subsidies for profitability, especially in the event of overcapacity problems in the global landscape.

Table 1 below summarises the challenges analysed above faced by the EU solar manufacturing sector.

Aspects	Challenges
Economic & Market	- High capital costs with high investment risks - Lack of economies of scale from supply chain vulnerabilities - Workforce and skills gap in the solar industry
Technological	- Lack of innovative and cost-effective solar technologies - Large companies' resistance to change - Restraint of carbon footprint and the improvements in recycling over the product life cycle of solar PV

Policy & Regulatory	- Complex policy and regulatory frameworks - Inconsistency and fragmentation in policy implementation - Complex financing regulations and access to funding

Table 1. Summary of challenges faced by the EU solar manufacturing

4. Opportunities within the EU Green Deal Industrial Plan

Although the challenges for the EU solar manufacturing industry exist in multitude, the EU Green Deal Industrial Plan represents a golden opportunity to escalate the solar energy transition process. With its four pillars: (1) simplified regulatory regimes, (2) faster access to funding, (3) skills gap measures, and (4) open trade for resilient supply chains (European Commission, 2023g), this acts as a comprehensive roadmap for the EU to ramp up its solar manufacturing capacity in the future and enhance the sector's competitiveness and resilience on the global map.

4.1. Policy Support and Investments

Under the EU Green Deal Industrial Plan, the EU has formulated several provisions to create a more relaxed and easy-to-understand legitimate environment for the clean energy as a whole and solar sector in particular. The Plan places emphasis on the promotion of strategic cross-country projects to improve their accessibility for all countries with the Provisions for Renewable Energy Manufacturing (European Commission, 2023g) in alignment with the Net-Zero Industry Act aimed at fostering domestic production, addressing the fragmentation in policy directions as mentioned above in Section 3.3. Given the competitive position of solar PV products as a key part in the clean tech transition (European Commission, 2023f), solar PV manufacturing projects stand a high chance of receiving strategic attention and the needed funding for future growth. Potential funding opportunities within the Plan are Horizon Europe and the Recovery and Resilience Facility (RRF) initiatives. Horizon Europe is the EU's "key funding programme for research and innovation" possessing a dedicated budget of 93.5 billion euros for the 2021-2027 time frame with a new European Innovation Council and an open-science policy aimed at ambitious, high-risk clean energy plans (European Commission, 2021a). Meanwhile, the RRF instrument serves as a temporary helping hand for clean energy infrastructure and green transformations for member state countries in the form of loans with 291 billion euros, and grants with 359 billion euros (European Commission, 2023e). The Plan even goes to the extent that it allows for certain degrees of flexibility in existing EU-level regulations such as giving greater flexibility in the State Aid rule for EU nations to provide financial aid in a temporary, limited, and supervised manner for specific projects, together with EU-level funding in terms of one-stop-shops, tax breaks and InvestEU Programme (European Commission, 2023g).

These funding opportunities have proven critical assistance for the EU's solar manufacturing field to address the issue of funding scheme inconsistencies and policy fragmentation across EU member states by standardising funding opportunities for companies. This also reduces the stress derived from higher CAPEX and OPEX for both solar manufacturers and investors by opening up a predictable investment environment and guaranteeing long-term financial commitments.

4.2. Technological Development and Innovation

With the establishment of the EU Green Deal Industrial Plan, the utilisation of advanced technologies and sustainable industry practices is high on the agenda to improve EU competitiveness in the solar market. With improved access R&D funding, combined with the Plan's vigorous focus on improving the EU's talent pool in the clean tech industry, there are numerous strategies in place to upskill the solar personnel in place namely the European Skills Agenda, the European Education Area and the European Pact for Skills that aim to enhance employability levels for 6 million people (European Commission, 2023g). Once the technical and non-technical levels of the solar labour force have improved, the EU's dedication to advanced industry tools and big data (European Commission, 2020) can bring fruition to the R&D for more cost-effective, less resource-intensive solar manufacturing technologies.

The groundwork laid by the EU Green Deal Plan is also critical in formulating eco-friendly, sustainable recycling and reuse frameworks for the life cycle of solar products, which has already been emphasised in the EU's general efforts to create a circular economy in various economic aspects (Radavičius et al., 2021; European Environment Agency, 2024). In the Plan, even greater importance is attached to the recycling and reuse of materials with the Critical Raw Materials Act to facilitate raw material reuse where relevant and reduce dependence on input imports (European Commission, 2023g). Furthermore, the EU Green Deal Industrial Plan also sets out guidelines for regulatory sandboxes in which environment solar manufacturing companies can experiment with novel technologies before official launch (European Commission, 2023g), giving them the opportunity to conduct rapid experimentation and have more motivation for disruptive, cutting-edge techniques within safe regulatory settings for authorisation and product certifications. This sandbox concept would be of the most values to small and medium enterprises, investors who have little experience in navigating the tricky EU market.

When efforts for technical, technological improvements are carried out in a comprehensive fashion, the optimal technologies for solar PV manufacturing can be accomplished without having to divide into stages and countries but still meet with current stringent environmental standards, thus paving the way for long-term deployment, patenting and commercialisation.

4.3. Regional Cooperation and Market Integration

Collaboration among EU member states occupies a tremendous role in reaching the clean energy objectives, particularly in the competitive and cost-effective renewable source like solar power. Regional cooperation is also the key to the standardisation and consistency of policy and technological innovation support for the solar manufacturing companies and investors. The EU Green Deal Industrial Plan highlights this paramount importance of regional cooperation by exhibiting its support for the development of various forms of collaboration with nations in the EU to accomplish net-zero industries (European Commission, 2023g). To exemplify, the EU Solar Energy Strategy has underscored the need for cross-border cooperation on solar energy projects, as well as cooperation between various stakeholders across the value chain, from law enforcement, solar production and environmental guidelines, transport, infrastructure to technical solar engineering and construction, social partners and regional authorities (European Union, 2022a). Therefore, the supply and demand side of the solar manufacturing industry can be coordinated together to generate a robust renewable energy industry.

What makes regional cooperation more vital is the integration of the solar production sector into other Green Deal initiatives. As the EU Green Deal Industrial Plan is concerned with multiple categories of clean energy, not just solar power, it is imperative to integrate the solar manufacturing policies with other green policy frameworks for the purpose of a well-rounded green energy scenario for the EU because the EU cannot just rely on solar power as the sole renewable source. In addition, integration into other Green Deal initiatives can spur sectoral innovation and market demand, which can be seen in the example of the EU Hydrogen Strategy when actions to enhance the hydrogen industry also involve greater allocation of budget to renewable energy funding and better policy framework design (European Commission, 2023c). As a result, the solar manufacturing sector should not be viewed as a standalone field that conflicts with other renewable energy sectors but rather as a united entity with other Green Deal initiatives under the support of the EU Green Deal Industrial Plan.

4.4. Energy Security and Independence

The EU Green Deal Industrial Plan puts overwhelming emphasis on energy security and independence. With an aim to decrease dependency on oil and natural gas from Russia, as well as cheap input materials from China, the Plan establishes the framework for diversifying imports and trade partnerships, shifting away from almost monopolistic reliance on Russian and Chinese imports and avoiding the creation of supply chain bottlenecks. Therefore, the EU has made significant efforts to have a varied network of trade relationships with numerous partners across the world with trade openness as the motto, exemplified by the exploration of free trade agreements with other partners in the APAC region like Australia, India, Indonesia and New Zealand (European Commission, 2023g). Across the Atlantic, the EU-US Task Force on the Inflation Reduction Act aims towards practical remedies to EU concerns related to the value chains and the net-zero goal during the clean energy transition whereas across the Mediterranean, the EU has initiated Sustainable Investment Facilitation Agreements (SIFA) with African partners (European Commission, 2023g). Also, regarding the imports of REEs and other input materials, the EU is also shifting away from China and working in concert with similar partners to form a "Critical Raw Materials Club" along with the Critical Raw Materials Act to have a more secure, affordable and sustainable source of raw materials for the solar manufacturing, in combination with the use of International Procurement Instrument for the first time (European Commission, 2023g). Along with that, to create a level playing field, the EU Green Deal Industrial Plan also ensures fairness by taking advantage of trade defence measures to protect the Single Market of the EU from unfair trade activities including unjust subsidies or dumping from their trade partners.

These actions under the EU Green Deal Industrial Plan, when taken simultaneously, can create a brighter, more guaranteed scenario for the EU's energy security and independence as it can rely on diversified sources of input materials while at the same time working on the technologies to reduce its dependence on external assistance. These factors also mitigate supply chain vulnerabilities in the production of solar PV due to being able to avoid a single point of failure when every aspect has to depend on one nation, or in this case, China, considering the current geopolitical climate between it and the EU with conflicts on several fronts.

Chapter 3: Methodology

1. The PRISMA framework for systematic review

To identify the potential challenges and recommendations, the systematic review methodology is chosen for this study. The reasons for the choice of such a method is that systematic reviews are a method for pinpointing and synthesising all available existing pieces of research, literature, or measures for a particular topic (Scheerder et al., 2017). Also, different from the traditional literature review in the previous Chapter 2, systematic literature reviews have some fundamental differences in the following aspects: (1) having clearly defined and transparent methods of collecting information and data, (2) following a standardised set of stages for literature selection, (3) being "accountable, replicable, and updatable", and (4) engaging users in the process to guarantee its relevance and usefulness (Preston, 2023). This research method is particularly suitable for this particular study because in order to identify challenges in the solar manufacturing of the EU, it is essential to have a clear and detailed overview of the sector from the perspectives of policymakers and solar manufacturing companies so that the areas successfully addressed and the gaps remained can be thoroughly acknowledged, thus allowing for timely and effective recommendation establishments and laying the groundwork for future policymaking to compliment the EU Green Deal Industrial Plan.

The systematic review in this study will concentrate on reviews of the EU initiatives related to the solar manufacturing industry and the most representative solar manufacturing companies in the EU to provide a comprehensive picture of the success and challenges in the sector, as well as ensuring the effectiveness of the recommendations proposed in this thesis. Also, in all industries including the PV solar production, analysing issues from the standpoint of policymaking in various initiatives and representative companies can help uncover the gaps between policies and reality to make the initiatives genuinely useful for the solar manufacturing companies as the issues of the gap between energy sector policies and challenges are existent in several policies from different regions in the world (Savvidis et al., 2019). Also, specifically in the EU market, insufficient grid planning and lack of flexibility resources have the potential to derail the efforts and development boosts from the EU-level initiatives due to the inability to connect all relevant stakeholders involved and streamline the clean energy transition, thus potentially making the switch to PV solar panels unlikely to materialise (Meikle, 2024; SolarPower Europe, 2024f). Hence, the study conducts the systematic reviews for the EU initiatives pertinent to solar manufacturing first to understand what aspects of the sector have been addressed and how different initiatives have progressed over time to demonstrate EU's improvements in its commitment to the clean energy transition. Thereafter, reviews of representatives of solar manufacturing companies in the EU are implemented to uncover the real-life effects of EU initiatives on the company's side and the genuine challenges and opportunities from their perspective in order to fine-tune the recommendations and EU-level policymaking process. This review of EU firms would play a critical role in bridging the gap between policy on paper and reality in the region already known for its lengthy bureaucratic processes on several fronts.

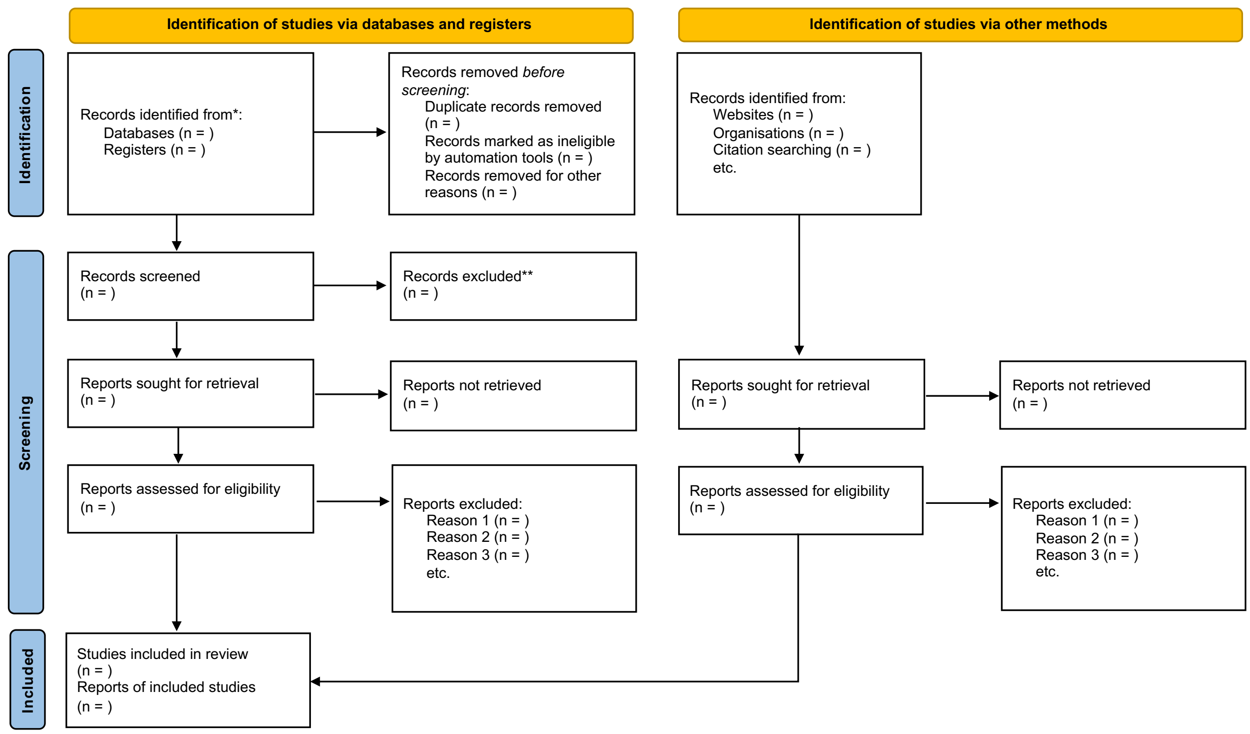
Once the subjects of the systematic reviews – EU initiatives for solar manufacturing, and EU solar manufacturing companies are selected, the systematic review framework is contemplated to ensure the rigour of the method. In this study, the framework chosen is the PRISMA structure, standing for Preferred Reporting Items for Systematic Reviews and Meta-Analyses, which is a transparent, vigorous, and structured process to systematically identify, screen, and analyse relevant case studies and literature in response to the given issue.

