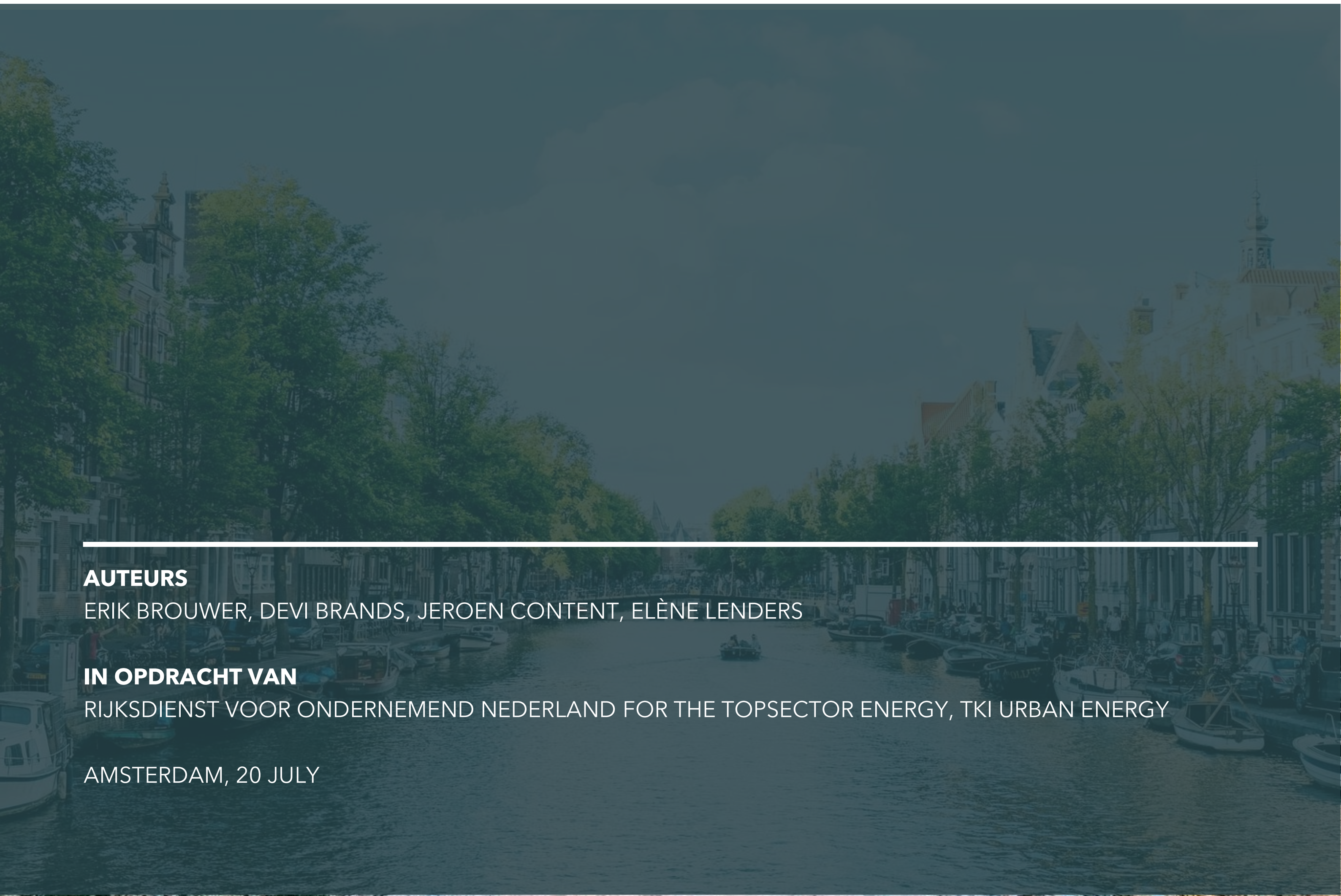
THE POSITION OF THE DUTCH SOLAR PV SECTOR IN THE EUROPEAN VALUE CHAIN

A MARKET ANALYSIS

FINAL REPORT

seo • economisch onderzoek



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Executive Summary

Our report sheds light on Europe's and the Netherlands' positioning in a future solar PV value chain. In order to rebuild a Dutch solar PV supply chain, European collaboration is key. The Netherlands holds a unique position in the integration of PV modules in the built environment.

Through desk research and interviews with industry experts we address relevant market failures that affect the European solar PV supply chain and provide strategic perspectives for rebuilding it. A scenario analysis explores the effect government support can have on the level of dependence on import from non-European countries and on the diversity of trading partners. The research outcomes presented in this report indicate that the potential role of the Netherlands in the PV supply chain cannot be assessed in isolation. The Netherlands' potential role is dependent on collaboration within Europe. This study therefore focusses on Europe, while zooming in on the Netherlands where possible.

Climate change calls for a cut in greenhouse gas emissions. The European Union aims to be climate neutral by 2050. Solar and wind energy, together with energy conversion and storage technologies, are the main pillars of the energy transition. Solar PV has experienced exponential growth, with global installed capacity exceeding 1 TWp and prices decreasing below 0.4 USD/W. As demand has been increasing ever since the introduction of the Kyoto Protocol, manufacturing of solar PV equipment and panels has shifted to Asian countries for cheaper and large-scale production.

However, recent price hikes in the energy market and the full-scale Russian invasion of Ukraine in 2021 have raised Europe's awareness of the energy market's vulnerability and dependence on foreign countries. In June 2022, European Energy ministers welcomed the RePowerEU plan to phase out dependency on Russian energy without compromising on climate and environmental goals. While RePowerEU aims for a target of 600 GWp of solar capacity by 2030, 83 per cent of all solar PV manufacturing stages still take place in China. Europe's share of solar PV manufacturing capacity is around two per cent. Furthermore, Chinese on-grid solar energy systems are produced with materials that have relatively high exposure to forced labour. In addition, 62 per cent of the electricity for the solar PV production process comes from coal-fired plants. The CO_2 footprint for PV systems produced in China is 43 g CO_2 eq/kWh. Producing the same system in Europe would use approximately 23 g CO_2/kWh. Because of this and the little resilience Europe has against potential supply chain disruptions, initiatives such as the IPCEI PV, the ESMC and the MCPV promote solar manufacturing in Europe. Nevertheless, solar manufacturing in Europe is hard because of high CAPEX expenses, long payback times, and higher labour and material costs. Due to their higher subsidies and import tariffs, the U.S. and India are perceived as more attractive locations to foster solar manufacturing.

The Netherlands' solar sector is not characterised by its size and can only be rebuilt by relying on European collaboration. The scenario analysis demonstrates that a subsidy of about 5 cents/Wp is required for European-made PV panels to compete with other global PV manufacturers. Scale is the main reason for Dutch companies to buy materials from Asian factories. Therefore, joint purchases of bulk equipment from European manufacturers can strengthen a more autonomous Dutch and European solar PV production chain. Further, the Netherlands has a pioneering role in the development of mass customisation and lightweight panels. By building on that strength, they can gain a competitive international position in the integration of PV modules in the built environment. For that,

clear technological and product standards between the construction sector and the solar PV sector are necessary. Since Asian companies are quick to catch up with technological advances, collaboration between (European) knowledge institutes, government and companies is crucial to shift towards a more local PV supply chain. The IPCEI PV presents a unique opportunity to support the Dutch solar PV industry and foster collaboration between European suppliers. Furthermore, the government should ensure sufficient budget for technology demonstration and system development and should also address efficient energy storage possibilities. International governance should enable transparent standards on products associated with forced labour and harmful environmental practices. Standards for the latter should be based on a life cycle assessment (LCA) approach. At the same time, there is a responsibility for government, companies and knowledge institutes to explore and support recycling of critical materials in the solar PV industry.

Content

1 Introduction

This study aims to identify the Netherlands' position in a growing European solar PV value chain, its obstacles and opportunities. The study relies on literature research, desk research, and interviews with industry stakeholders.

1.1 The objective of the research

Solar panel power generation has experienced remarkable growth worldwide. In the Netherlands, the installed capacity has grown from just 90 MWp in 2011 to more than 10,000 MWp in 2021. Since 2010 the levelised cost of energy has fallen about 80 per cent (IEA 2019). Triggered by European demand, China experienced a boost in the PV manufacturing sector and now accounts for approximately 83 per cent of global solar manufacturing capacity. The concentration of production in China has some drawbacks, which has been emphasised by recent developments: rising fuel and transport costs, the ongoing war in Ukraine that illustrates the downsides of dependence on one geopolitical region, growing evidence of forced labour in parts of Chinese production processes and a relatively high CO_2 footprint in the Chinese production chain of solar PV. At the same time, expanding the solar capacity is a widely acknowledged necessity to achieve climate goals and energy security and thus create a better quality of life for future generations.

The strategic importance of an independent solar panel industry is recognised throughout Europe. Industry initiatives, such as the European Solar Strategy are proof of the willingness to rebuild a European solar PV manufacturing supply chain. In the Netherlands, solar PV companies support this development, and research institutes are investigating improvements in technological efficiencies and applications. The Top Sector Energy's TKI Urban Energy is a driving force behind innovations fostering a CO_2-emissions free energy system and therefore investigating the role of the Netherlands in the European solar industry.

What are the opportunities for investing in the Dutch PV industry, and what are the risks and obstacles? Is the current ecosystem properly equipped to contribute to a European value chain? What could adequate support for Dutch solar companies look like? Commissioned by the Dutch Enterprise Agency (RVO) for TKI Energy, this research maps out the potential role of the Dutch PV industry in a more independent European solar PV manufacturing industry. The focus of this report is on the Netherlands, but it takes a broader European perspective when required due to the fact that the Netherlands' potential role is dependent on collaboration within Europe. The aim of the research is to answer the following research questions:

1. How is the European value chain for PV products currently constructed, and what developments are expected in the first 5-10 years?
2. What does the future production chain look like? What role can the Netherlands play?
3. How far back in the chain must we go to take up a sufficiently safe position in the chain?
4. Is it realistic that larger European ingot, wafer and cell manufacturers will emerge? What are the preconditions?
5. What is the financing requirement to build a Dutch PV industry?
6. What are other preconditions to achieve a 'healthy' industry?

1.2 Method

For this research, we use literature, information on websites and interviews with various stakeholders. A list of interviewed parties can be found in Appendix A. Interview partners are selected to capture different segments of the value chain. Interviewees from research institutes, industry associations and the government provide insights from the perspective of public organisations. Interviews with private companies give insight from the perspective of equipment manufacturers, material producers, solar panel manufacturers and project developers. Eight interviews have been conducted in total.

In order to answer the research questions, this report first gives an overview of the industries that are deemed strategically relevant for the energy transition. In this way, the solar PV industry's engagement and governmental support is put into perspective. For this overview, we mainly rely on desk research, particularly from governmental websites from the European Commission and the Dutch Enterprise Agency.

Next, we follow a top-down approach from the global solar PV industry to the Dutch solar PV industry. The first research question is answered mainly by describing the global and European solar PV value chain. Also, outlining the European solar PV industry helps identify the Netherlands' role and dependence within this sector. It provides a basis for answering questions such as "From which value chain segment can we start to take up a sufficiently safe position in the value chain?" and "Is the emergence of larger European ingot, wafer and cell manufacturers realistic?". This part of the research relies mainly on literature research.

After this description, future trends concerning CO_2 reduction, advancing solar PV technologies and market failures are taken into account. Here, we also use the insights of interviews with employees of solar PV companies, officials from the government and industry associations and scientific experts. The interviews serve to identify the role of the Dutch solar PV industry in the European value chain, its strengths and ambitions.

Building further on this, the next step contains a scenario analysis in which the future roles of a European and Dutch solar PV value chain are investigated. Visions for the future of the interviewed parties have been used as important input in the development of these scenarios as well.

1.3 Definitions

Online and literary sources are not always clear about which kind of capacity rating for solar power plants is used. Sometimes, the capacity is expressed in DC peak capacity of the solar, while other times it refers to the AC output deliverable to the grid. For this paper, we follow the recommendations of WikiSolar[1]: MWp or GWp is used when referring to DC capacity and MWac for the AC capacity. MWdc is higher than MWac, since MWac has to be converted to MWdc and therefore requires more energy. When web and literary sources neither indicate AC or DC, we assume that they refer to the peak capacity of the plant.

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[1] https://wiki-solar.org/data/glossary/capacity.html

1.4 Reading guide

Starting from the introduction in Chapter 1, Chapter 2 elaborates on the current climate goals of the European Union and the Dutch government. Next to solar PV, other technologies and their industries play a key role in the energy transition. We consider their ambitions and ways of support from a holistic perspective and learn which role Europe and the Dutch government play in these sectors and how we can possibly apply policy to the PV industry.

Chapter 3 gives an overview of the global solar PV value chain and describes where production takes place, the environmental consequences, mainly in terms of greenhouse gas emissions, and if there are social aspects to consider about the production process. The analysis of these aspects finally provides an explanation for the renewed interest in European solar PV production.

Chapter 4 zooms in on the European solar PV industry. First, the production capacity per value chain segment and key industry players are described. Equipment manufacturers and material producers are considered next. Industry initiatives and their relation to each other are elaborated on after that, followed by a paragraph that considers existing and potential requirements to reduce the carbon footprint while realising a European solar PV value chain. Part of that reduction in the carbon footprint can come from an advancement in more efficient technologies, addressed in the next paragraph. Here, historical perspectives and interview results give insight into the comparative advantages between Europe and China. The final paragraph of the chapter identifies reasons for market failure, with particular attention to current government intervention in the Netherlands.

Chapter 5 contains an overview of the main Dutch solar PV companies, knowledge institutes and their focus topics. Building on interview results, we present the strengths and ambitions of the Dutch solar PV industry.

Chapter 6 creates a scenario analysis in which potential future scenarios for a Dutch and European solar PV industry are developed. These scenarios explore the dimensions of dependence on non-European imports, diversity among trading partners, and the scale of financial incentives and import tariffs. This approach clarifies the consequences of CO_2 emissions in the value chain, as well as the financing and innovation necessary for a more autonomous supply chain.

Chapter 7 concludes with the most important findings about the current European and Dutch solar PV value chain and its role for the future.

2 Strategic industries in the energy transition

Solar and wind energy, together with energy conversion and storage technologies, are the main pillars of the energy transition. National support for solar PV systems focusses mainly on expanding the capacity, whilst a major part of national support for wind and hydrogen addresses demonstration and innovation.

Greenhouse gas emissions have to be cut by 55 per cent in 2030 and Europe aims to be climate neutral by 2050. The European industrial strategy and the Dutch National Climate Agreement are set to support the development of technologies and their respective industries which enable these climate goals. The hydrogen and battery sector have received approval for an IPCEI in their field. The Netherlands is also participating in the IPCEI for hydrogen. The topic of energy autonomy emerges strongly in the European industry strategy. The Dutch National Climate Agreement is less focussed on achieving energy autonomy, as it does not yet take recent events such as the war between Russia and Ukraine and rising energy prices and demand into account.

The European Commission mostly supports projects through funding, while the Dutch government employs specific subsidies for various technologies and their commercialisation phase. Wind and solar are both technologies that are supported by subsidies for innovation and commercialisation. This is in line with IEA's roadmap, which names solar and wind as key pillars in achieving the 55 per cent reduction in CO_2 *emissions by 2030. Both technologies are represented in the Dutch SDE++ subsidy applications and TKI dispositions. Interviews with experts and company employees reveal that there has been a strong focus on expanding solar installations and that targeted solar subsidies towards the integration and efficiency of solar PV lags behind. Still, integration and efficiency are addressed by the amount of TKI dispositions in electric infrastructure. Investments in hydrogen are growing the fastest. Discussions with stakeholders in the solar industry reveal that all technologies play a key role in realising the energy transition and supporting the solar industry.*

2.1 European strategic industries

Strategic industries for Europe and the Netherlands play a key role in realising (inter)national climate ambitions. The European Commission has set the goal to cut greenhouse gas emissions by 55 per cent in 2030 and to become climate neutral by 2050 (this latter goal being the main target of the Green Deal). This aligns with the Paris Agreement, which aims to keep global temperature rise below 2C° and hold it at 1.5 C°. To reach the goals of the Green Deal, the Fit for 55 package is meant to establish the necessary regulation. It includes topics such as renewable energy, energy efficiency, energy performance of buildings, land use and forestry, alternative fuels and transport emissions. Each of these topics affects different industries with promising technologies and evolving market trends that can help achieve the goals. Therefore, the European Commission has set up the Green Deal Industrial plan. This is complementary to the industrial strategy with industry alliances for relevant industries that bring together many partners to promote investments and support the creation of a value chain. The industrial strategy should enhance the autonomy of European industry, the realisation of European Climate goals and the competitiveness of European industry (European Commission 2023). The names of the industry alliances in Table 2.1 illustrate which technologies and industries are especially relevant in the energy transition. No industry alliance on wind energy was formed, but this is due to the fact that an association for wind energy has already been in existence since 1982. The industrial alliances originate from the more recent European industrial policy, which started in 2017.