1.1. The PRISMA framework

The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) is a structured framework for developing systematic reviews to ensure that all the relevant findings are collated and synthesised. This approach is able to provide a coherent comprehensive picture of the investigated topic and serve the role of tackling the issues that cannot be done by individual studies of separate items (Page et al., 2021). Even though the PRISMA structure is designed mostly for research in the field of healthcare interventions, the set of stages and checklist items are applicable to other sectors such as social and education policies (Page et al., 2021).

One of the most useful aspects of the PRISMA framework is that its clearly defined procedures enable readers and other relevant stakeholders to evaluate the suitability, appropriateness, and reliability of the findings, thus able to understand the applicability of the studies to their circumstances (Page et al., 2021). As a result, the PRISMA structure, in the context of the EU solar manufacturing sector, affords EU policymakers and companies the overall situation of the industry to acknowledge what has been done and what can be done further, given the uncertainty of the sector in terms of pricing and regulatory challenges. In addition, the checklist items and the eligibility criteria of the PRISMA framework provides future research with easy opportunities to replicate and update the systematic reviews and reduces the "research waste" as later studies are not required to go through all the existing items and reports covered in the study again (Page et al., 2021). Considering the fact that the policymaking process of the EU is highly complex with various strategies and initiatives already in place or awaiting for future rollout, there can be many more initiatives enforced by the EU to further support solar manufacturing capacity improvements and deal with market trends from China and other markets, as well as the possibility of rising new EU companies in this sector. Also, from the perspective of firm reviews, the PRISMA framework allows future studies to update the list with analysis of more companies that can rise in the future or serve other specific research purposes without having to go through already analysed companies to create "research waste". Following the PRISMA structure, hence, addresses that with the ability to retrace and update the list with future changes in the EU initiatives and contemporary trends in solar manufacturing companies.

The PRISMA framework follows the structure as illustrated in Figure 6.



*Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).
**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.

Figure 6. PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources. Source: PRISMA (2020)

Figure 6 shows the three main stages of the PRISMA systematic review procedures: identification, screening and inclusion. The first stage involves identification of relevant documents from all sources: databases, registers, websites, organisations, and citation searching, which are all subject to preliminary filters first to remove duplicates or illegible files. The reasons for removal in this stage is usually related to the formatting and content duplicates rather than for more in-depth reasons in terms of content relevance. After that, screening proceeds with eligibility criteria established to remove the literature that is not of great value or interest to the study. This is the most crucial step, which mainly depends on the criteria set to assess eligibility and allow for the inclusion of the most crucial literature only, so it can be understood that the robustness of the systematic review lies in the eligibility criteria in the screening stage to a significant extent.

Once the fundamentals of the PRISMA framework is elaborated on, the above procedure is applied to the search for EU initiatives pertinent to solar manufacturing, as well as EU solar manufacturing companies in order to identify the subjects for the systematic review of this study.

1.2. Applying the PRISMA frameworks for inclusion of EU solar manufacturing initiatives under the EU Green Deal Industrial Plan

The selection process of EU solar manufacturing initiatives under the EU Green Deal Industrial Plan follows the above mentioned three-stage procedure of the PRISMA framework with details of each step as follows.

1.2.1. Identification

For sources of initial identification, the following databases and registers are chosen for filtering relevant content

- **EUR-Lex**: The official database to access verified and complete repertoires of EU law documents, which will be the largest source of literature for this study.
- **European Commission**: The official website of the European Commission, the executive body of the EU responsible for the proposal, implementation of new laws and policies in the region and the allocation of funding for regional schemes and activities.
- **International Energy Agency**: The international agency responsible for bringing forward analysis, data, and policy suggestions in the energy sector for governments and organisations to work towards green energy transition.
- **SolarPower Europe**: The primary association for the solar PV sector of the EU region representing more than 300 "companies and organisations across the entire solar value chain", mostly based in the EU (SolarPower Europe, n.d.-b), which collaborates with governments and solar companies in Member States to address policy-related opportunities and bottlenecks in the industry.
- **Google**: The most popular general search engine on the Internet. Even though this is not the main method for the identification stage, this serves as a compliment to the above websites and databases for a more effective and exhaustive search.

The search strings to initially identify relevant literature include: "EU Green Deal Industrial Plan", "Green Deal Plan", "EU Green Deal", "solar PV", "solar manufacturing". Thereafter, as the websites and databases show multiple results, duplicate removals in each website and database above are implemented to allow the unique values or literature to go through.

1.2.2. Screening & Exclusion

The next step is screening, which involves finding records and literature for retrieval and setting eligibility criteria for the final literature to be included in the systematic review. The retrieval and eligibility filter method is based on the following exclusion criteria:

- **Non-English publications**: To ensure understandability and transparency of this study, any records not available in English will be excluded.

- **Non-EU initiatives**: Policies and initiatives that do not focus on EU or have a rather broad international focus will be removed as this study revolves around the solar manufacturing sector within the EU.
- **Broad Energy sector focus**: Policies and initiatives that only concentrate on the general energy sector without particular focus on the solar PV industry are also excluded because the study is concerned about the solar manufacturing only, not other types of green energy.
- **Non-official documents of communication**: Documents for policies and initiatives on the EU levels have several forms and variations, such as opinions, preparatory law documents, provisional assessments, and cover notes, so only official files for communication purposes are accepted and any other non-official documents are excluded to preserve the integrity and leanness of the systematic review.
- **Pre-2020 initiatives**: Because the EU Green Deal Industrial Plan has been built upon the EU Green Deal, which was presented on December 2019 (European Commission, 2021b). Since this time stamp was already at the end of 2019, any policies and initiatives that dated prior to 2019 are excluded as they are not directly related to or has fundamental differences in goals and solution directions compared to the EU Green Deal Industrial Plan.
- **Policies and initiatives not under the EU Green Deal**: This study is focused upon the challenges and recommendations for improving solar manufacturing capacity under the EU Green Deal Industrial Plan, any documents and reports that do not fall under the context of the EU Green Deal Industrial Plan or its base initiative EU Green Deal are removed so that only the most relevant literature related to the Plan is analysed for further discussions.

The list of policies and initiatives that can pass the above exclusion criteria will be the final candidates for the systematic review that is subject to thorough reviews and analysis to highlight the successful areas addressed and the remaining aspects unresolved, laying the groundwork for discussions and recommendations.

1.3. Applying the PRISMA frameworks for inclusion of EU solar manufacturing companies

For this section, due to the time and resource constraints of this study, the approach will be altered to a small extent compared to the section for the EU initiatives. While EU-level initiatives related to the solar manufacturing sector can be rather finite in numbers and make it easier to set eligibility criteria, there are 166 solar manufacturing companies in all aspects of the supply chain as of 2025 (SolarPower Europe, 2025). Meanwhile, many companies have, to a small or large extent, similar scope of operations and levels of support from national governments and the EU in different types ranging from funding to policy streamlining, so analysing the large number of companies, even though they may contain slightly different features in their missions and activities, would be repetitive. Therefore, the aim of the PRISMA selection procedure for EU solar manufacturing companies is to choose two most representative companies that serve different purposes in the activities across the solar supply chain to illustrate the real-life effects of EU initiatives in the industry. The identification and screening process is elaborated on with more details as below.

1.3.1. Identification

With respect to sources for initial identification, this study uses the **SolarPower Europe** website as the main platform with complete information on the list of EU solar manufacturing companies as SolarPower Europe is the official association for the solar sector in the region. However, other sources are also utilised as auxiliary platforms to retrieve more detailed information related to those companies, which include:

- **European Commission**: The official website of the European Commission, which can provide data related to companies that have exposure to EU initiatives and funding programmes.
- **Company reports**: The official reports published publicly in the company's websites that reveals information related to the firms' missions, activities, and policies, as well as operational and financial performance for further evaluation.
- **Google Search**: The most popular general search engine on the Internet, serving as the exhaustive search platform to obtain relevant data and news bulletins in all aspects of solar manufacturing companies in the EU that are not publicly stated by the firm itself or the European Commission.

1.3.2. Screening and Exclusion

Once the initial identification step is conducted, the chosen subjects are subject to screening based on the following exclusion criteria:

- **Headquarters based outside EU and limited EU production**: Companies that have headquarters located in a different country other than those in the EU or still have their main office in Europe but have less than 20% of their production based in EU will be excluded because those companies' strategic positioning, supply chains, and market directions differ from those mainly operating in Europe, making them marginally affected with EU policies and less representative for policy-focused analyses in this study.
- **Companies only engaged in research, installation and distribution**: As this thesis is concerned with solar PV manufacturing capacity, companies that concentrate exclusively on research and development, installation, and distribution of solar PV will be excluded as the merits and demerits for these are dissimilar from those involved in solar PV production.
- **Companies with insufficient public data**: Companies with inadequate publicly available information can pose difficulties to creating a thorough and accurate analysis, thus making it challenging to evaluate policy and operational relevance under the EU Green Deal Industrial Plan.

- **Companies without any exposure to the chosen EU-level solar manufacturing initiatives**: This concerns companies that operate within the EU but do not receive any benefits or challenges and are not relevant to any of the chosen EU initiatives. These were discussed in the previous analysis section but will also be excluded.

After this exclusion stage, the selected candidates will go through one more eligibility criterion as the procedure for company selection is slightly different. The eligibility criterion at this step is the representation of unique segments in the solar PV value chain as only two solar manufacturing firms are singled out. To be specific, one representative comes from upstream manufacturing focusing on the production of input materials while one representative comes from the downstream manufacturing focusing on the assembly and sales of the final product (Giacinti, 2023), which together create a holistic understanding of how EU companies reap benefits and encounter challenges in the entire supply chain of solar PV manufacturing.

2. The SWOT analysis method for subjects of the systematic review

As for the final candidates included in the systematic reviews, they will be subject to further analysis following the SWOT technique. The SWOT framework is a strategic analysis tool to help identify internal factors: strengths and weaknesses, and external factors: opportunities and threats, within business to provide a comprehensive assessment about the current situation of a business, a strategy, and assistance in further fine-tuning of the strategy to achieve a specified goal (Australian Government, 2024; European Commission, 2025b). Table 2 gives an overview of factors included in the SWOT analysis.

	Favourable for achieving objectives	**Unfavourable for achieving objectives**
External origin	**Opportunities** Positive externalities which can provide an advantage for the intervention, but remain beyond its control	**Threats** Negative externalities which can put the intervention at risk, but remain beyond its control
Internal origin	**Strengths** Positive internal factors controlled by the organisation or country, and which provide foundations for the future	**Weaknesses** Negative internal elements which are controlled by the organisation and to which key improvements can be

Table 2. Factors to contemplate in the SWOT analysis

Source: European Commission (2025)

The merits of the SWOT analysis lie in the ability to provide an understanding of the business or strategy and priority areas that require more considerable prioritisation for future actions (Australian Government, 2024; CIPD, 2025). This has been proven useful when analysing the activities of a company and the policymaking process of several fields within EU countries (Uhrenfeldt et al., 2012; Giusti et al., 2020; European Commission, 2025b). In the context of this study, the SWOT framework can, allow for the understanding of how well EU solar initiatives and policies have been implemented and how effectively EU solar manufacturing performed so far so that success stories and room for improvement are accurately identified. Even though the SWOT technique for analysis can be subjective due to its dependence on the writers' point of view on the discussed matter (European Commission, 2025b), this is already mitigated by the thorough and transparent PRISMA framework systematic framework to choose the most representative EU solar initiatives and solar manufacturing companies.

CHAPTER 4: EMPIRICAL RESULTS

1. Systematic review and analysis of EU initiatives for solar manufacturing under the EU Green Deal Industrial Plan

1.1. Systematic reviews of EU initiatives

The PRISMA procedure has yielded the following results, as illustrated in Table 3.