Table 2.1 European industry alliances and respective associations

Industry Alliance	Year	Associations
Alliance for Zero-Emission Aviation	2022	
European Raw Materials Alliance	2020	
European Solar Photovoltaic Industry Alliance	2022	European Photovoltaic Industry Association (Solar Power Europe)
European Clean Hydrogen Alliance	2020	European Hydrogen Association
European Battery Alliance	2017	Eurobat
Circular Plastics Alliance	2019	
European Alliance for Industrial Data, Edge and Cloud	2020	
Industrial Alliance on Processors and Semiconductor Technologies	2021	
Renewable and Low-Carbon Fuels Value Chain Industrial Alliance	2022	
Electrification Alliance	2021	The European Association for Electric Mobility
		The European Wind Energy Association

Source: SEO (2023), based on European Commission (2023)

The Green Deal Industrial plan focusses on providing skills for the industry, a predictable and simplified regulatory environment, fostering open trade for resilient supply chains and faster access to sufficient funding. Again, this is complemented by additional goals of the industrial strategy: promoting advanced technologies, supporting innovation through policies and programs, acting on intellectual property, developing clusters and providing platforms for discussion and dialogue (European Commission 2023). Funds that cover these strategies are shown in Table 2.2. Next to these funds, there are other important contributions in the form of Important Projects of Common European Interest (IPCEI). Via these, the hydrogen and battery sector have gained 5,4 billion and 2,9 billion euros of public support respectively from member states.

Table 2.2 European funds supporting the energy transition

European Climate and Energy Funds
Horizon Europe Cluster 5
European Innovation Council (part of Horizon Europe)
LIFE Clean Energy Transition sub-programme
European Maritime and Fisheries Fund and BlueInvest
Innovation Fund
Cohesion Policy (ERDF, ESF, Cohesion Fund and Just Transition Fund)
Connecting Europe Facility (Transport and Energy)
Invest EU Programme

Modernisation Fund

Recovery and Resilience Facility

Renewable Energy Financing Mechanism

Source: European Commission (2023)

According to the International Energy Agency, wind and solar energy are seen as the main technologies to enable reaching the national and international climate goals. According to IEA's roadmap to carbon neutrality in 2050, 630 GWp of global solar PV and 390 GWp of global wind power are necessary by 2030 for the pathway to the 55 per cent reduction in 2030.[2] Therefore, the European Commission has introduced specific strategies for solar (the EU Solar Strategy) and offshore wind (EU Strategy for Offshore Renewable Energy Sources). The EU Solar Strategy aims for a target of solar capacity (592 GWac solar by 2030, equivalent to 750 GWp), increasing the initial Fit for 55 package's proposal of 420 GWac. Other vital pillars for decarbonization are energy efficiency, electrification, hydrogen and hydrogen-based fuels, bioenergy, and Carbon Capture, Utilisation and Storage (CCUS). Compared to Dutch goals, batteries are not as explicitly highlighted in the Fit for 55 package and are covered by general topics, such as energy efficiency or electrification.

2.2 Dutch strategic industries

The Dutch climate goals emphasise similar topics as the Fit for 55 package, such as mobility, industry, built environment, and electricity. Compared to the industrial strategy, the Dutch 'Klimaatakkoord' (Climate Agreement) puts energy autonomy less at the forefront. Dutch climate goals have not yet been fully updated in the face of rising energy prices and demand and the war between Russia and Ukraine (Solar Power Europe, 2022). However, the Dutch government considers strategic autonomy to be of major importance for the recalibration of the Dutch innovation programme (MMIP) of 2022. The Klimaatakkoord entails similar instruments to the ones of the European industrial strategy. They entail supporting innovation, standardised payback periods for reduction options, a program for hydrogen, clustering development, promoting employment, strengthening the EU-ETS, and expansion of subsidies for renewable energy and carbon capture and storage (Klimaatakkoord 2019). Topsector Energie backs specific subsidies that promote innovation. Subsidies such as MOOI (Missiegedreven Onderzoek, Ontwikkeling en Innovatie) or TSE (Topsector Industrie Onderzoek en Ontwikkeling) are addressing the first technology readiness levels. Other subsidies, which focus more on the demonstration stages of a project, are DEI (Demonstratie Energie en Innovatie) or VEKI (Versnelde klimaatinvesteringen industrie). One of the foremost subsidies for more commercial technologies is SDE++ (Stimulering Duurzame Energieproductie en Klimaattransitie).

The Dutch goals reflect the importance of solar and wind energy, too. In 2030, the Dutch government wants to realize 21 GW of offshore wind, striving towards 70 GW in 2050. The Klimaatakkoord states a generation of 35 TWh of wind and solar on land. Furthermore, the Dutch climate goals strongly emphasise batteries and electric infrastructure, thus addressing the pillar of energy efficiency. An important energy carrier, hydrogen, is expected to play a key role in energy storage. Electrolysis capacity should be at 8 GW by 2032. Additionally, the Netherlands strives to be an international leader in battery systems for heavy-duty transport and to develop a battery with 130 hours of storage duration by 2030. The electric infrastructure should contain 1,8 million charging stations for electric vehicles in 2030.

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[2] In 2020, global solar PV reached 710 GWp, including a global addition of 125 GWp that year.

0 gives an overview of the technologies that will enable the Dutch climate goals and their respective amount of support by the SDE++ and TKI subsidies (the latter supporting the pre-commercial development phase). Furthermore, it shows the respective sector associations and the accompanying programs and knowledge centres.

Table 2.3 Dutch subsidies and industry programs per strategic industry

	Wind	Solar	Battery	Electric infrastructure	Hydrogen	CCUS
SDE++ applications 2019-2021 (in mln €)	386	6,408	-	-	?	9,399
TKI dispositions 2019-2021 (in mln €)	83,1	39,5	?	62,2	30,8	13,4
Dutch association	Nederlandse WindEnergie Associatie	Holland Solar	Energy storage NL	Nationale agenda laadinfrastructuur	Nederlandse Waterstof en Brandstofcel Associatie	-

Source: SEO (2023), based on Topsector Energie (2023) and various websites of the corresponding associations

Note: No SDE data on the year 2019 was found.

The first row shows that CCUS obtained the highest total SDE++ subsidy amount between 2019 and 2021, despite being introduced in late 2020. CCUS is backed by little or no industry alliances and associations. Subsidies for earlier technological development phases (such as the TKI dispositions) are relatively small in this sector compared to the other technologies. This, and the lack of programs, innovation, and knowledge centres, might be a signal for a more mature technology that still needs stimulation (in the form of the SDE++) for further commercialising and expansion.

Solar and wind are both strongly supported by many subsidy schemes. 0 shows that SDE++ awarded more financial support to the solar sector between 2019 and 2021; this could have several reasons: first, the assumed costs to calculate the SDE++ subsidy amount for wind deviated from the actual levelised costs of electricity (LCOE) for wind. Especially for offshore wind installations, the LCOE was between 4 and 8 cents per kWh wind on land (Fraunhofer 2021), whereas the costs assumed for the SDE++ subsidy were between 3.9 and 6 cents per kWh for wind on land (PBL 2021). The difference was stark for wind offshore costs: between 7 and 12 cents per kWh LCOE and 5.9 cents per kWh assumed SDE++ costs. This led to fewer SDE++ subsidy applications for wind energy. Furthermore, wind installations experience more social resistance when they are built in proximity to residential areas. Another reason could be the maturity of the technology; many solar projects are being applied for, but subsequently, they do not reach the stage of realisation. The preference towards installation of solar PV can also be observed in the Dutch Regional Energy Strategies (RES) plan. The RES guides the Netherlands on a regional level in realising the national goal of annually generating 35 TWh of electricity from renewable energy sources on land by 2030.

A relatively large amount of the TKI subsidies go to offshore wind. Therefore, financing of this sector is relatively prominent in the demonstration and innovation phases. From 2012 until 2022, TKI subsidies for wind energy innovations have increased by a factor of 7.4, while TKI subsidies for solar are less frequently occurring and have even decreased by 34 per cent over the same period.

With a factor of 31, hydrogen has experienced the fastest growth in the disposition of TKI subsidies (from 2017 until 2022). The Netherlands have also committed to IPCEI in the field of hydrogen. SDE++ subsidies for this sector also exist, but the exact applied for amount has not been specified. Nevertheless, hydrogen is clearly one of the upcoming and most promising technologies. Electric infrastructure had the highest TKI dispositions between 2019 and 2021 due to the fact that it is necessary for the development of other technologies, such as wind and solar. The high amount of TKI dispositions for electric infrastructure underlines the necessity for innovations and efficient solutions in this sector, such as energy storage. As electric infrastructure entails many technologies, industry alliances often contain the input of other associations: for example, the European Electrification Alliance is an initiative backed by many other associations, such as SolarPower Europe, Wind Europe, the European Heat Pump Association.

3 The solar PV value chain

China accounts for approximately 83 per cent of all solar PV manufacturing stages. Most electricity for the energy-intensive production process comes from coal-fired plants. Chinese on-grid solar energy systems are produced with materials that have relatively high exposure to forced labour. These conditions and market disruptions raise interest in an autonomous European solar supply chain.

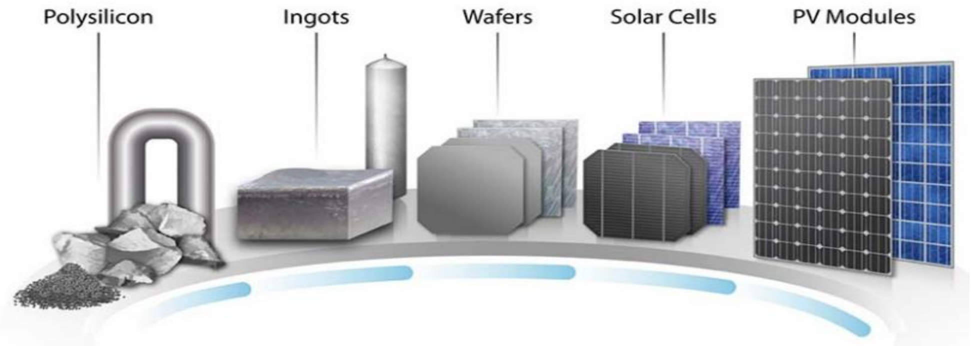
Crystalline silicon (c-Si) modules account for 95 per cent of the global solar PV production. Silicon is won from quartzite gravel or sand. The manufacturing stages start by purifying the quartzite gravel into metallurgical-grade silicon. From there, the silicon is further manufactured into polysilicon, ingots and wafers, cells and modules. Except for the purification of quartzite gravel, China accounts for approximately 83 per cent of the solar PV manufacturing stages. 42 per cent of that manufacturing capacity is located in one single Chinese province, Xinjiang. Xinjiang is home to the Uyghur population, an ethnic minority, which is suppressed in internment camps and later subdued to forced labour for the production of polysilicon. The production of polysilicon requires large amounts of electricity, while China's foremost electricity source comes from coal. Due to geographical dependencies and the energy crisis, the European Commission has introduced RePowerEU, which aims for an expansion of 600 GWp solar PV in Europe in 2030. The question is how this goal can be realised, while also caring

3.1 Global production of solar PV modules

Currently, two global technologies dominate the solar PV market: crystalline silicon (c-Si) modules, accounting for over 95 per cent of global production, and cadmium telluride (CdTe) thin film PV technology. The U.S. (and the company First Solar) is the leading manufacturer for the latter type of technology. Other technologies are using copper, indium, gallium and selenium (CIGS), amorphous silicon cells (a-Si) or gallium arsenide (GaAs) (IEA 2022).

For c-Si modules, one can distinguish between monocrystalline PV cells (the black coloured modules in Figure 1.1) and polycrystalline cells (the blue coloured modules in Figure 1.1). The difference is that the first uses a single crystal of silicon while the latter has fragments of several crystals of silicon melted together. Monocrystalline modules are more efficient (with an efficiency between 20 and 23 per cent) but also more expensive and more wasteful to produce than polycrystalline modules (efficiency between 18 and 21 per cent) and thin film modules (Unbound Solar 2022). Figure 1.1 shows the value chain of the c-Si module.

Figure 1.1 Supply chain segments PV modules



Source: NREL 2022

First, raw silicon is obtained from quartzite gravel or sand via coke reduction. This silicon can either be used to make silane for amorphous silicon or to be purified into high-purity silicon for crystalline photovoltaics. In nature, silicon only has a purity of 98 per cent. The 98 per cent pure raw silicon is purified from quartzite and quartz pebble into metallurgical-grade silicon (mg-Si) at high temperatures. Next, the silicon is crystallised into mono-crystalline or multi-crystalline silicon ingots, which are sliced very thinly and cleaned to form wafers (IEA 2022). To become a solar cell, the silicon wafers need to go through various steps such as doping, cleaning and coating. Lastly, the cells are connected, an electric circuit is created, and they are connected to a frame to form a solar module. Components that include aspects beyond the photovoltaic panels themselves are referred to as the Balance of System (BOS). This includes the wiring, switches, assembly system, and battery. Several modules form an array, and several arrays form a system.

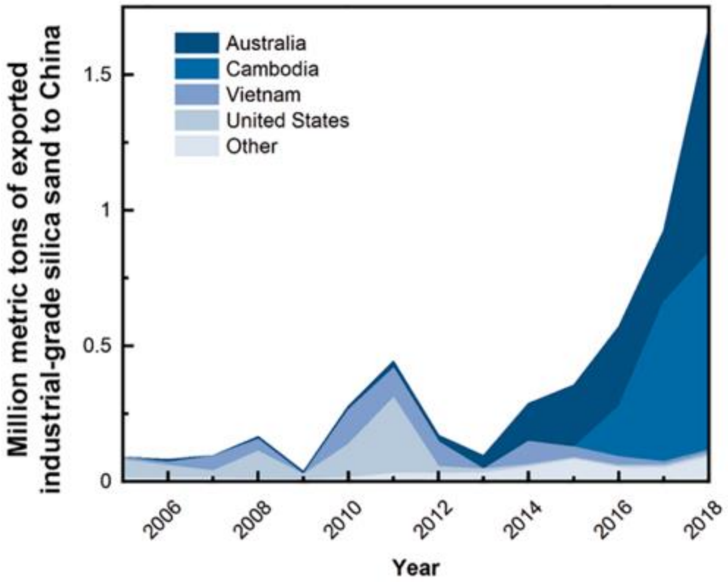
Compared to the c-Si cells, thin film photovoltaics are thinner, lighter and more flexible. Instead of using polysilicon as a main material, specific minerals such as cadmium and tellurium are refined from copper and zinc. Thin layers are then deposited on a substrate (usually glass), structured on cells with an electric circuit and wired and framed, depending on application. Ideally, solar cells with one material (pn-junction) could capture 25 to 27 per cent of the incoming energy from the incoming photons. Solar cells with more materials (2 pn-junctions) can reach efficiencies above 30 per cent (TNO 2021).

3.1.1 Geographical production aspects

China is the market leader in all of the production steps explained above. They account for approximately 83 per cent of the manufacturing stages (IEA 2022).

Despite China being the world's main producer of solar PV, it relies on imported silica sands from other countries for the steps prior to production: extraction and mining. Industrial-grade quartz deposits are most readily available in the U.S., and until 2012, the U.S. was China's main supplier of silica sands. After that, Australia, Cambodia, Vietnam, Malaysia and Pakistan became China's main suppliers (Heidari and Anctil 2022). Figure 1.2 gives an overview of that development.

Figure 1.2 China's main silica sands suppliers



Source: Heidari and Anctil 2022

Between 2010 and 2021, the production of solar PV has experienced a major geographical shift. All segments of the supply chain are now mostly dominated by China. 42 per cent of that manufacturing capacity is located in one single Chinese province, Xinjiang. Xinjiang also contains the largest manufacturing plant, making up 14 per cent of the total global production capacity. For wafers, cells, and modules, Southeast Asian countries such as Malaysia, Vietnam, Thailand, and South Korea still hold some of the manufacturing capacity. Malaysia has approximately 5.4 per cent of the world's solar cell manufacturing capacity, and Vietnam holds 6.8 per cent of world's solar module manufacturing capacity (IEA 2022).

Europe only holds a small share of global solar PV manufacturing. Germany is a prominent supplier for polysilicon and has a share of 10 per cent in that market. Table 1.2 sums up the manufacturing capacity for China in each solar PV segment and shows which other countries hold a share of the capacity as well.

Table 1.2 Market domination per solar PV supply chain segment

Production step	China	Remaining shares
Polysilicon	80%	Germany (10%), Malaysia (4%), the U.S. (5%), Other (1%)
Ingots and Wafers	97%	Asia Pacific (3%)
Cells	81.2%	Southeast Asia (11.6%), Europe (1.3%), U.S. (1%), South Korea (2.3%), Other (2.6%)
Modules	75%	Southeast Asia (12.2%), Europe (0.9%), U.S. (2.7%), South Korea (3.3%), (2.7%), Other (6%)

Source: SEO (2023), based on IEA 2022

Although countries such as Malaysia, Vietnam, South Korea, as well as the U.S., Germany, and Japan, hold some considerable manufacturing capacity, their demand for solar PV exceeds their supply. This is not the case for China.