Stage	Number of Documents searched	Number of Documents proceeding to the next stage
Identification	EUR-Lex: n = 1819 European Commission: n = 9513 IEA: n = 4 SolarPower Europe: n = 7 Duplicate filters already applied to show unique results	n = 11,343
Screening	Documents removed by removal reason: • **Non-English publications**: n = 249 • **Non-EU focus**: n = 980 • **Too general focus**: n = 2,645 • **Non-official documents of communication**: n = 4,136 • **Pre-2020 initiatives**: n = 1,459 • **Policies and initiatives not under the EU Green Deal**: n = 1,869 Note: due to significant overlapping, many initiatives are excluded for multiple reasons but only counted once at the first applicable rationale.	n = 5

Inclusion	n = 5	

Table 3. The PRISMA procedure for the selection of EU initiatives

Even though the initial number of documents searched appear staggering and unmanageable, most of the files are variants of the same plan and initiative or just derivatives from different, fragmented policies as the search engine shows all the possible results when they have the slightest relevance to EU Green Deal or just the solar sector only. This poses a challenge to the screening so for this stage, it has to combined with Google search engine fine-tuning in order to identify unsuitable literature. After a thorough and exhaustive search and filtering process, this study identified 5 initiatives:

- **REPowerEU Plan**: An initiative under the EU Green Deal to mitigate energy dependence on Russia, with specially dedicated strategy sections for the solar industry: the EU Solar Energy Industry and the European Solar PV Industry Alliance (European Union, 2022b).
- **Net-Zero Industry Act**: An initiative under the EU Green Deal Industrial Plan to transform the region into the manufacturing hub of clean technologies and occupations and achieve net zero objectives over the next few decades (European Union, 2023b).
- **Critical Raw Materials Act**: An initiative under the EU Green Deal Industrial Plan with a view to establishing a secure supply of critical raw materials essential for clean technologies and the green energy transition by dint of strategic partnership formations and permission system streamlining (European Union, 2023a).
- **Innovation Fund under EU Emissions Trading System (ETS)**: An EU funding scheme for climate policy with a particular emphasis on the energy and industry sector aimed at putting climate-centred strategies and activities into practice and decarbonising the EU economy but still maintaining its competitiveness (European Commission, n.d.-c). Under the new EU ETS established in 2023, the size and scope of the funding scheme has been expanded to account for greater ETS allowances, more novel financial support tools and involvement from Member States with geographical disadvantages (European Commission, n.d.-c).
- **Horizon Europe**: An EU flagship research & development funding scheme for the 2021-2027 time frame aimed at addressing climate change and the United Nations' Sustainable Development Goals with the establishment a new European Innovation Council, open-access publications and science principles, and objective-driven industry collaboration (European Commission, 2021a).

These five EU-level initiatives are the most suitable final subjects for the systematic review because these initiatives have key performance indicators and strategies specific to the solar sector. As a result, these as a whole cover comprehensive aspect of solar manufacturing, ranging from deployment and industry alliances, manufacturing capacity and raw material supplies, to factory and R&D financing. As a result, a systematic review of these five initiatives can provide the current circumstances and prospects of the solar manufacturing industry in the EU and outline for timely, effective discussions and recommendations.

1.2. SWOT Analysis of EU Initiatives in Solar Manufacturing

After selecting the relevant subjects through the PRISMA framework, the five initiatives are assessed with the SWOT analysis to identify their strengths and weaknesses, as well as the opportunities and threats derived from the context of such initiatives. All the analyses are then synthesised all together in order to pinpoint areas that these policies have successfully dealt with and have failed to address effectively, leaving the gaps for future recommendations.

1.2.1. REPowerEU Plan

REPowerEU Plan plays a central role in the EU's response to the energy security threats due to the Ukraine-Russian conflict, mainly aimed at speeding up the region's renewable energy transition and reduce the reliance on fossil fuels imported from Russia (European Union, 2022b). Even though the need for energy dependence reduction already existed, it was manifested in the most transparent manner through the establishment of the REPowerEU Plan and prompted EU Member States to tackle this issue with clear actions. Within the broad initiative, solar energy is set as a key driver of the energy transition, hence the two critical components of the REPowerEU Plan specifically dedicated to this industry: the EU Solar Energy Strategy and the European Solar PV Industry Alliance.

The EU Solar Energy Strategy is a sub-initiative under the REPowerEU Plan and sets ambitious deployment goals with over 320 GW of solar PV by 2025, and nearly 600 GW by 2030 to replace 9 billion cubic metres of natural gas consumed per year by 2027 (European Union, 2022a). The strategy also highlights legitimate actions namely compulsory rooftop installations for new and existing buildings, including public, commercial and residential types, by different time stamps, combination of agricultural land with PV to create agri-PV, simplified permit-granting procedures, PV-connected grid upgrades to bolster large-scale utilisation across the EU.

To further complement this strategy, the European Solar PV Industry Alliance was established to foster resilience and strategic independence of the EU's solar PV value chain. By congregating various stakeholders across the solar PV value chain from both the public and private sectors such as manufacturing companies, social and education partners, R&D organisations, the alliance aims to ameliorate cooperation, innovation, and investment by aiding in pinpointing opportunities, challenges, and solution proposals to remove bottlenecks and boost domestic solar production and deployment. Together with the EU Solar Energy Strategy as sub-components of the REPowerEU Plan, the alliance is expected to streamline the region's efforts to achieve the above ambitious targets for solar utilisation.

The following SWOT analysis assesses the REPowerEU Plan, as well as its corresponding solar initiatives in order to showcase their strengths, weaknesses, opportunities, and threats within the context of enhancing solar manufacturing of the EU.

- **Strengths**

The most evident strength of the REPowerEU Plan is the ambitious goals with clear motivation and focus. While the need for environmental policies and initiatives is a foregone conclusion in the current context, these initiatives sometimes turn into a tool of political rhetorics rather than real actions, hence the wide gap between rhetorics and action in climate change measures (Price, 2021), which may manifest in the form of bold statements of vague words and phrases. However, in the case of REPowerEU Plan, the goal is clearly specified with detailed and specific wording which is "to phase out Europe's dependency on Russian energy imports as soon as possible" "by fast forwarding the clean transition and joining forces to achieve a more resilient energy system and a true Energy Union" (European Union, 2022b). Besides the fact that the wording is specific about its target, the Plan also sets out ambitious and quantifiable goals for solar PV with almost 600 GW of newly installed solar capacity by 2030. The clear strategic focus and goals from the REPowerEU Plan already shows a significant strength from the first step as it allows and incentivises the EU Member States to ramp up their actions and keep their promises when the Plan has been publicly announced, as well as understanding what outcomes and directions need to be implemented with the presence of quantifiable objectives.

This strength also relates to another aspect that can be included as additional strength: the real-world acceleration of solar deployment in the European Union. As a matter of fact, the newly installed solar capacity of the EU constantly beat records each year, with the figures for 2022, 2023, and 2024 being 40, 62.8, and 65.5 GW respectively (SolarPower Europe, 2024a). Also, the actual cumulative capacity exceeds the expectations from 2021 to 2023, to varying extent and is on track to meet the long-term targets through 2030 for the solar sector (Losz, 2023). This proves that the ability of the REPowerEU Plan with all its sub-initiatives to make genuine contributions to improved solar manufacturing capacity and utilisation in the region and lays the foundation for a more auspicious solar future for Europe to meet the final 2030 goals.

Furthermore, the capability to establish an industry alliance, the European Solar PV Industry Alliance, is a unique strength of the REPowerEU Plan. This is because the ability to engage direct stakeholders: manufacturers, research institutions, investors in the solar industry and motivating them to work together and form alliances plays a critical role in streamlining the manufacturing process across the solar supply chain, but this can be a challenge to accomplish due to the potential prolonged duration and conflicts of interest among different parties in this issue. The alliance has been able to contribute to various solar and decarbonisation projects across the EU, also set up ambitious quantified targets of its own: enhancing the solar capacity by 30 GW annually by 2025 (European Solar PV Industry Alliance, 2022). Therefore, the success of creating an industry-specific alliance that can make actual contributions reflects the strength of the REPowerEU Plan with its serious dedication to achieving the clean energy transition goals with the solar sector being a key driver of the process.

- **Weaknesses**

The REPowerEU Plan also exhibits several weaknesses, the first of which lies in the absence of legally binding manufacturing requirements to meet the targets set by the Plan. Even though the Plan establishes clear and ambitious goals, it does not specify legally binding requirements for EU Member States to achieve those targets. In the absence of such factors, national governments and manufacturers in the industry may lack the incentive or pressure to invest in larger-scale solar manufacturing projects as failure to do so does not bring any legitimate consequences for them so achieving those objectives mostly depends on voluntary actions emanating from environmental awareness, morality, and political will. As EU countries have already been notorious for its high levels of bureaucracy, putting a damper on productivity and innovation (Bauer, 2024), this lack of enforceability and accountability just makes it worse for the various stakeholders in the EU solar manufacturing industry to make their utmost efforts and threatens the capability to meet the Plan's long-term targets as they may prefer sticking to the original way of thinking and working.

Another weakness of the REPowerEU Plan is the fragmentation in the solar project funding and solar policy implementation across Member States. The funding from this initiative remains allocated for each country in the EU differs significantly from each other and fails to reflect the actual amount needed in relation to the extent of Russian energy dependence. For instance, Germany received only 8% of the Recovery and Resilience Facility funds despite enormous Russian dependence while Italy, with half as much energy derived from Russia, received 20% (Weingärtner, 2024). Also, the national policy implementation pertinent to the solar manufacturing sector varies from one country to another within the EU as different countries set different priorities for solar manufacturing and deployment targets. While France offers tax credits from its own national budget to provide financial support for solar manufacturing companies (IEA, 2024a), Poland mostly just relies on EU-level funding (European Commission, 2025a). In other aspects, Germany sets ambitious goals of 215 GW of installed solar PV by 2030 with shares of renewables already at 50% in 2023, initiates funding schemes for both domestic solar manufacturing and R&D (IEA, 2024a), Czech Republic's share of solar PV in total electricity generation only accounted for 4% in 2023 and was criticized to set unambitious goals for this share, at just 22% by 2030, which later increased to 30% (Gordon, 2024). Permitting time also varies significantly with countries like Spain already able to streamline the solar PV approval process into just a duration of 2-4 months (Serrano, 2024), its takes 9-12 months in Czech Republic and Romania for the same procedure (Fratila & Dulamea, 2024; Hejduk et al., 2024) while in Italy, the duration is 30-75 days but usually prolonged to 2 years by lengthy environmental reviews (Review Energy, 2024). These examples do suffice to illustrate the discrepancies between the level of policy commitment and implementation under the REPowerEU Plan between EU Member States, threatening the integrity and possibility of achieving the mutual goals.

- **Opportunities**

Under the context of the REPowerEU Plan, there exist several opportunities from external sources that can act as a useful boon to the Plan's established objectives. With the Russia-Ukraine conflict, the uncertainty of post-COVID economy, and the rising sentiment of protectionism and nationalism, reshoring and nearshoring in manufacturing has been gaining traction for the sake of reduced transportation and tariff costs, together with reducing risks and maintaining the sustainability of the supply chain of the production (Evans, 2024). This is particularly the case when geopolitical risks have risen (IEA, 2023b) and the US government with Donald Trump administration is sparking a tariff fight between nations against international trades. Therefore, energy sovereignty emerges as a key strategic position in today's era of uncertainty to secure the EU's industrial competitiveness (Mathieu Didry, 2025) so this urgency can motivate different stakeholders in the solar manufacturing sector to take energy self-reliance into serious consideration and make genuine efforts to scale up domestic solar PV manufacturing.

Another emerging opportunity for the REPowerEU Plan is related to the breakthroughs in solar manufacturing technologies that have been taking place globally. During recent years, there have been a multitude of innovative modifications and novel technologies for solar PV to allow the solar sector to provide improvements in various aspects. Those innovations entail perovskite-silicon tandem cells that have exceptional energy yields and lower manufacturing expenses, bifacial solar cells to absorb sunlight from both sides, flexible and lightweight panels for portability and new applications, transparent solar panels to enhance aesthetics and integration into the urban settings, panels for nighttime and rain, as well as AI, quantum computing, and IoT to optimise solar performance (Elliott, 2024; Team GreenLancer, 2024). Therefore, it lays a robust groundwork for the future development of the EU's solar manufacturing industry and has the potential to address some of the technological challenges of solar PV.

- **Threats**

When it comes to external sources, threats must also be given equal attention to identify outside factors that may hinder the progress of the REPowerEU Plan. The main threat lies in the possibilities of supply chain disruptions across the solar PV supply chain. The supply of critical raw materials for solar PV has met with serious bottlenecks after China's imposition of stringent control on these materials' exports (Baskaran & Schwartz, 2024), leaving little time for the EU to find alternative partners on time to meet the domestic demand. External shocks such as similar pandemic onslaught like COVID-19, more frequent natural disasters, or most importantly during recent days, uncertain and seemingly random trade defence measures from the Donald Trump administration in the US from the beginning of 2025, can disrupt the supply chain of solar PV manufacturing any time while the EU may not have adequate time to secure alternative sources of materials.

Besides that, the competition between different kinds of renewable energy also represents a complication in terms of funding and policy priority on both the EU and national levels. Even though this is still within the REPowerEU Plan, it does not come from within the solar manufacturing field so it can be considered as a threat from an external origin. As the REPowerEU Plan also entails other categories of green energy such as wind, and hydrogen, stakeholders in the area of solar manufacturing have to face competition for priority and funding with these sources but the funding sources for this initiative is also finite and has strict eligibility criteria for the receipt of investment capital. Compounding this fact is that targets for wind and hydrogen energy are not on track to meet the 2030 targets (Losz, 2023) so the solar PV manufacturing sector may have to give way to these types in policy commitments and funding.