3.1.2 Greenhouse gas emissions in the solar PV supply chain

With every step in the production process, CO_2 (equivalent) is emitted. Studies on the greenhouse gas emissions of solar PV production often distinguish between the extraction of resources and the production of the modules and their components.

The supply chain starts with the mining of quartz and silica sand extraction. The carbon footprint per metric ton of silica sand extraction lies between 46.8 kg CO_2 eq to 117 kg CO_2 eq, depending on the country of import. (Heidari and Anctil 2022). The production of mg-Si adds another 12 kg CO_2 eq per kg of mg-Si to the carbon footprint of solar PV produced in China. As the quartz silica is melted in an arc furnace with temperatures reaching 1700 °C, this step of production is relatively energy intensive. Life cycle analyses show that the production of Si-modules in China has a high impact on particulate matter, acidification and marine and terrestrial eutrophication (Müller et al. 2021).

The CO_2 footprint of solar power generated in Europe with panels produced in China is estimated to be 43 g CO_2/kWh (excluding the extraction steps). To compare, the CO_2 footprint of electricity generated by a coal power plant is 730 g CO_2 eq/kWh, which is 13 to 25 times more than power generated from solar energy. The number of years a PV system needs to run to produce as much energy as necessary for its installation is the energy payback time. For solar panels made in China and installed in North-Western Europe, the energy payment time is 1.24 years (Fraunhofer 2022). Solar PV systems return 20 times as much energy as it cost to make them (TNO 2021).

Table 3.1 shows the relative contribution in terms of CO_2 emissions of each production step in the solar PV system supply chain. The production process as depicted in Figure 1.1 (excluding BOS and transport) accounts for approximately 60 per cent of emissions. A significant share of emissions comes from the production of polysilicon (23 per cent) and BOS 38 per cent. The most common process to produce solar-grade polysilicon (So-si) is the Siemens process, which is highly electricity-intensive. Also ingot and wafer production, which together account for 16 per cent of the emissions, require heat for lengthy time periods; up to 100 to 200 hours. Most of the electricity needed for production is supplied by coal (62 per cent). Production is centred in Yunnan, Xinjiang, and Jiangsu, which are provinces that rely on coal for more than 75 per cent of their power supply (IEA 2022). Table 3.1 finally also shows that transportation emissions are minor and take up only three per cent of total CO_2 emissions.

Table 3.1 Share of CO2 emissions per production step for solar PV systems from China

Production step	China
Polysilicon	23%
Ingots	15%
Wafers	1%
Cells	6%
Modules	14%
Balance of System	38%
Transport	3%

Source: Fraunhofer Institute for Solar Energy Systems (2021)

3.1.3 Labour conditions in solar panel production

Next to Xinjiang being one of the foremost Chinese regions for polysilicon production, it is also home to the Uyghur population, one of China's officially recognised ethnic minorities. Studies from Cockayne et al. (2022), Murphy and Elimä (2022), and a report of the Clean Energy Council of Australia have shed light on the forced labour that the Uyghur population is subjected to. As a part of state-sponsored programs targeting "poverty alleviation" and "anti-terrorism" the Uyghur that have been released from internment camps are transferred to factories to produce polysilicon, ingots and wafers near the camps where they were once interned. The nature of these labour transfers is coercive, resulting from the constant threat of re-education and internment. The state-sponsored programs have been documented as a source of human rights abuse (Murphy and Elimä 2022). The study of Murphy and Elimä also provides insight into which factories are involved in these labour transfers. Main suppliers of photovoltaic materials receive significant subsidies for taking forced labourers.

Forced labour is not only present in Chinese supply chains. Cockayne et al. (2022) calculated a Forced Labour Index (FLI) between zero and one (with one representing the highest dependence on forced labour) for the top 30 PV-producing countries. With an index of 0.71, Chinese on-grid solar energy systems are produced with materials that have relatively high exposure to forced labour. Second in ranking is India (0.66), followed by Ukraine (0.56), Vietnam (0.53) and South Africa (0.44). Complementary technologies, such as batteries, are not considered in that study but are also known for their unethical labour conditions (Bamana et al. 2021). In that case human rights abuse of labourers is fostered by household poverty instead of state policies. This for example takes place in the production of Congolese cobalt, which is used for battery production.

Some countries have already taken action against these circumstances. In the U.S., the Uyghur Forced Labor Prevention Act came into force in June 2022, banning the import of any goods made wholly or partly in the Xinjiang Uyghur Autonomous Region. Australia, Canada, Mexico, the EU and UK are actively exploring and proposing similar bans (Murphy and Elimä, 2022).

3.2 New interest in the European solar production industry

In 1884, the first solar energy module was installed on a roof in New York. Since then, the interest in solar energy has peaked at different points in time, such as the space race in the 1950s and 1960s or the oil crisis in 1973. Solar PV has experienced exponential growth, with global installed capacity exceeding 1 TWp and prices decreasing below 0.4 USD/W (IEA 2022, Our World in Data 2021). In 2008, Spain opened the world's largest solar power plant (60 MWp) in Olmedilla. The biggest solar power plant in the world is now located in India, with an installed capacity of 2245 MWp. Module prices fell more than 80 per cent in the last decade and now represent one of the world's most affordable energy sources (McKinsey 2022). In the meantime, demand keeps on growing. According to a new report by the IEA, renewable energy capacity additions will exceed 300 GWp in 2022, of which 60 per cent is forecasted to come from solar (180 GWp). The increasing importance of solar has revived the interest in the European manufacturing industry for solar PV and in becoming more energy independent.

The new interest in becoming more energy independent is preceded by a timeline of continuous developments to strengthen Europe's renewable energy sector. It goes back to the first feed-in tariffs for Germany in 1991, followed by introducing the Renewable Energy Directive (RED). This target binds member states to a certain percentage of renewable energy consumption. The need for more renewable energy is further emphasised with the European Green Deal, a commitment to be climate neutral by 2050. Next to these developments, more recent events have shaken the energy market. The rising demand after the COVID-19 pandemic and the cold winters in 2020 and 2021 in Asia and Europe contributed to rising natural gas prices. At the same time, the military build-up and full-scale Russian invasion of Ukraine in 2021 and 2022 led Europe to impose sanctions on Russia, prohibiting the purchase, import or transfer of crude oil and petroleum products from Russia into the EU. In June 2022, European Energy ministers welcomed the RePowerEU plan to phase out dependency on Russian energy without compromising on climate and environmental goals (European Council 2022).

Figure 1.3 Goals RePowerEU

Source: SEO (2023), based on European Council (2023)

The REPowerEU plan is accompanied by the EU Solar Strategy, which is depicted in Figure 1.3. This strategy increases Europe's solar ambition by 43 per cent and includes new guidance on permitting, a Solar Rooftops Initiative, a Solar PV Industry Alliance and a Solar Skills Partnership. Pursuing the goals of RePowerEU implies obtaining the necessary energy from other sources. Therefore, it could also increase the dependence on the Chinese solar industry. However, due to ethical reasons, such as relative CO_2-intensive production and forced labour, Europe is compelled to become more independent from China's solar supply chain.

4 The European solar PV industry

On average, Europe accounts for approximately three per cent of the global solar PV production capacity. Over the years, high-tech capabilities and knowledge have been transferred to Asia, where they have been rapidly adopted for mass production. While European initiatives to address market vulnerabilities are emerging, they are not as advanced as initiatives seen outside of Europe.

Europe currently holds eight per cent of the polysilicon production worldwide, most of it taking place in Norway and Germany. There are currently no new polysilicon capacity expansions announced. Ingots and wafering only hold a small global production share: about one per cent which equals 1.4 GWp and is mostly produced in France, Germany, and Norway. Another 5.4 GWp of capacity addition is announced. With the greatest producers in Germany and Italy, cell manufacturing is even less. However, approximately 8 GWp of new capacity has been announced. Requiring the lowest investment cost among the manufacturing stages, module production is widely spread in Europe, with smaller local companies often producing less than 1 GWp. This amounts to about 2 per cent of global production, with 38 GWp of new capacity announced. Only a few high-quality production lines for solar manufacturing equipment have remained in Europe, while much has been shifted towards mass production in Asia between 2004 and 2008. Despite a reputation for high quality, sophisticated technology, China is expected to catch up quickly with technological advantages. This is not only the case for solar manufacturing equipment but also for new cell technologies, including PERC, heterojunction, IBC, or TOPCon.

The CO_2 footprint for PV systems produced in China is 43 g CO_2 eq/kWh. Producing the same system in Europe would use approximately 23 g CO_2/kWh. Because of this and the little resilience Europe has against potential supply chain disruptions, initiatives such as the IPCEI PV, the ESMC, and the MCPV promote solar manufacturing made in Europe. Market certificates and labels are still a work in progress, with a need for more transparency. Solar manufacturing in Europe is hard because of high CAPEX expenses, long payback times, and higher labour and material costs. Due to their higher subsidies and import tariffs, the U.S. and India are perceived as more attractive locations to foster solar manufacturing. According to interviews, subsidies in the Netherlands are not addressing the implementation of technology sufficiently.

4.1 Key players and stakeholders in the European PV industry

The players in the European PV industry can be divided by each step in the value chain. Some stages have many small producers spread out across Europe, like module production. Other stages have more concentrated, large-scale production in certain countries, like silicon production. The value-added stage discusses the key players. An overview of the key players per step in the value chain and their respective production capacity is given in Figure 4.1.

4.1.1 European capacity per value chain segment

The most important European players in terms of the production of **solar silicon** are located in Norway, Iceland, and Germany. There are two types of silicon used in the PV production process: polysilicon and metallurgical silicon. Metallurgical silicon is a step in the production of polysilicon. The polysilicon production in Europe amounts to 22.1 GWp. This is about 7.6 per cent of the total polysilicon production in the world, which is roughly 290 GWp per year.

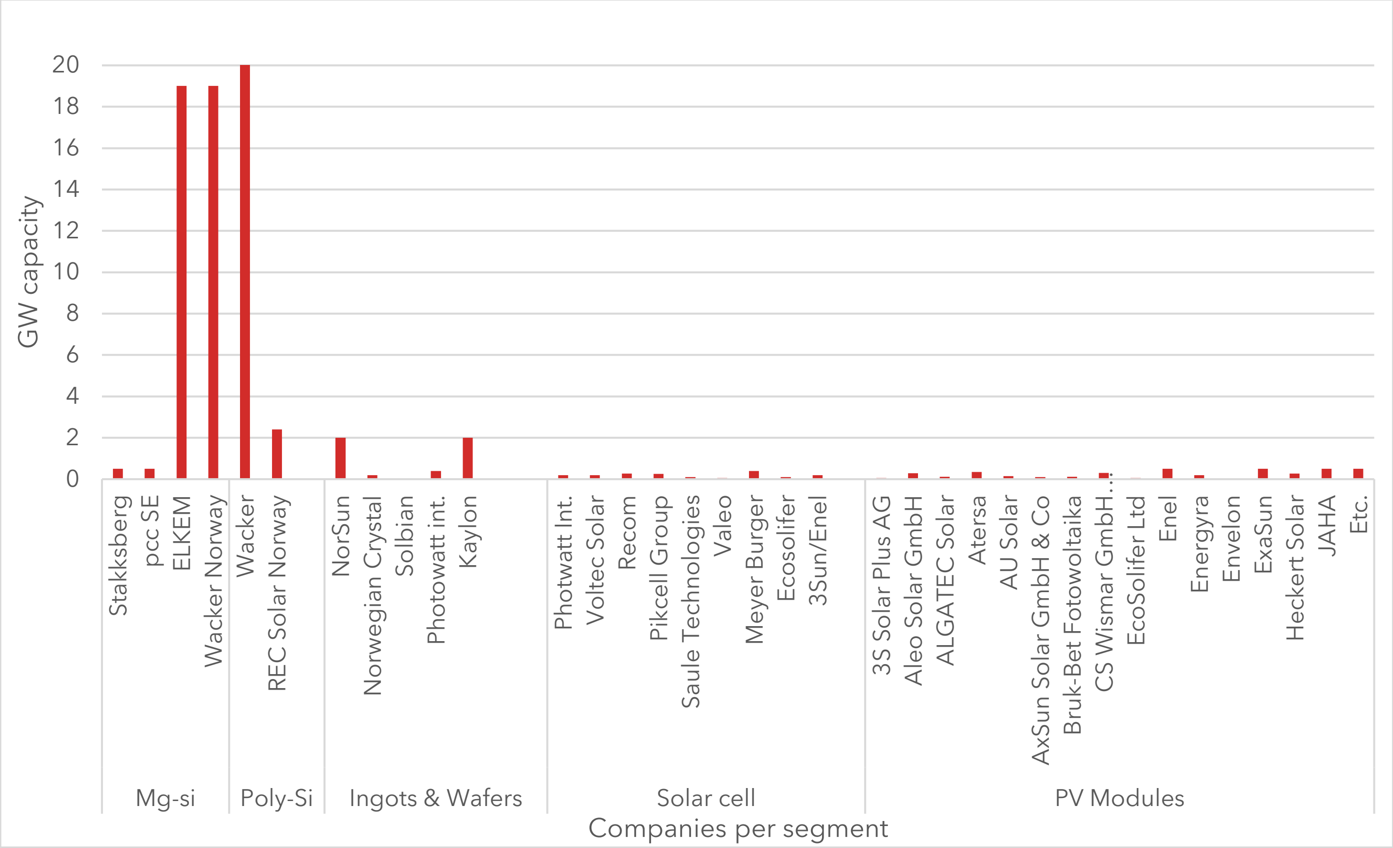
Europe’s largest polysilicon producer and simultaneously largest producer in the entire value chain is Wacker, located in Germany, with 20 GWp of polysilicon production. REC Solar Norway is another polysilicon producer located in Norway, producing more than 1 GWp. The total production of mg-Si in Europe is 38.2 GWp. China’s polysilicon production consists of approximately 227 GWp. The global polysilicon production is 290 GWp. The largest European producer of mg-Si is Wacker Norway. While the exact capacity is publicly unknown, their capacity reaches beyond 1 GWp of mg-Si. Their produced mg-Si is subsequently shipped to Wacker Germany for the production of polysilicon. There is one other mg-Si producer in Norway, ELKEM, whose production also exceeds 1 GWp. Iceland also has some mg-Si production capacity via the companies Stakksberg and pcc SE, both producing over 500 MWp.

Europe has a limited number of large manufacturers specialising in **silicon ingots and wafers**. There is one integrated producer based in France called EDF PhotoWatt. Their production capacity ranges between 0.1 GWp and 0.5 GWp. Additionally, Norway hosts two wafer capacity producers, Norwegian Crystal and NorSun, with a production capacity ranging between 0.5 GWp and 1 GWp. Germany is home to a wafering start-up named NexWafe, although it is currently in the developmental stage, making it challenging to determine its current production capacity. These manufacturers have a combined capacity of approximately 1.4 GWp (Fraunhofer ISE, 2022). This is a very small share of the global production capacity, considering that China accounts for 97% of the global manufacturing capacity (IEA, 2022).

There are a few **solar cells** producers in the EU. According to the EU Market Outlook for Solar report, Europe's total production was around 1.4 GWp in 2022. When compared to the global production of 460 GWp, Europe's share is relatively small. In contrast, China alone accounts for around 85 per cent of the world's production, producing roughly 391 GWp. The largest European companies are Meyer Burger in Germany and Enel/3Sun in Italy. These companies produce solar cells for internal use and develop them into **PV modules**. Meyer Burger has a current production capacity of 321.1 MWp in terms of its solar cells production but is working on increasing its production volume to 1.4 GWp by the end of 2023 (PV Europe, 2023). Enel’s current production capacity at its 3Sun factory is 200 MWp, and they plan to increase this to about 3 GWp per year by 2024 (European Commission, 2023). Then there are EcoSolifer in Hungary and ValoE in Lithuania, with capacities smaller than 100 MWp per company.

Besides Meyer Burger and Enel, which produce their cells in-house, many **PV modules** producers import their cells from Asia and further develop them into PV modules within their factories. Europe's PV module production capacity is 8.28 GWp, approximately 2 per cent of the global production of around 400 GWp (Fraunhofer, 2022). China dominates with 75 per cent of the world's production (about 300 GWp). Several PV module companies also have ties to solar cell manufacturing, like ValoE /SoliTek. Pure solar module manufacturing requires the lowest investment cost among the solar module manufacturing chain stages. This solar manufacturing segment has been seeing the largest activity, mostly through small, local companies with capacities in the sub-GW range (SolarPower Europe 2022). In 2022, at least 54 module manufacturers operated factories in the EU (SolarPower Europe 2022). The largest ones are Soluxtec, Sonnenstromfabrik, and Solarwatt in Germany. Two other large producers are Meyer Burger and Enel. These latter two are also the most ambitious in Europe, currently expanding their production activities into the U.S. Their expansion activities were initially planned in Europe, which changed after the U.S. Inflation Reduction Act (IRA) was introduced. Turkey houses numerous PV module manufacturers, with at least 15 companies located there. REC Solar won a grant to build a module factory in France, however, they have announced to put its plans on hold due to “various changes in market conditions”.