1.2.2. Net-Zero Industry Act

Net-Zero Industry Act, announced in 2023, is an initiative under the EU Green Deal Industrial Plan. The Act's primary objective is to ameliorate the region's manufacturing capacity for net-zero technologies and their corresponding components (European Union, 2023b), which is a narrower strategic focus compared to the above initiative REPowerEU Plan. The following SWOT analysis for the Net-Zero Industry Act is conducted to highlight its strengths, weaknesses, opportunities and threats within this context.

- **Strengths**

As the Net-Zero Industry Act defines what constitutes net-zero technologies, solar energy has been explicated cited as a strategic net-zero technology (European Union, 2023b). This transparent and straightforward recognition has emphasised the importance of the solar energy in the EU green transition and put the pressure on relevant stakeholders and even the EU itself to push forward with its solar manufacturing capacity. As a matter of fact, the Net-Zero Industry Act is the first Act among all other initiatives to establish a specific EU-wide self-sufficient manufacturing target for the solar energy sector of 40% of the deployment demand by 2030 (European Union, 2023b) – a quantified objective that enables the region and national governments to assess their progress in this path.

Another strength lies in the ability to set a clear duration for streamlining the grant-permitting procedures for net-zero technologies, or the solar PV manufacturing in this case, across EU Member States. Rather than using vague wording, the Net-Zero Industry Act clearly specifies that the duration for the grant-permitting process is 9 months for the construction of facilities with manufacturing capacity of less than 1 GW, 12 months for those with more than 1 GW capacity, and the duration is even halved for the expansion of existing facilities (European Union, 2023b). With this specific time targets, the bureaucracy in the EU Member States' governments can be effectively tackled to remove unnecessary barriers and smoothen the setup and expansion of new and existing solar manufacturing facilities in the region.

- **Weaknesses**

The primary weakness of the Net-Zero Industry Act is the absence of enforceable mechanisms for the established targets. As there are no clauses outlining the binding requirements and consequences for the failure to meet the target, the effectiveness of the Act depends extensively on the voluntary will and actions from EU Member States, which consequently leads to fragmentation in policy commitment and implementation. Countries with high uptake of solar energy already have resources and greater motivation to grow the solar manufacturing capacity further whereas countries with slower uptake, especially in Eastern Europe, will be even slower in ramping up this industry without binding pressure and pose a threat to the possibility of accomplishing the long-term 2030 aims. To make it worse, the Act also does not mention any new dedicated funding channels for net-zero technologies (Ragonnaud, 2025) so it means that existing funding sources will continue to drive the projects within the Act such as the Recovery and Resilience Facility, Horizon Europe, and Innovation Fund, which already have to cater to a wide range of green energy projects. As a consequence, the resultant financial assistance for solar manufacturing projects to improve its capacity may face unnecessary competition and only receive inadequate amounts.

Also, another weakness of the Net-Zero Industry Act is related to its strategic technological focus. It targets 19 net-zero technologies simultaneously, which can be excessive for one Act and deprives it of a strategic focus (Ragonnaud, 2025). This can engender distraction from the main goal and once again subject the solar manufacturing sector to unwanted competition with other clean energy sources for policy focus and prioritisation from the government and from the EU in general. Also, the technological focus in this Act excludes polysilicon production, which is an important element in solar manufacturing and a key bottleneck in the solar production supply chain within the EU (IEA, 2022). As a consequence, this absence can induce negligence of important input materials for the solar manufacturing industry and take away the deserved recognition and priority for polysilicon in particular and other equally important materials in general, setting a negative precedent for the sector in future EU policies. These two factors indicate several acute issues within the focus subjects of net-zero technologies within the Act due to the overwhelming focus that yet omits critical factors in the solar manufacturing industry.

- **Opportunities**

One of the opportunities for the Net-Zero Industry Act is concerned with the supply chain diversification both under normal circumstances to avoid risks related to over-dependence on one single source of input materials, and in the context of the US-China trade war. The uncertainty resulting from the conflict and constant tariff impositions from the US has motivated all other countries and regions to seek for trade partners elsewhere rather than focusing on just some large-scale trade partners (Hoang, 2025).

In this circumstance, considering the fact that solar PV costs have reduced by 90% from 2010 to 2023 (International Renewable Energy Agency , 2024), if the EU can look for a variety of trade partners to diversify its material production sources for the solar manufacturing supply chain, it can secure inexpensive sources but still at the same time strengthen its supply chain resilience and achieve cheap, robust domestic solar PV production. Also, the EU has been a long-standing big trade market so it is an attractive market for global trade partners when they are also striving to diversify their supply chain away from the biggest markets like the US and China in the era of trade war and uncertainty, so the EU can even find suitable trade partners in solar PV production more easily.

The room for opportunities to foster the Net-Zero Industry Act is present in the green energy investment momentum across the globe. This trend has become more prevalent in almost all countries in the world as investments in the transition into low-carbon energy broke the record to accomplish a 11% growth to $2.1 trillion in 2024 (BloombergNEF, 2025) or with initiatives like the Inflation Reduction Act in the US to promote investments in energy and climate, and the GX Strategy in Japan to boost the utilisation of green energy. This provides the motivation and momentum for the EU's Net-Zero Industry Act in particular and the green transition of the whole region in general to make further endeavour in its own solar manufacturing sector, as well as allowing the EU to find better opportunities of foreign direct investment, co-financing, and R&D collaboration in solar PV with fewer difficulties.

- **Threats**

The threats for the Net-Zero Industry Act are fundamentally similar to those faced by the REPowerEU Plan, which involves the possibilities of supply chain disruptions to the solar manufacturing sector in times of trade uncertainty and competition with other clean energy sources. However, a unique threat deriving from the context of this Act is the possible backlash from the WTO and other trade partners in response to the EU's trade-distorting subsidies (Valero et al., 2024), which can make the EU become protectionists and potentially have to roll back some of the self-sufficiency policies or reduce the domestic manufacturing target of the Net-Zero Industry Act as the region plays a huge role in international trade organisations like the WTO.

1.2.3. Critical Raw Materials Act

The Critical Raw Materials Act, announced in 2023 in the same day with the Net-Zero Industry Act, is an initiative focused on ensuring a sustainable and resilient supply of critical raw materials (CRMs) necessitated by the EU's green and digital transitions, or in particular, the field of solar manufacturing - an industry that relies on several CRMs for the final product (European Union, 2023a). The key objectives outlined in the Act is to allow for no more than 65% of EU's any strategic CRMs to originate from one single country, extract at least 10% of CRMs domestically for the EU's annual consumption, process at least 40% domestically, and recycle at least 25% of CRMs with a view to a circular economy, all of which are accompanied by the requirements for company-scale supply chain audits, environmental standards, and international cooperation (European Union, 2023a). Once the basics are outlined, the SWOT analysis for the CRMs Act is applied to understand the four aspects of this initiative.

- **Strengths**

One of the most obvious strengths of the Critical Raw Materials Act is the specific and measurable targets established. With clear wording and detailed figures for each of the target such as 10% for domestic extraction, 40% for domestic processing, and 25% for domestic recycling (European Union, 2023a), the Act, similar to the two previous initiatives, has made it easier for the EU Member States to understand the directions they need to take, what outcomes they need to head for, and how they can measure their progress log. In this way, the region is able to bring a concrete policy framework to help policymakers, and the industry navigate the CRMs market and build a resilient supply chain for the solar PV materials such as silicon, and gallium. Besides that, in terms of permit-granting procedures, the Act also specifies a maximum of 24 months for strategic projects entailing extraction, and 12 months for those entailing processing and recycling only (European Union, 2023a), thus driving the Commission and national authorities to commit themselves better to the deadline for quicker rollout of material sourcing for solar PV manufacturing.

Another strength of the CRMs Act is the specific policy priority and financial support for strategic CRMs projects, thus improving investor confidence, public trust, and private-public cooperation. Besides usual channels of support such as funding from the Recovery and Resilience Fund, Horizon Europe, and Innovation Fund, the Act also lists out various other sources and programmes for further amelioration namely Regional Development & Cohesion Funds, the Just Transition Fund, the European Fund for Sustainable Development Plus facility, the Technical Support Instrument, and the Single Market Programme (European Union, 2023a). This list is more varied and specific compared to other initiatives, able to incorporate a diversity of support platforms so that key projects for solar PV raw materials can have multiple options and reduce its dependence on Chinese imports of RREs.

- **Weaknesses**

In terms of weaknesses of the CRMs Act within the Commission’s control, one point, similar to all the previously analysed initiatives, is the excessive reliance of the Act’s success on national policy commitment and implementation. Again, as there is no legally binding requirement for the specific quantified targets, the progress of the region will rely on the level of dedication and prioritization in each nation, thus creating a wider gap between nations with higher uptake of CRMs production developing further and nations with slower uptake staying stagnant. This situation can leave repercussions for the EU-scale progress of CRMs self-sufficiency and the supply chain of solar PV manufacturing.

However, a particular weakness for the CRMs Act lies in the failure to acknowledge the costs and time involved in improving CRMs resilience supply chain. This is a heavy industry which is not quite the long-standing strength of Europe as its forte mostly revolves around the services and light industry sectors, so the path to expand this rather underdeveloped CRMs industry in the EU poses an enormous challenge to the Commission and Member States (Findeisen & Wernert, 2023). As a consequence, this process will be accompanied with colossal bills for construction, processing, and transportation of CRMs, as well as for the fiscal and administrative investments to streamline the bureaucracy in regulatory and environmental standards already infamous within the region and fund these projects. Besides that, the extraction, processing, and recycling of CRMs is a high-risk project with uncertain returns on investments (Findeisen & Wernert, 2023). These inherent factors of this field are what the CRMs Act fail to back up with data and specific policy support, which, if left unaddressed, can come with arduous unexpected difficulties in achieving the 2030 goals for the EU, and even worse, stagnation, environmental damage, and bureaucratic chaos in the CRMs sector.

Another technical drawback of the CRMs Act is the limited coverage of important solar PV materials. Even though the Act already acknowledges many crucial raw materials for the production of solar PV namely silicon, lithium, cobalt, and rare earths, it fails to incorporate some also critical materials for this process, the primary of which is silver as silver with its powder plays a vital role in electricity generation capacity for solar PV (The Silver Institute, 2023). Hence, the increasing demand for solar panels has made silver supply become more limited and competitive (Mining.com, 2023), thus representing a potential source of disruption to the EU's solar PV production supply chain. Additionally, indium is still an essential raw material that the EU is still vulnerable to (European Technology & Innovation Platforms, 2023) but is not included in the list of strategic raw materials in the Act. Hence, the list of strategic raw materials is inadequate in terms of covering raw materials necessary for the production of solar PV in the EU.

- **Opportunities**

There exist numerous external opportunities within the CRMs Act that can act as indispensable enabling factors for the progress of the EU. Like the opportunities for other initiatives for green energy transition, the global situation has given favourable conditions for accelerating the transformation in the energy usage thanks to increased awareness and investments for green energy in which the solar PV is a primary pillar. Also, geopolitical tension between large-scale trade partners in the world and the shift towards production localisation and supply chain diversification have motivated the Member States to reshore their solar PV manufacturing within the EU and seek alternative trade partnerships with countries such as Canada, Australia, and Southeast Asian nations, other than China with a seeming monopoly on RREs extraction and processing.

Furthermore, the CRMs Act can benefit from a variety of recycling innovations for solar PV that occur all around the world. Examples of solar recycling technologies are abundant in various countries, from fully recyclable PV modules in China (Kahana, 2024), automated, low-waste solar panels in the US (Thompson, 2025a), University of New South Wales's waste solar cell recovery for silicon, silver, and tin in Australia (Thompson, 2025b). This provides a strong momentum for the EU to invest in R&D for recycling CRMs for solar PV production, an opportunity for technology transfers in this area so that the EU can be independent in this industry, and possibly cheaper alternatives for the manufacturing of solar panels to make the EU become more competitive.

- **Threats**

The threats for the CRMs Act are partly similar to those outlined in the previously mentioned initiatives as CRMs in the EU may have to face considerable competition from other countries such as China that holds the lion share in REEs processing (Onstad, 2024), or the United States that has been rigorously expanding REEs extraction and processing as well (Easley, 2023). Therefore, even if the EU is able to achieve efficient mining techniques for CRMs, the EU may still have to rely on other countries, particularly China, for processing these materials for solar PV manufacturing.

Besides this cut-throat competition, the threats for CRMs even extend to price volatility and geopolitical risks. The prices for important CRMs are subject to severe fluctuations (European Union, 2023a) and leave the CRMs industry with a lack of confidence and future prospect guarantee. Also, to be more specific, some important materials for solar PV manufacturing are under medium to high risks in several categories; cobalt, for instance, face medium supply risks but extremely high levels of geopolitical risks, at 84% chance "of mining by one single country in 2030", or REEs represent both high supply risks with price volatility and geopolitical risks at 77% chance "of refining by one single country in 2030" (IEA, 2024b). These risks can put a damper on CRMs projects within the EU as the risks involved can be too high to encourage public or private investments in the sector, given the already challenging entry conditions for this heavy industry.

Last but not least, this threat is within the EU region but not necessarily within the CRMs Act and the Commission's control, but negative public perception of the mining industry can exert a detrimental impact on the implementation of extraction, processing, and recycling projects in the region. The mining field, as a heavy industry, still represents a negative sector from the public's standpoint due to its impact on the environment and the communities around the mining site (ICMM, 2023), which is also true for the EU – a region that already deviated from heavy industries and has stringent environmental and sustainability standards (EIT Raw Materials, 2025). In order to achieve the self-sufficiency goals established by the CRMs Act, new mining and factory sites are inevitable yet may face acute backlash from the public due to environmental and health concerns, thus prolonging these projects or even resulting in complete cancellation.