Figure 4.1 Production capacity per company in the value chain in Europe

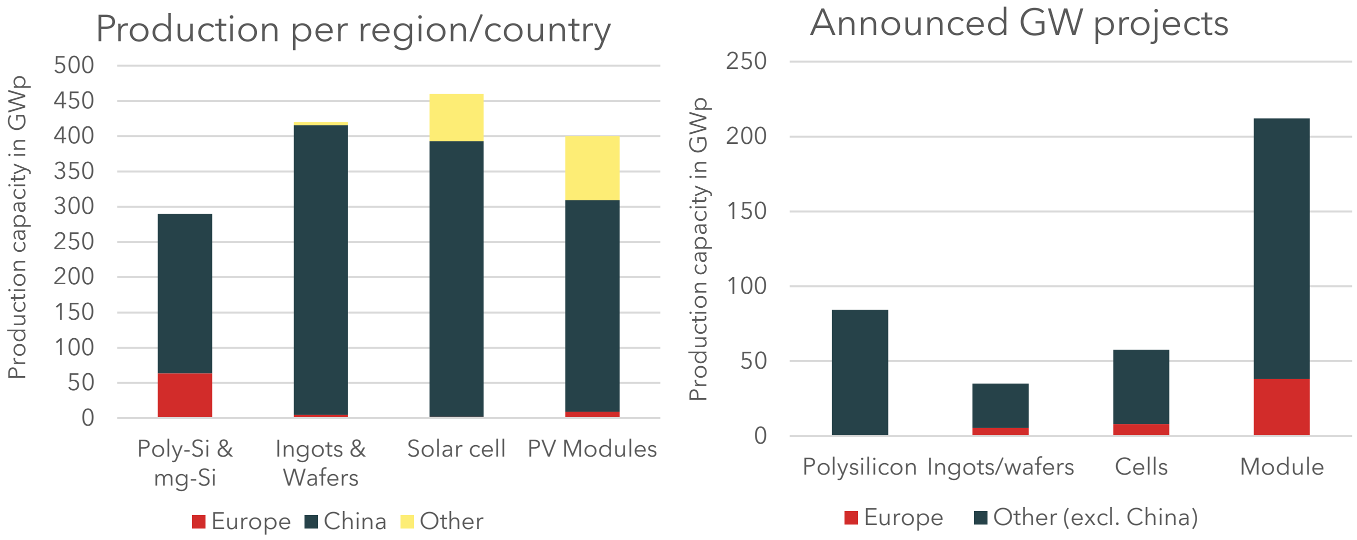


Source: SEO (2023), based on Solar Power Europe (2022) and Fraunhofer Institut (2022)

Note: For the mg-Si producers ELKEM and Wacker Norway, the given production capacity is an estimation based on the SolarPower Europe 2022 and the Fraunhofer Photovoltaics 2022 report. The report states that these two companies are the only two companies producing more than 1 GWp and that the total European production of mg-Si is 38.2 GWp. Therefore, we have allocated half of this to each company. However, it could be the case that the ratio is different than 50/50.

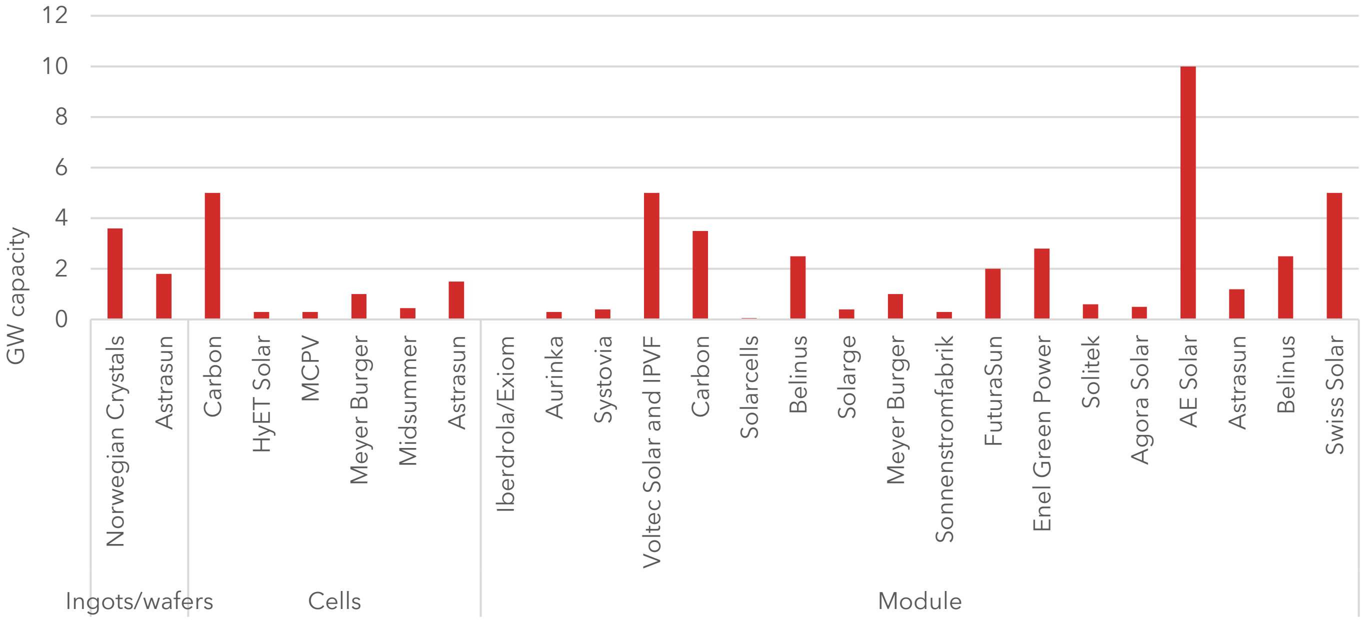
Figure 4.2 presents the current capacities and announced projects for Europe, China, and the rest of the world per segment. No data was found regarding announced projects in China, but this does not imply that no projects are underway to increase production. Figure 4.3 provides a closer look at the announced projects per industry segment and company.

Figure 4.2 Share in existing and announced production capacity per region



Source: SEO (2023), based on Ultra Low Carbon Solar Alliance (2023)

Figure 4.3 Announced new capacity in Europe per company



Source: SEO (2023), based on Ultra Low Carbon Solar Alliance (2023)

Note: Does not include Nationaal Groeifonds plans

4.1.2 European equipment and material manufacturing

The figures above do not include equipment manufacturers involved in producing cells and modules, nor do they account for component producers and inverters. Since different equipment and materials are needed per segment in the value chain, the scope of equipment for solar cell production is too broad to include here. The **processing**

materials and production equipment for cell and module production are predominantly made in Asia (SolarPower Europe 2022). Between 2004 and 2008, many Chinese PV cell manufacturers purchased production lines from Western countries, mainly Germany, to produce solar cells and export them back to Europe (Huang et al. 2016). As the European industry did not embrace this successful and high-quality equipment development back then, China gained a competitive advantage in this industry segment. According to interviewed companies, some leading European companies still can accommodate most processes in terms of equipment. However, these equipment manufacturers are scarce, and Europe is not self-sufficient when it comes to processing materials. Most equipment producers have either shifted their scope, gone out of business, been acquired, or relocated to Asia. Von Ardenne in Germany is a large producer of coating equipment for many types of solar cells. SM InnoTech and Bürkle from Germany are an example of delivering high-quality equipment for the lamination of various types and dimensions of solar modules. Borealis in Austria produces polyolefins for thermoplastic encapsulant film and back sheets. Eurotron is a Dutch manufacturer of automated production lines for back-contact PV modules.

Nine major players hold nearly half of all manufacturing jobs for **inverters**. The largest one is SMA, in Germany. They specialise in designing and producing all-sized inverters for all types of solar panels. Another large company in this segment is Fronius from Austria. Fronius focuses on developing and implementing innovative methods to monitor and control energy for welding technologies, photovoltaics, and battery charging. Both SMA and Fronius have a production capacity of over 10 GWp. Despite a global shortage of inverters due to the global semiconductor chips shortage, inverter production holds by far the largest capacity of European solar manufacturing segments (SolarPower Europe 2022).