1.2.4. Innovation Fund under EU ETS

The Innovation Fund is an important funding programmes dedicated to "the deployment of net-zero and innovative technologies" for climate policy, particularly for the fields of energy and industry (European

Commission, n.d.-c). This funding channel's primary objective is to put forward market solutions for European decarbonisation and foster the EU's green transition and competitiveness. The projects targeted by the Innovation Fund are those with "innovative low-carbon technologies and processes in energy-intensive industries, including products that can substitute carbon-intensive ones", "carbon capture, utilisation, and storage" and "net-zero mobility and buildings" (European Commission, n.d.-c). The sources of funding for this programme are through the EU Emissions Trading System as the revenues are generated by auctioning ETS allowances for companies operating within the EU and invested back in the clean energy transition for the region.

The Innovation Fund will then be subject to the SWOT analysis as below to further highlight its roles and challenges.

- **Strengths**

The principal strength of the Innovation Fund is the robust and clearly structured financial backing system for green technologies, solar PV manufacturing included. The total funding amount can be equivalent to 40 billion euros for the 2020-2030 time frame and with 2023 revisions to the EU ETS, the overall size of this funding initiative has been augmented from 450 million ETS allowances to approximately 530 million ETS allowances (European Commission, n.d.-c), which contributes to the establishment of a dedicated and scalable funding source connected to carbon pricing. The initiative is also transparent on its ability to cover projects of multiple scales: large-scale ones with capital expenditure of more than 7.5 million euros, small-scale ones with that of less than 7.5 million euros (Agentschap Innoveren & Ondernemen, 2020). The financial support from the Innovation Fund also specifies criteria for capital recipient eligibility, which are based on "(1) effectiveness of greenhouse gas emissions avoidance, (2) degree of innovation, (3) project maturity, (4) replicability, and (5) cost efficiency" and subject to independent expert reviews (European Commission, n.d.-c), which make it easier for companies to acknowledge their own scoring and chances of guaranteeing the investment, together with reducing the risks of political favouritism. Also, along the way, the initiative awards fund based on the performance of the funded projects in terms of emission avoidance to ensure that the impacts are genuine and those responsible for those projects are held accountable and committed to the long-term aim. Hence, this vigorous and systematic support framework for capital investments from the Innovation Fund can prove a reliable tool for solar PV manufacturing companies and investors to push further in the sector.

Another strength of the Innovation Fund is its emphasis on fostering "first-of-a-kind highly, innovative technologies" so it means that not only does the funding programme invest in green technologies, but it also shares the risks with highly innovative ones that are just at its infancy. Therefore, the Innovation Fund can bridge the vast distance between R&D and market deployment that are commonly found in any sector, particularly in the field of green energy and solar PV manufacturing, as well as bringing breakthrough technologies to reality that can make the EU's solar PV sector become more competitive and scalable.

- **Weaknesses**

One of the glaringly obvious weaknesses of the Innovation Fund is the complex and time-consuming application process. The procedures to apply for funding receipt from this programme is highly technical and administratively difficult process as the applicant has to go through long application forms and wait for extensive approval time (Rossi, 2023), which can be a deterrent to the small and medium enterprises (SMEs) which often do not have the levels of liquidity and technology maturity required but represent the most potential. As a matter of fact, in all of the projects signed by the Innovation Fund not confined to the solar energy sector, the proportion of SME participants only accounts for 15.28% of the total, which is a small level and reflects the dominance of big, large-scale corporations (European Commission, 2023b). Also, when it comes to solar energy alone, the number of signed projects is only 8 spanning from 2021 to 2024 and the number of participants coming from SMEs is also 7 out of 25 for the solar sector (European Commission, 2023b).

To add to the downside to the Innovation Fund, the programme's revenue is also dependent on ETS Carbon Price. As carbon prices in the EU tend to be volatile and has been following a downward trajectory from the 2022-2023 period up until the beginning of 2025 (Trading Economics, 2025), the funding for the projects in this support channel may fluctuate frequently and subject itself to global and regional trends that can change on a daily basis. This adds to the uncertainty of the funding's timely receipt and support along the implementation process. One example can be witnessed in April 2024 when a drop in the price of carbon in the beginning of that year already eradicated 4.1 billion euros in the potential revenues of the EU (Abnett et al., 2024) so the dependence on carbon prices – a commodity characterised by volatility can be a significant threat to the stability of the Innovation Fund's ability to support decarbonisation projects.

- **Opportunities**

The opportunities for the Innovation Fund to prove its worth further again resemble those already relished by the initiatives analysed above. The increasing momentum for green energy investments and energy independence, both in the global landscape and within the EU has bolstered the region's motivation to commit to clean energy sources in general and the solar sector in particular as a primary driver of the process. This is coupled with the global surges in global climate finance and technology demand, as well as corporate demand for low-carbon solar energy to meet the decarbonisation targets (RE100, 2023), so companies both in Europe and in the world will need more scalable and cost-effective solar technologies, thus representing a valid opportunity for the EU technologies to become marketable and practical for the market. Some of the examples can be seen in the launch of the RESiLEX research project across 8 Member States for silicon recycling in solar PV (RESiLEX , 2023), the development of solar PV cells using "heterojunction/SmartWire technology" to generate higher yield and efficiency by Meyer Burger in Germany (Meyer Burger, 2024b), and the creation of "ultra-thin high-efficiency, low-cost photovoltaic solar wafers" by NexWafe in Germany also (Escárzaga, 2024).

Another opportunity that the Innovation Fund can take advantage of is the synergy between the Innovation Fund and other initiatives on the EU level. The aim of the funding programme is in alignment with other EU policy instruments such as the REPowerEU Plan, the Net-Zero Industry Act, and the EU Solar Energy Strategy, which is to reduce energy dependence and accelerate the green transition, so the presence of such initiatives can provide the momentum for the Innovation Fund to support more various companies in the solar sector, along with opening opportunities for policy coherence and co-financing channels for the firms that need capital investment the most. This allows the funding channel to become a more stable and trustworthy platform and incentivises innovations within the field.

- **Threats**

Similar to the threat analysis for the previous initiatives, as a policy supporting the green energy transition, the Innovation Fund also faces the same threats from external environments, ranging from the possible public backlash against solar projects that affect the environment, RREs bottlenecks from China and exporting countries, to global competition within the field as well, especially that coming from China and the US. In fact, the price dumping in China's solar PV and the shift to the US for more profitable investments with its Inflation Reduction Act have been responsible for Swiss solar firm Meyer Burger Technology AG's plan to close solar manufacturing factories in Germany, and Swedish solar firm Midsummer AB's plan for layoffs after receiving the Innovation Fund's grants of 200 million and 30 million euros (Mathis & Ainger, 2024). Therefore, even with the support of this funding platform, EU solar manufacturing companies may even encounter arduous challenges to compete on the global market.

Furthermore, as it is a capital funding source, it also subjects itself to macroeconomic uncertainty as capital-intensive climate projects face either medium or high risks of failure or insolvencies. Particularly in the context of the EU, despite efforts to bring down the near-term uncertainty, the majority of policy-related categories of uncertainty are above the historical averages, demonstrating "ongoing political polarisation, prospective regulation and the global energy transition" (Koester et al., 2023). Compounding this issue is the rising and uncertain interest rates in the EU. Despite efforts to diminish the key European Central Bank interest rates to 2.5% as of 12th March 2025 – a significant downturn from 2023-2024 period (European Central Bank, 2025), it still represents a scenario of uncertainty, particularly considering the US's uncertain tariff and international trade policies, making solar manufacturing companies hesitant to borrow money for future R&D and deployment and even making it difficult for the Innovation Fund to lend out their capital as well.

1.2.5. Horizon Europe

Horizon Europe acts as the EU's principal flagship funding channel specially dedicated to research and development for the time span from 2021 to 2027 with a budget set at 93.5 billion euros (European Commission, 2021a). By dint of research funding support for frontier projects and knowledge sharing, the main aim of the programme is to address climate change and render assistance in the progress towards the United Nations's Sustainable Development Goals, together with bettering the EU's growth and competitiveness (European Commission, 2021a). The following SWOT analysis is presented for a better grasp of the initiative's upside and downside from both the internal and external perspectives.

- **Strengths**

The most conspicuous strength of the Horizon Europe is the record budget for the programme, at 93.5 billion euros, which is the largest amount committed to research and innovation in the history of EU policies (European Commission, 2021a). This is further strengthened by the utilisation of a comprehensive and strategic three-pillar structure: "(1) Excellent Science, (2) Global Challenges, and (3) Industrial Competitiveness, and Innovative Europe" (European Commission, 2021a) with a view to a balanced approach to critical, innovative research direction with a high level of practical application and market readiness, as well as the integration of EU missions and European partnerships: co-funded, co-programmed, and institutionalised. All these factors contribute to the coherence in the funding framework and guarantees a strong, reliable funding base for the domestic solar manufacturing sector.

The strength of the Horizon Europe also manifests itself in its support for broadening Pan-European participation from all legal entities within the EU and associated countries (European Commission, 2021a). This can lead to effective cross-border collaboration and sharing of clean energy expertise so that the EU Member States can join forces, avoid duplication and fragmentation in research funding, and compete in the global solar PV market. For instance, this programme has provided a staggering budget of 20 million euros for tandem PV technologies to achieve low costs with the aid of earth-abundant materials, which was a project aimed at both EU and non-EU members for funding receipt (Horizon Europe, 2020). Besides, the Horizon Europe has been responsible for the funding of the Carbon-Based Perovskite Solar Cells – a unique technology for producing solar panels with improved efficiency and stability, attracting cooperation from organisations in several countries: Germany, France, Switzerland, Italy, the UK, Spain, and Sweden (Solar-Era.Net, 2023).

- **Weaknesses**

The weakness of the Horizon Europe is similar to other initiatives as well – the complicated and bureaucratic application process. Despite being an improved version of the Horizon 2020, on average projects under the Horizon Europe take longer to be approved, 273 days between the closing day of grant calls and the signing day of grants, 23 days longer than its predecessor due to the longer list of requirements (Matthews, 2024). This is a burden for all companies and entities wanting to fast-track their innovations and put them into practice, which especially hurts SMEs lacking initial capital expenditures and liquidity to put their ideas into reality. When this situation occurs, this can create delays in project approval and fund transfer, generating a domino effect on other projects as well as future projects have to wait for previously delayed ones to go through first.

- **Opportunities**

Identical to the previously examined initiatives, the Horizon Europe also gains favourable conditions for future growth and implementation from the increasing momentum of green energy awareness and investments in the global landscape as climate change has been increasing dawning on the public and national governments' mindset. Also, as the funding programme is specifically aligned with the United Nations' Sustainable Development Goals, so it is probable for this channel to receive further policy support from the EU and international levels thanks to policy synergies and joint ventures. It is worth mentioning also that even within the EU, the companies in the region have seen an increasing trend in R&D investments, even surpassing the US and China in terms of 2023 growth rates, at a rate of 9.8% (ERA Portal Austria, 2024), thus boosting the morale for R&D in the private sector for domestic solar manufacturing and providing valuable opportunities for co-financing between the EU and the private sector to bring the most funding assistance for solar companies.

From a technical standpoint, the Horizon Europe also benefits from breakthroughs in solar technologies around the world and in Europe. For example, with the rise of artificial intelligence (AI) and deep learning across all fields, the solar PV sector has also observed their applications in solar PV such as in the aspects of "maximum power point tracking, power forecasting, and fault detection within the PV system" (Hu et al., 2024), or the use of Generative AI to predict performance, identify suitable sites, and integrate grids (Mousavi et al., 2025). These innovations provide chances of technology learning and transfer, and more pressure and motivation for EU companies to step up their games and engage more in the worldwide race of solar PV innovations, thus creating more successful potential solar projects for Horizon Europe to invest in.

- **Threats**

Threats surrounding the Horizon Europe similarly emanate from the increasing global competition, particularly from the US and China. The US has been augmenting their clean energy R&D and saw a 23% growth in 2023 to a total of 50 billion USD with a staggering 160 billion USD in the private sector (Gupta, 2024) whereas for Horizon Europe, the average yearly budget is just around 13 billion euros while China holds the world record for solar cell patent applications (AFD China Intellectual Property, 2024) and take a proactive shift from a manufacturing hub to a solar IP innovator (Xiong, 2024), both of which countries highlight the fact that R&D in solar PV, which can impede the progress of research and innovation in the EU as it cannot compete quickly enough to acquire patenting rights for the innovations and eliminate the EU technologies' marketability.

Another threat for the Horizon Europe originates from the region's regulatory barriers in terms of digital sovereignty and data privacy. As the EU has enforced strict rules related to this aspect to protect the digital world and intellectual property in the region (European Commission, 2023h), the regulation can become a hurdle to the implementation of knowledge sharing and open-access science policy of the Horizon Europe. If not, the funding programme is not conducted properly and the laws regarding of digital sovereignty and data privacy are not adapted for the sake of open-access knowledge sharing, the Horizon Europe can become a source of intellectual property disputes and knowledge theft or a disincentive for companies to apply for R&D funding from this support platform.

1.3. Synthesis of findings from the SWOT Analysis of EU Initiatives

Table 4 summarises all points related to the strengths, weaknesses, opportunities, and threats in the context of five chosen EU initiatives: REPowerEU Plan, Net-Zero Industry Act, Critical Raw Materials Act, Innovation Fund, and Horizon Europe.

Initiative	Strengths	Weaknesses	Opportunities	Threats
REPowerEU Plan	- Clear strategic focus and ambitious goals - Established industry alliance	- No binding requirements - Fragmentation of implementation and funding	- Rise of reshoring and nearshoring - Innovations in solar technologies	- Supply chain disruptions - Competition between different renewable energy sources
Net-Zero Industry Act	- Solar as a strategic net-zero technology - Clear deadlines for permit grants	- No enforceable mechanisms - Too broad strategic technological focus	- Global green energy investment momentum - Supply chain diversification	- Similar to REPowerEU - Backlash from WTO, trade partners for trade-distorting subsidies

Critical Raw Materials Act	- Specific and measurable targets - Specific policy priority and financial support	- Reliance on national policy commitment and implementation - Failure to acknowledge the costs and time involved	- Similar to Net-Zero Industry Act - Recycling innovations for solar PV	- Similar to REPowerEU - Price volatility and geopolitical risks of CRMs
Innovation Fund	- Robust and clearly structured financial backing system - Emphasis on fostering "first-of-a-kind highly, innovative technologies"	- Complex and time-consuming application process - Revenue dependence on volatile carbon pricing	- Similar to Net-Zero Industry Act - Synergy between the Innovation Fund and other initiatives on the EU level	- Similar to REPowerEU - Macroeconomic uncertainty
Horizon Europe	- The record budget for the programme - Support for broadening Pan-European participation	- Complex and time-consuming application process	- Similar to Net-Zero Industry Act - Breakthroughs in solar technologies	- Increasing global competition - Regulatory barriers in terms of digital sovereignty and data privacy

Table 4. Summary of the SWOT analysis for EU initiatives

From Table 4, all the initiatives under the EU Green Deal Industrial Plan are able to cover various areas needed to foster the green transition and the solar manufacturing capacity, from the general policy support, reduced permit grant wait time, R&D incubation, and operation funding. What these policies are able to achieve uniformly is establishing clearly quantified and ambitious targets, which lay a robust foundation for future endeavour to augment domestic solar PV manufacturing among policymakers, politicians, and companies. Also, with the two funding initiatives' emphasis on innovative technologies, solar manufacturing capacity in the EU has the potential to improve enormously in terms of efficiency and cost effectiveness, so the EU solar products can become more competitive. With regard to the positive externalities, the EU solar manufacturing sector can benefit significantly from the global momentum for green energy policies and investments, as well as breakthroughs in the solar production process, hence better chances of knowledge sharing, improved public and private sector perception to receive more support in various forms.

Nevertheless, all these initiatives face their own unique challenges, but the most noticeable downsides lie in the lack of binding enforcement mechanisms and the complex, time-consuming bureaucracy in the EU authorities. This may, in turn, deter solar investors and manufacturers from making their utmost efforts to ramp up the production capacity to meet the EU demand due to high risks and possible low returns on investment whereas on a macro level, this leaves EU Member States with limited guidance and motivation to devote themselves to the ambitious targets and makes the implementation become fragmented across countries. These issues are particularly problematic for such ambitious solar energy objectives that require joint efforts to accomplish and in an era of supply chain disruptions and uncertainty roaming across the globe, together with tough competition from different nations like the US and China with state-of-the-art solar technologies and large clean energy subsidies.

2. Systematic review and analysis of EU solar manufacturing companies under the EU Green Deal Industrial Plan

2.1. Systematic reviews of EU solar manufacturing companies

Table 5 shows the results generated from the PRISMA procedure for the selection of EU solar manufacturing companies analysed in this study.

Stage	Number of Documents searched	Number of Documents proceeding to the next stage
Identification	SolarPower Europe: n = 166 Duplicate filters already applied to show unique results	n = 166
Screening	Documents removed by removal reason:	n = 24

	• **Outside-EU headquarters with limited within-EU production**: n = 83 • **Companies only engaged in research, installation and distribution**: n = 21 • **Companies with insufficient public data**: n = 7 • **Companies without any exposure to the chosen EU-level solar manufacturing initiatives**: n = 31 Note: due to significant overlapping, many initiatives are excluded for multiple reasons but only counted once at the first applicable rationale.	
Inclusion	**Eligibility criterion**: only one upstream and one downstream manufacturing company are chosen to represent unique segments in the solar PV supply chain • Excluded: n = 22	n = 2

Table 5. The PRISMA procedure for the selection of EU initiatives

Finally, the two candidates singled out for further analysis are as follows:

- **Wacker Chemie AG**: an upstream manufacturing representative
- **Meyer Burger Technology AG**: a downstream manufacturing representative.

The underlying rationale for these choices are that Wacker Chemie AG – a firm headquartered in Germany, plays a leadership role within the EU region in upstream production of silicones and polysilicon – fundamental input materials for the solar PV (Wacker Chemie AG, 2025a), while Meyer Burger Technology AG – a firm headquartered in Switzerland but with major production bases in Germany, has been a long-standing pioneer in the downstream solar PV manufacturing in the global landscape specializing in solar panel assembly and marketing of final solar modules (Meyer Burger, 2023). Thus, a SWOT analysis of these two EU companies is able to capture the typical strengths, weaknesses, opportunities, and threats from the standpoint of solar manufacturing companies and provide diverse perspectives on the effectiveness of initiatives under the EU Green Deal Industrial Plan.

2.2. Wacker Chemie AG

Wacker Chemie AG or Wacker for short is a German chemical and biotech company that positions itself as a "modern chemistry leader" specialising in a wide range of chemical products with more 3,000 product listings (Wacker Chemie AG, n.d.). In terms of the solar industry, Wacker has a division concentrating on polysilicon and in reality, one of the few firms that can produce high-quality, hyperpure polysilicon for highly efficient solar PV cells and semiconductor chips (Wacker Chemie AG, 2022a), positioning the company as a critical component in the solar supply chain. The four aspects of the company in the SWOT framework are evaluated for in-depth discussions.

- **Strengths**

The most conspicuous strength of Wacker Chemie AG is its positioning as the leading supplier of materials for clean-tech value chains. As the company is among the few global competitors to be able to manufacture one of highest-quality polysilicon necessary for highly efficient solar PV cells (Wacker Chemie AG, 2022a) with polysilicon capacities reaching 60,000 metric tons in Europe (Longo, 2024), it helps to put the EU in the global map of solar manufacturing and allows the region to source solar input materials domestically instead of relying on Chinese imports and achieve the ambitious goals set by the Net-Zero Industry Act. Also, the fact that Wacker's polysilicon is capable of benefiting from multiple industries, including the solar and semiconductor sectors, enable the firm to diversify its revenues and withstand market volatility in case one of the above industries suffers from setbacks. Thus, the company can consolidate its leading position in polysilicon production and provide a sustained, crisis-proof source of crucial raw materials for solar PV manufacturing in the EU.

Another strength of Wacker lies in its long history of policy priority and investments in R&D. The company was launched in 1914 and from that onwards until the present, it has associated itself with a tradition of constant innovations to become more resilient and adapt to changing market conditions with its wide-ranging repertoire of innovative products in multiple categories: silicones, polymers, biotech and solar products (Oberoi, 2024). To be specific, in general the company set aside 3.6% of group sales for R&D and employed a total of 956 employees for this department (Wacker Chemie AG, 2024a) while for the solar manufacturing field, the company has recently commercialised hyperpure polysilicon for highly efficient cells, solar silicone rubber grades to connect solar-cell laminates, and self-adhesive ELASTOSIL solar silicones to connect the glass cover and housing (Wacker Chemie AG, 2025a). In the context of the EU Green Deal Industrial Plan, Wacker's dedication to innovation is manifested in its leverage of Horizon Europe funding in its RHYME (Renewable Hydrogen and Methanol) Bavaria project in 2020, resubmitted in 2022 (Wacker Chemie AG, 2022b), which, despite not being relevant to the solar manufacturing sector, shows that it cares about innovation. Therefore, its history, R&D investments, and perseverance with seeking innovation funding lays a firm foundation for beliefs in future solar manufacturing R&D.

The capabilities for vertical integration and diversification are the next forte of Wacker. As the firm has multiple divisions focusing on different lines of products serving various end markets from electronics, construction to consumer goods (Wacker Chemie AG, n.d.), it can enhance its resilience in times of market downturns in one field or another. For instance, if the solar sector in the EU faces certain setbacks, the polysilicon division of Wacker can avert sales diminution by branching its focus onto other sectors like the semiconductor industry and wait for the solar manufacturing sector to stabilise again, rather than collapsing together with the downfall of the solar sector. Also, with its wide product range, the firm can benefit from multiple industries under the EU Green Deal Industrial Plan such as hydrogen and wind energy so it can act as a strategic player for the EU in its green energy transition and bring enormous benefits to the region in not just the solar manufacturing industry.

- **Weaknesses**

The first weakness of Wacker Chemie AG lies in its dependency on raw material imports. Even though Wacker is already an upstream manufacturing company providing input materials for solar PV production, it still has to rely on further upstream raw materials namely silicon in primary forms for polysilicon, as well as other specialty chemicals and metals as confirmed by its import trade data (Eximpedia, 2024). Therefore, it is vulnerable to raw material dependency and supply chain disruptions in case of international trade tensions, price volatility, and global scarcity. This dependence on a single third country for raw material imports is already a weakness of the EU as pointed out under the Critical Raw Materials Act (European Union, 2023a), so this can be a point of serious vulnerability for Wacker in case of emergency, especially in the current tense geopolitical climate between the EU and other large trading partners like Russia, China, and the US. Also, finding alternative partners for sourcing raw materials of solar PV polysilicon may take time to finalise the trade agreements, thus making the firm unable to contribute to the domestic processing goals of raw materials by 2030 set by the Critical Raw Materials Act.

In addition, in terms of output product sales, Wacker also presents a geographical market imbalance. Its sales distribution of polysilicon – a critical raw material for solar PV is tipped in favour of Asia, particularly the Chinese market as China has become the largest market for the company's shipping of this product as of 2024 (Norman, 2024). This can represent a rather ironic situation when Europe's domestic solar PV production only met 23% of local demand but a significant portion of critical raw materials for solar PV is shipped to external markets instead of catering to the EU. Hence, Wacker is tied to external markets to a great extent and any volatility in these markets can lead to serious repercussions for the company's sales figures, evidenced by profit slumps in 2024 when exports to the Asia market dwindled (Norman, 2024) whereas the production capacity of the EU requires time to absorb the output amounts produced by Wacker and is unable to help counter its profit reductions immediately. Therefore, market imbalance is an acute weakness that Wacker must consider improving its positioning and operational resilience.

- **Opportunities**

The first and foremost opportunity for Wacker Chemie AG comes from soaring demands for clean energy within the EU. With the ambitious goals set by REPowerEU Plan, Net-Zero Industry Act, and other renewable energy initiatives, organisations and individuals will increasingly seek for domestically produced renewable products to contribute to the targets of over 320 GW of solar PV by 2025, and nearly 600 GW by 2030 under the Plan. This, in turn, will drive upward the demand for raw materials of solar PV namely polysilicon, silicone encapsulants, and other materials which Wacker is the leading supplier, so the company's output can be absorbed locally rather than relying on exports to Asia. Additionally, under the Critical Raw Materials Act, upstream companies that are capable of processing and recycling CRMs domestically can receive significantly more orders from downstream firms within the EU, as well as R&D deals from research centres and companies with a view to technology transfers and collaboration. Hence, with the establishments of several EU initiatives related to the solar manufacturing sector, Wacker can source its sales revenues from a wider range of local sources without having to rely on external markets, which also strengthen its leader position in the EU market.

Another opportunity is from the favourable permit-granting and financial conditions created by renewable energy policies on the EU level. The REPowerEU Plan, Net-Zero Industry Act, and Critical Raw Materials Act all set strict deadlines for the permit-granting process of solar energy, thus allowing Wacker to expand and launch new projects with greater ease and reduce the time needed to put these projects into reality from approval wait and environmental reviews, particularly in the context of the high level of energy intensity from Wacker as a chemical company. With regard to the financial conditions, as all the above initiatives have been ramped up by the Commission, the funding sources for renewable energy such as the Innovation Fund and Horizon Europe are also mobilised to a greater extent to provide timely investments for the needed clean technology projects. Therefore, Wacker can take advantage of its position as the leading supplier of key raw materials for solar PV to guarantee greater funding from the Commission and state aids as well to commit itself better to product R&D, production scale expansion so that it can ameliorate solar technologies and cater to the local demand for solar PV input materials.

- **Threats**

The most significant threat facing Wacker Chemie AG is the intense competition from other global competitors like the US and China. Similar to the threats encountered in the previously analysed EU initiatives, Wacker may have to face cut-throat competition from other countries due to superior technologies and lower costs of materials, particularly cheap imports coming from China that results from the overcapacity and price dumping issues. In contrast, the company, as a typical firm operated within the EU, usually faces higher costs for production and thus have higher-priced products. This may make it unable to compete with other global competitors not only in the global markets but even within the local EU market itself. Compounding this problem further is macroeconomic uncertainty from the rising interest rates and inflation, along with the constantly changing trade measures from the US that can deter investors from pouring capital into the company's activities. This may discourage the board from embarking on more ambitious solar material projects in the near term.

Besides, Wacker is liable to policy and regulatory uncertainties within the EU. As climate change progresses, the EU is expected to impose more stringent regulations in Europe to curb greenhouse emissions and carbon footprint, which could exert a detrimental impact on the product portfolio of Wacker via increased taxes and production costs (Wacker Chemie AG, 2024b). Even worse, the operation of the firm is characterised by the high level of energy intensity, increased energy costs resulting from the EU's climate policies can affect its bottom-line performance unless it can find energy-efficient methods for the production of solar input materials, which again takes time, potentially later than 2030 – the year goal set by most EU initiatives. Therefore, these factors can hurt the competitiveness of the companies and pose difficulties to the decision-making process by the director board when it comes to sustainability policies for the short, medium, and long term.

2.3. Meyer Burger

Meyer Burger's background is a manufacturer of solar cells and solar modules founded in 1953 and headquartered in Switzerland as the main office for the senior management and as a research centre. However, it has production bases in the US and sales office in China and Singapore, but the major portion of production facilities and activities are located in Germany (Meyer Burger, 2025b). The company has expressed its desire to position the company as the leading European solar brand that is able to integrate the production solar cells and solar modules (Meyer Burger, 2021) and has been hailed in the "Top Performer" category for its solar products in numerous quality aspects (Meyer Burger, 2025a), thus acquiring reputation for its reliability. With this background information, it is imperative to delve deeper into Meyer Burger by dint of the following SWOT analysis.

- **Strengths**

Meyer Burger's pioneering role in solar manufacturing technologies is the company's most prominent strength compared to its counterparts in this industry. The company has been able to develop heterojunction solar cell technology with interdigitated back contacts so it can reach 22% efficiency rate compared to the normal market level of 18-20% due to its products' ability to reduce electron losses (Meyer Burger, 2025a). Also, its bifacial design and temperature-proof absorption enable Meyer Burger's solar panels to maximise the generation of electricity, withstand climate conditions better and thus, achieve longer expectancy than that of other solar products by its competitors (Meyer Burger, 2025a), so these excellent qualities have placed the company in the premium tier in the industry and contribute to the reputation of Made-in-Europe solar PV panels.

Another strength of Meyer Burger can be found in the firm's ability to secure robust policy networks and financial support from EU initiatives. The company has succeeded in taking advantage of EU-level support resources when it received funding equivalent to 200 million euros from the Innovation Fund with its HOPE (High-efficiency Onshore PV module production in Europe) project in collaboration with NorSun – a Norwegian company, with a view to scaling up the manufacturing capacity by 3.5 GW more in Germany and potentially Spain as well (European Commission, n.d.-a). This represents a huge strength for the company because funding programmes in the region such as Horizon Europe and Innovation Fund are already notorious for their bureaucratic approval process so the ability to tap into these support channels proves the company's reputation and lobbying capability even within the EU level. Also, as the company is an active member of the European Solar PV Industry Alliance (European Solar PV Industry Alliance , 2023), it can play a part in shaping the sector's regional position and EU-level initiatives, as well as establishing networks with other solar companies and policymakers. Hence, it can exert certain degrees of power in influencing the policy design for solar manufacturing in Europe, as well as securing trade and research agreements with other EU and non-EU partners in China and the US, already exemplified by its cooperation in the HOPE project with NorSun and its manufacturing investments in the US.

- **Weaknesses**

One of the most obvious weaknesses of Meyer Burger is its financial and operational fragility. Even though the company already achieved a manufacturing capacity of 1.4 GW as of half-year 2024 (Meyer Burger, 2024a), it still lags far behind compared to other global competitors. For instance, in China, the top 10 solar manufacturing plants all have their capacity ranging from 1.5 GW to over 18 GW (Ctube, 2024) so this is still a relevant gap for Meyer to keep pace with and leads to the lack of economies of scale. This, in turn, is synonymous with higher unit costs, demonstrated by Europe's 45% higher cost for producing PV modules compared to the price tag in China (Molina, 2024) and hinders the firm's ability to compete on prices with Chinese competitors, forcing it to adopt the market positioning as the premium product. When following the premium markets, Meyer cannot achieve ambitious sales figures due to limited market share and have to rely on local preferences and policy support such as funding and tariffs in order to stay profitable and operational with limited production scale. However, as a matter of fact, Meyer Burger recently published negative information related to its financial performance with an EBITDA loss of CHF 210.4 million or roughly 225 million euros for the fiscal year of 2024, employee layoffs, and cancellation of US solar factory construction (Fichtner, 2025) and even lost its biggest customer in the US, suffering from huge financial setbacks (Revill & Kaesebier, 2024). While following the niche premium market for its solar products, the company also does not have multiple revenue streams to support itself during setbacks in its solar manufacturing, worsening the company's issue of dependence on premium client segments and policy subsidies. This is clear evidence of Meyer Burger's financial and operation fragility just to maintain its current scale of solar production, let alone scale up its manufacturing activities.

Another weakness is to some extent similar to that faced by Wacker Chemie AG that is the reliance on external suppliers in the solar supply chain. As it is a downstream solar manufacturer, it has to source input materials such as silicon wafers, glass, backsheets, junction boxes, and frames from external companies, which means relying on Asian imports and certain materials have to wholly sourced from Asia namely ingot pullers, crucibles, hot zones, and diamond wire saws (Bettoli et al., 2022). Despite efforts to source locally from European suppliers such as acquiring wafers from Norwegian Crystals (Enkhardt, 2022) and from NorSun in its collaboration for the HOPE project, it does not entirely eliminate the issue of dependence on outside EU suppliers. Consequently, any disruptions to the solar supply chain can cost Meyer Burger significant delays in production and order cancellations or in the future, plans to ramp up its manufacturing capacity as this kind of material shortages already happened to the firm's production branch in Arizona, the US (Markets Insider, 2025).

- **Opportunities**

The opportunities for Meyer Burger come from the preferential investment and manufacturing environments created by EU-level initiatives for solar manufacturing. With the Net-Zero Industry Act's target of 40% domestic production, Meyer Burger would be positioned as the leader in the region's expansion efforts to enhance solar manufacturing capacity as it already has one of the largest-scale production facilities in Europe, thus allowing for easier access to more funding programmes such as the Innovation Fund and Horizon Europe. Also, with all other initiatives namely REPowerEU Plan with its Solar Energy Strategy, domestic solar panels would be in greater demand, which enable Meyer Burger to seek for new customers more easily with its Made in Europe branding as their products have 25-year guarantee and make it easier for the company to bring guarantee services locally, as well as coping better with harsh weather conditions in Europe where certain areas do not have stable amounts of sunlight all year round. Therefore, with the launch and spread of several EU-level initiatives supporting the solar manufacturing sector, Meyer Burger can enjoy a wider domestic market and better support tools in terms of permit granting and capital investments.

Also, Meyer Burger can benefit from the increasing momentum of solar technology advancements occurring in Europe. As already analysed in the opportunity section for the REPowerEU Plan and Horizon Europe, the EU has witnessed several breakthroughs in solar technologies to improve solar panels' efficiency and durability. As a result, Meyer Burger, already a solar brand with premium technologies, and with the aid of public R&D backing, can benefit from this trend through technology transfers and collaboration to accomplish more advanced, cost-effective solar technologies that can help it maintain the premium product advantage and find ways to scale down the high production costs. Some examples can be discerned in the perovskite-silicon tandem cells and manufacturing process automation that Meyer Burger can work on to combine with its exceptional heterojunction solar cell technology to achieve better efficiency, in the Net-Zero Industry Academies within the Net-Zero Industry Act to recruit highly skilled workforce for the R&D department.

- **Threats**

Similarly to the threats encountered by Wacker Chemie AG, Meyer Burger has to deal with increasing competition with other global competitors, particularly from the US and China, together with growing likelihoods of supply chain disruptions both under normal circumstances and in the context of increasing international trade tensions between global trade partners. However, these types of threats may be even more severe for Meyer Burger because of its weaknesses examined above. As it does not possess a significant degree of vertical integration in its solar production chain and has to rely significantly on non-EU suppliers, the firm may even face greater supply chain vulnerabilities in case of disruptions. Also, as it belongs to the premium product tier, the dumping prices of Chinese solar PV modules and panels can reduce the attractiveness of Meyer Burger's products to customers due to the easily available cheap solar PV cells with the same or even slightly lower quality, making the company's long-standing advantage become obsolete.

Furthermore, as Meyer Burger prides itself on its excellent solar technologies, a corresponding threat would be the fast innovation cycle. Superior solar technologies can be a double-edged sword as this can be both an opportunity when utilised tactically and a threat when the firm is unable to pay close attention to the technological cycle. Technologies can grow at an exponential rate and in a rather unexpected pattern so other global competitors in the solar manufacturing industry, especially those from the US and China with the support of the Inflation Reduction Act for the former and government subsidies for the latter, have dedicated themselves deeply to solar R&D to achieve more efficient and cost-effective products and production techniques. For example, China has developed solar cells using TOPCon technology that is able to contain unabsorbed sunlight, thus improving its electricity generation ability (Pickerel, 2025), and also successfully adopted TOPCon cells with aluminium paste instead of using silicon with lower efficiency yet significantly lower costs (Malayil, 2024). Therefore, if Meyer Burger does not pay close attention to global solar technology trends and improvements of its own technologies, the company will run the risks of falling behind the tech race in solar manufacturing and even losing its premium technology advantage that it often advertises to customers.

2.4. Synthesis of findings from the SWOT Analysis of representative EU solar manufacturing companies

Table 6 summarises the four aspects of the SWOT analysis for Wacker Chemie AG and Meyer Burger Technology AG from the above sections.

Company	Strengths	Weaknesses	Opportunities	Threats

Wacker Chemie AG	- Highest-quality supplier of input solar materials - Long history of policy priority and investments in R&D - Vertical integration and diversification	- Dependency on raw material imports - Geographical market imbalance	- Soaring demands for clean energy within the EU - Favourable permit-granting and financial conditions	- Competition from other global competitors - Supply chain disruptions - Policy and regulatory uncertainties within the EU
Meyer Burger Technology AG	- Pioneering in solar manufacturing technologies - Ability to secure EU-level backing in finance and policies	- Financial and operational fragility - Reliance on external suppliers	- Preferential investment and manufacturing environments - Increasing momentum of solar technology advancements	- Similar to Wacker - Fast solar innovation cycle

Table 6. Summary of the SWOT analysis for EU solar manufacturing companies

Both the two representatives from the upstream to downstream solar manufacturing sector demonstrate their strengths in the superior levels of solar technologies with top-quality input materials and solar panels, matching with the strength of Europe in its long-standing R&D history and can benefit hugely from the establishments of EU initiatives for solar manufacturing in terms of greater local demand and policy support. Nevertheless, the common theme of challenges found in both companies is the external dependence on outside EU suppliers and fierce competition with US and Chinese competitors as these two EU companies struggle to keep pace with their rivals' lower cost advantages and struggle to source their input materials within the EU majorly. Furthermore, the SWOT analysis for these two companies reveals a particular nuanced difficulty for EU solar manufacturing companies – the difference made by vertical integration and multiple revenue streams. When Wacker Chemie has multiple product lines, it can have recourse to other sales streams in case its solar materials encounter setbacks whereas for Meyer Burger, concentrating exclusively on solar panel manufacturing has left repercussions for its performance when it cannot compete aggressively in this sector with continuous earning losses. This would be a more prevalent problem for downstream manufacturing companies since their upstream counterparts can sell their processed materials to other sectors while downstream manufacturing firms usually concentrate on solar products for the most part, thus making it difficult for them to diversify their product portfolios.

Chapter 4: Discussion and Recommendations

1. Discussion

The SWOT analysis of EU initiatives and solar manufacturing companies under the Green Deal Industrial Plan has revealed several thought-provoking insights about the solar manufacturing sector in the region. Among the enabling factors, the solar transition momentum created by the ambitious goals set by all the relevant EU initiatives under the Green Deal Industrial Plan has incentivised different stakeholders within the region to commit themselves more to ramping up solar manufacturing capacity domestically. Specifically, this situation has necessitated the domestic utilisation and sourcing of solar panels and critical raw materials for solar PV, thus creating domestic demand for EU companies to have a wider market and leading to positive domino effects across the solar supply chain. When downstream companies like Meyer Burger have a wider market reach for their products, upstream companies like Wacker Chemie also benefit from selling more input materials to the former category, thus bringing advantages to the entire domestic solar supply chain and representing a win-win situation. Also, EU-level funding programmes like the Innovation Fund and Horizon Europe continue to bolster one of the region's strongest points – innovation and R&D in solar technologies. This commitment of support for innovative solar solutions from the Commission can facilitate companies within the region positioned in the premium tier product categories such as Meyer Burger with heterojunction cell technology, and Wacker with hyperpure polysilicon, to stay in the forefront of the innovation race with other global competitors in Asia and America. These factors act as an enormous boon to the solar manufacturing industry within the EU, not only in the form of policy support on paper but also of policy implementation and financial investments to scale up the sector, so it creates an image of strong political and industrial will for the region and genuinely motivates relevant parties in this matter to take vigorous actions in reality.

Nevertheless, the analysis conducted in this study highlights that there remain an array of flaws and challenges existing within and outside the EU that the region's solar sector needs to take into serious consideration. The most conspicuous constraint lies in the lack of integrated solar supply chain at scale. Due to the large reliance on external suppliers for several components in the value chain such as ingot and wafer, solar manufacturing companies in the EU have to resort to imports for key inputs to either a small or large extent. This fragmented supply chain prevents the ability to implement economies of scale to drive down costs, consolidate supply chain sovereignty, and bridge the gap between innovation and commercialisation. This is in contradiction to Asia who can adopt vertical integration with little difficulties thanks to its ability to process materials and assemble final products within the region, especially in China that holds a near monopoly over REEs processing. This supply chain bottleneck has been acknowledged in many EU initiatives like the REPowerEU Plan and the Critical Raw Materials Act and addressed by ambitious goals and large funding channels. However, this effort to diversify the sources of critical raw materials for solar input requires time and scrutiny from the Commission to finalise the trade deal with partners. Also, in the interest of fairness, several raw input materials for solar manufacturing cannot be found and processed in abundance to meet the EU demand due to natural resources availability such as silicon, silver, or other materials for specific panels like gallium for perovskites, indium for CIGS thin-film solar cells, and tellurium for CdTe thin-film solar cells, making dependency on imports inevitable. Solving this unavoidable reliance necessitates either unprecedented discoveries of natural resources for solar PV manufacturing within Europe or breakthrough solar technologies that employ input materials more available in the continent, which may take years or decades or even never materialise due to future uncertainties. In reality, Wacker also suffered from sales declines in polysilicon in 2024 owing to significantly lower volumes of solar-grade polysilicon mined (Wacker Chemie AG, 2025b). Hence, it can be inferred that supply chain bottlenecks due to external dependency remain a significant issue in the endeavour to enhance the solar manufacturing capacity in the EU as initiatives on the regional level only acknowledge it yet fail to pinpoint effective remedies for this complication.

Another major tension in the industry comes from the market dynamics and global competition. As the open market has been the focal point of the establishment of the Union (Bauer et al., 2024), the region has to face exposure to external competition from global trade partners, especially from the flood of Chinese cheap imports resulting from enormous economies of scale and state subsidies. This creates a non-level playing field for EU solar manufacturers as it has to compete heavily on costs – an aspect that EU products in general fail compared to Asian imports, which can be seen in the case of Meyer Burger's losses due to market distortion in Europe and the absence of trade defence measures. However, if trade defence measures are in place, the EU may have to face backlash from WTO Members due to going against open trade principles set by the organisation and is also going against its own principles when establishing this Union. The dilemma even extends to the trade-off between rapid deployment and local manufacturing capacity. When the EU-level initiatives set ambitious goals for solar deployment and installation, the region can achieve these by importing cheap solar PV panels, but this undermines the domestic manufacturing industry, thus representing a conflict of interest between solar PV final users and manufacturers in the EU with the resolution responsibility falling on the Commission. All these factors constitute several dilemmas for EU policymakers to make decisions on: the trade-off between open trade and trade defence, the balance between protectionism and supply chain globalisation, the interests of installers, users and manufacturers.

From the perspective of governance efficiency, the EU also has to address its own flaw – the bureaucracy and fragmentation among Member States' solar manufacturing policies. The region already has a reputation for the long bureaucratic process for government-related documents such as environmental reviews for solar extraction and manufacturing projects, permit granting, which is worsened by the lack of coordination between EU countries in implementing support policies and state aids for the sector. This issue, if left unresolved, can cause the solar supply chain across the region to be further segmented as this capital and resource-intensive industry urgently requires cross-country cooperation between Member States to become fruitful for the sharing of technology, natural and human resources. Also, the bureaucracy in the authorities exacerbates the situation in countries with already lower uptake of solar energy, particularly in Eastern Europe, widening the gap between nations while the ambitious goals set by the relevant EU initiatives are for the whole region and impossible for one or a few nations like France, Germany, and Italy to accomplish alone. Given the cross-border nature of EU firms' operational activities such as Meyer Burger headquartered in Switzerland with production based in German, utmost regional endeavour must be made equally by all Member States to ensure the smooth interdependence and favourable industry ecosystems for solar manufacturing supply chain in the EU.

2. Recommendations

Based on the SWOT analysis and the discussions, numerous pragmatic measures should be implemented by the EU policymakers to improve European solar manufacturing base. The following recommendations proposed by this thesis to foster EU strengths and address the weaknesses and challenges for the industry with a view to higher solar manufacturing capacity with greater resilience for the region.

- **Secure the full solar PV supply chain and critical materials in Europe**

The EU must implement coordinated measures across Member States and solar companies in order to fill in the missing links and build a robust supply chain within Europe. Under the Critical Raw Materials Act, the Commission must carefully outline a comprehensive list of critical input materials for solar cells and panels, particularly silver, silicon, and other REEs, and contemplate the plans to establish production sites across Europe to ensure a secure and sufficient supply for local demand and reduce foreign imports. For materials that cannot be sourced locally in Europe, the Commission must establish strategic investments and partnerships with a variety of global partners other than just those from China to guarantee supply chain diversification and reduce vulnerabilities in case of disruption to one source of materials. This aligns well with the club approach or the Critical Raw Materials Club – a form of partnerships with like-minded nations wanting to reinforce global supply chains (European Council, 2024). This direction can be further future-proofed by developing solar technologies that do not require large proportions of materials not naturally available in Europe and for which Europe does not need to set up the supply chain internally in the region so that the supply chain of solar manufacturing can achieve higher levels of domestic procurements but this is majorly for the long term due to uncertain innovation prospects. What is more pragmatic in the current context is that the EU can pay meticulous attention to material recycling so that it can reuse certain amounts of already used materials and limit the need for importing raw materials from elsewhere such as recovering silicon from end-of-life panels. Therefore, with a robust supply chain of upstream materials, downstream manufacturers can form networks with domestic suppliers and as a result, formulate a majorly domestic solar supply chain for the industry in the EU.

- **Implement criteria for sustainable and locally produced products in solar deployment tenders and public procurement**

To encourage domestic solar manufacturing, the EU and Member States must have clear policies to support the use of Made in Europe solar products in the local market. This can be done by incorporating sustainability criteria in auctions and public solar procurement projects such as the provisions of bonuses and preferential treatments by renewable energy tenders when using EU-produced panels, seen in Germany's plan for resilience bonuses and auctions (Clean Energy Wire, 2024). This can be implemented in a WTO-compatible manner by emphasizing quality factors namely limited carbon footprint, exceptional efficiency, and sustainability recognition across the EU, which most EU-made products already possess. The feasibility of this approach can be observed in France's approved policies of tax credits for green energy (UN Trade and Development, 2024), and in Italy's tax credits for using EU-made solar modules (Tripodo, 2025) so these countries can serve as a lesson for other Member States to follow suit and incentivise local deployment and even global suppliers if they want to work in the EU business environment.

- **Establishing a dedicated solar manufacturing scale-up fund**

To tackle the gap in costs and scale, the EU should establish a dedicated funding programme for solar manufacturing scale-up projects to co-finance new solar facilities or infrastructure expansion. This funding channel could be structured and operated as an Important Project of Common European Interest (IPCEI) for the solar PV supply chain so that critical solar PV manufacturing gigafactories can pool resources from both the Commission and national budgets in a valid way. Following this, countries can provide state aids directly to individual companies in an appropriate amount to support business activities of solar companies in their countries in case of financial setbacks and technological innovations, which particularly applies to the case of Meyer Burger and the German government. When this kind of funding works in tandem with other funding programmes such as the Innovation Fund and Horizon Europe, it helps to mitigate the risks of failure and defaults in exceptionally large investments and cover the high CAPEX often required for innovative, first-of-its-kind solar projects. Besides that, this scale-up fund should be able to provide financial incentives related to production and maintenance throughout the process on a sliding scale so that it can provide continuous support for solar companies a few years later rather than just for the initial phases.

- **Foster innovations for next-generation solar technologies**

To accomplish future-proof solar manufacturing capabilities, EU policymakers should take transparent and vigorous actions to maintain its edge in innovations and R&D in solar technologies. Even though this is already a forte for the region, fast innovation cycles mean the region can easily lose this competitive edge if failing to pay close attention. As a result, Horizon Europe and national R&D policies must maintain focus on breakthrough, first-of-its-kind solar PV technologies in the aspects of perovskite tandem cells, integrated PV, and process automation, to name but a few. It must be noted during this innovation process that EU-funded solar technologies should strive to utilise materials that can be sourced naturally within Europe so that these technologies can bring not only efficiency advantages but also supply chain security and make them easily producible within the region. However, this focus must be accompanied by actions to narrow the gap between innovation and commercialization in Europe, which can be realized by pilot-line hubs, tech incubators, and regulatory sandboxes where innovative technologies can be tested under a relaxed and pre-mass production scale before the large-scale launch. In addition, fostering innovation requires high-skilled, innovative workforce to research and design technologies so addressing the skills gap is essential to achieve this purpose. With the Net-Zero Industry Academies and the recently launched European Solar Academy aiming to upskill 65,000 solar workers for the sector (European Institute of Innovation & Technology, 2024), the EU must match this workforce with the companies and institutes that need it the most to ensure the optimal outcomes and employment prospects of these highly trained people. Nevertheless, besides these dedicated training programmes for the solar industries, the Commission can organise vocational training courses in public education institutions and establish public-private partnerships in solar manufacturing education to ensure sufficient labour force for future demand such as re-skilling workers from other industries for the solar manufacturing sector.

- **Establish binding requirements for national policy implementation and cross-country collaboration**

As the effectiveness of the EU Green Deal Industrial Plan and its supporting initiatives like the REPowerEU Plan, the Net-Zero Industry Act, and the Critical Raw Materials Act is still constrained by the absence of coordinated national policy implementation and cross-country collaboration, the introduction of legally binding requirements is high on the agenda. This will involve the enforcement of critical solar manufacturing-related provisions on a national scale such as permit granting, funding and resilience procurement criteria, together with participation mandates in cross-country cooperation channels, especially for areas where economies of scale or shared supply chains are of paramount importance. To be more specific, these binding requirements must be able to set enforceable national milestones for solar manufacturing capacity, implement compliance monitoring and corrective measures for failure cases, and formalize mandatory cooperation clusters to ensure coordinated catch-up growth for Member States with lower uptake. In this way, this binding coordination of efforts between countries can reduce fragmentation in national policy implementation to ensure that all EU nations play an equitable role in contributing to the ambitious solar targets and build a single, predictable European market for solar manufacturing setups and investments, hence higher investor confidence. Also, this allows solar manufacturing companies within the EU to cooperate better with one another and genuinely complement the missing links in the supply chain to create a coordinated production environment for the industry.

Chapter 5: Conclusion

The reinvigoration of the solar manufacturing industry and improve the production capacity within the EU has been a central topic to the Union's efforts for the green energy transition to ensure energy security, combat climate change and achieve a net-zero Europe. This thesis has investigated the upside and downside to several EU-level initiatives for the solar manufacturing sector, including the REPowerEU Plan, the Net-Zero Industry Act, the Critical Raw Materials Act, the Innovation Fund, and Horizon Europe, and their dynamics with key industrial players, represented by Wacker Chemie AG and Meyer Burger Technology AG. With a transparent PRISMA framework for selection and an in-depth SWOT analysis, several cross-cutting patterns emerge: the ambitious goals and transparent financial support tools are crucial enablers for EU companies to maintain its technology edge, the EU solar manufacturing industry is under significant pressure derived from fragmented national implementation, global market competition, and supply chain vulnerabilities in critical materials. Without timely and vigorous intervention remedies, EU solar production can be put in jeopardy from solar products made in the US and China. The case studies of Wacker Chemie AG and Meyer Burger Technology AG both demonstrate that in spite of their pioneering role in solar technologies, both firms have to encounter systematic weaknesses inherent in the EU operating environments and considerable external threats that individual firm-level strategies cannot tackle alone.

Resolving these stumbling blocks necessitates going beyond policies on paper to real-life actions. This study proposes a comprehensive set of pragmatic strategies and tactics aimed at EU policymakers: guaranteeing full solar PV supply chains for solar product components and materials, incorporate sustainability and EU-made product criteria in public projects, introducing a dedicated solar project funding platform, bolstering innovation for future solar technologies, and enforcing binding requirements for national implementation and cross-member cooperation. These recommendations are of critical necessity in ensuring not only European competitiveness for its solar products but also the feasibility of meeting ambitious goals set by the EU-level initiatives.

While this thesis offers a thorough analysis of EU initiatives related to solar manufacturing and corresponding key industrial players, it still contains several limitations that need to be addressed. First and foremost, the analysis relies exclusively on publicly available information for policy documents, company and industry reports as of early 2025. However, the market trends and external circumstances undergo constant changes over time, combined with the fact that confidential information within the EU level or solar manufacturing companies may present different information, both of which may render the results from the analysis irrelevant in the future. Additionally, the SWOT analysis, albeit structured and easily interpretable, may inadvertently simplify the interrelationships between EU-level and firm-level strategies, as well as with global supply chains and external competitors. Thirdly, the case study selection just focuses on two representatives Wacker Chemie AG and Meyer Burger Technology AG so despite being able to capture the pros and cons existing in essential segments of the solar supply chain, the analysis may fail to consider the diversity of challenges faced by solar SMEs and new entrants in the market. Therefore, future research should expand the scope of this study by incorporating quantitative data related to cost and pricing structures, macroeconomic factors to examine the EU solar manufacturing sector under diverging scenarios, as well as comparative case studies with a more diverse pool of EU and non-EU companies of various scales and growth phrases in the industry. Besides that, it is noteworthy for future studies to investigate the impacts of social, environmental, and regional regulatory aspects on solar manufacturing expansion in Europe – especially with respect to workforce transitions and regional disparities so that a more in-depth understanding of the sector in the EU can be achieved to address cross-country coordination and more holistic policymaking.

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