The **Balance-of-System (BOS)** refers to all the components of a PV system, except for the PV panels itself. There are two EU countries with two companies each that are involved in this line of business. Germany houses K2 and Schletter, while Spain houses Soltec and Trina Solar’s Trina Tracker.

4.1.3 PV industry initiatives

There are multiple initiatives in Europe for numerous companies, sectors and countries to work together.

The **PV-IPCEI initiative** (Important Project on Common European Interest) is one of these initiatives. It’s a project where multiple European countries work together in order to restore the European PV industry. Van Gastel (2022) wrote a news article on this initiative, explaining that the goal of the initiative is to create a production capacity of 20 GW by 2025 and 100 GW by 2030. Europe has access to state-of-the-art technology, but it misses the larger scale to benefit from economies of scale like China does. By working together, the included countries try to benefit from economies of scale and reduce development risks. Currently, the project includes five countries: Austria, Spain, Lithuania, Poland, and Luxembourg. The Netherlands and Belgium have not yet decided on whether to join the project. The initiative currently focusses on six projects. Some of these projects correspond directly with other initiatives and alliances. For example, one project focuses on the ‘Manufacturing of TOPCon PV cells’. Its goal is to upscale the European production of TOPCon-cells and be able to sell them for a relatively low price (less than 10 euro cents per watt). This project corresponds with one of the pillars of the European Solar Photovoltaic Industry Alliance, ‘Solar Manufacturing Accelerators’. This will be further explained when discussing the European Solar Photovoltaic Industry Alliance.

An initiative that falls under the IPCEI umbrella is **ESMC** (European Solar Manufacturing Council 2022). ESMC promotes solar manufacturing in Europe, the political environment to support industrial manufacturing and relevant research. A spin-off of the ESMC is the **MCPV**. Founded in 2019 by a team of leading solar industry experts, it is an industry start-up with plans to establish next-generation heterojunction (HJT) PV manufacturing in Europe. MCPV is actively working on bringing HJT to a gigawatt scale and they do this within the IPCEI framework (MCPV 2023).

Another initiative is the **EU Solar Energy Strategy**. This initiative is part of the REPowerEU plan. It aims to ensure that solar energy achieves its full potential in helping to meet the European Green Deal's climate & energy targets. The initiative pursues this objective through a three-fold approach. Firstly, it involves the identification of obstacles that hinder the widespread adoption of solar energy. Secondly, it puts forth a set of measures aimed at accelerating the implementation of solar energy solutions. Lastly, it focuses on enhancing the competitiveness and resilience of solar energy systems within the EU. The EU Solar Energy Strategy proposes 3 initiatives: The European Solar Rooftops Initiative, the EU large-scale skills partnership, and the EU Solar PV Industry Alliance.

- The **Ultra-Low Carbon Solar Alliance** focusses on the large differences in PV solar supply chain emissions. This initiative consists of companies across the solar PV value chain and other stakeholders committed to expanding market awareness and deploying ultra-low-carbon PV to accelerate reductions in solar supply chain GHG emissions.
- The **European Solar Rooftops Initiative** aims to accelerate the large and underutilised potential of rooftops to produce clean energy. It includes a proposal to gradually introduce an obligation to install solar energy in different types of buildings over the next years, starting with new public and commercial buildings.
- And lastly, the European Commission (2022) has initiated a **large-scale skills partnership** to maintain and regain technological and industrial leadership in areas such as solar.

Then there is the **European Solar Photovoltaic Industry Alliance**, which was launched by SolarPower Europe & EIT InnoEnergy. This initiative aims to scale up solar PV manufacturing capacity in Europe, thereby increasing GDP and the number of jobs. The initiative has two pillars:

- *Solar Manufacturing Accelerators*: A platform to facilitate solar PV manufacturing projects in Europe, strengthening EU leadership in Clean Energy Technologies and fostering re-industrialisation. Strategic partners include ESMC, ETIP-PV, IPVF, and VDMA.
- *Solar Business Investment Platform*: A platform connecting project developers and investors, inspired by the European Battery Alliance investment platform and leveraging the Solar Manufacturing Accelerator initiative.

Furthermore, there are the **European Technology & Innovation Platforms (ETIPs)**. Their goal is to improve Europe's PV industry competitiveness to keep a strong position in the global PV market, both in the upstream and downstream segments. The ETIPs have been created by the Integrated Roadmap Strategic Energy Technology Plan (SET Plan). It brings together EU countries, industry and researchers in key areas. The platforms have gathered over 200 experts working in different working groups covering the entire PV value chain. An important part of their activities is promoting the market uptake of the main energy technologies, which is done by pooling funding, skills, and research facilities.

4.2 Requirements for reducing the carbon footprint

4.2.1 European initiatives

The European Commission is researching whether to regulate the environmental effects of photovoltaic products. A public consultation and a feedback period on this matter have already taken place. The outcome of their research is planned to become public in the fourth quarter of 2023. The European Solar Manufacturing Council also backs this. Policies include mandatory Ecodesign and Energy labelling and a voluntary Green Public Procurement (European Commission, 2023).

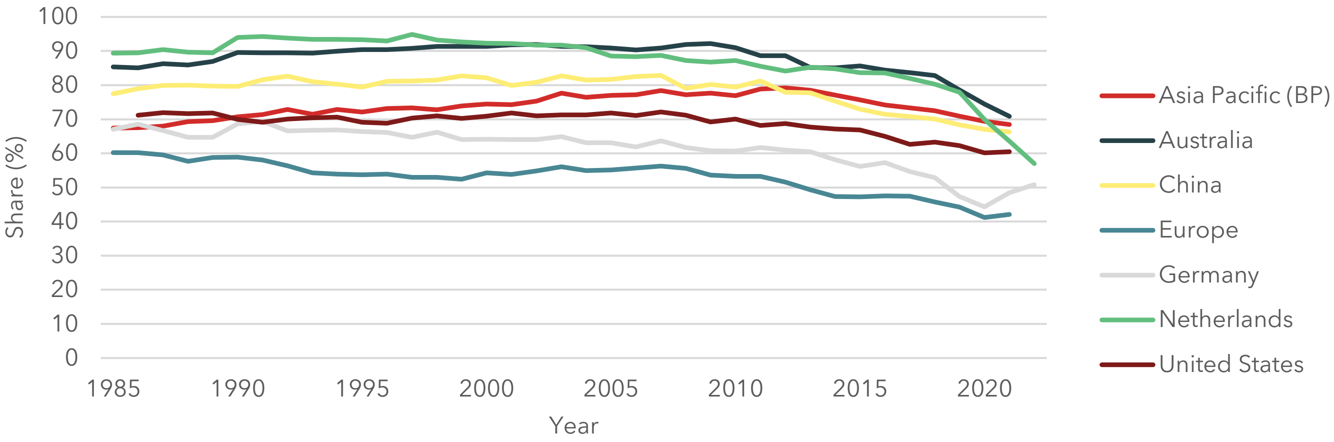
Energy labelling refers to the provisioning of information about categories of energy efficiency (A to G). For the solar PV sector, there are additional considerations about adding information about recyclability and the use of certain toxic materials. This would give consumers the ability to consider these factors when purchasing solar panels.
Ecodesign entails minimum requirements about the lifespan, the degradation, CO_2 footprint, quality and recyclability of solar panels. The Green Public Procurement would allow governments and other clients to use standardised voluntary criteria to prioritise the procurement of solar panels produced in a very sustainable manner.
Currently, the European Commission maintains a taxonomy regulation that outlines the conditions for economic activities to qualify as environmentally sustainable. The regulation does not oblige investors to only invest in the activities that meet the criteria, but it serves as a facilitator for promoting more sustainable investment. However, the criteria for electricity generated using solar PV are not very specific (TNO 2021; European Commission 2021).

Despite being a work in process, European regulations can incentivise producers and consumers to strive for more sustainable solar PV technology. Currently, European producers often choose a “cradle to cradle” certificate, which evaluates products and their processes on their used materials, options for recycling, use of renewable energy, sustainable water use, and social equality. However, studies such as Massana et al. 2015 and Bjørn and Hauschild (2012) show that this approach lacks stages that would have been otherwise taken into account by an LCA. LCA’s take resource use, CO_2 emissions, and use of the environment into account. Next to transparent recycling criteria, an LCA provides a good basis to evaluate the sustainability of a product.

4.2.2 Potential supply chain efficiencies

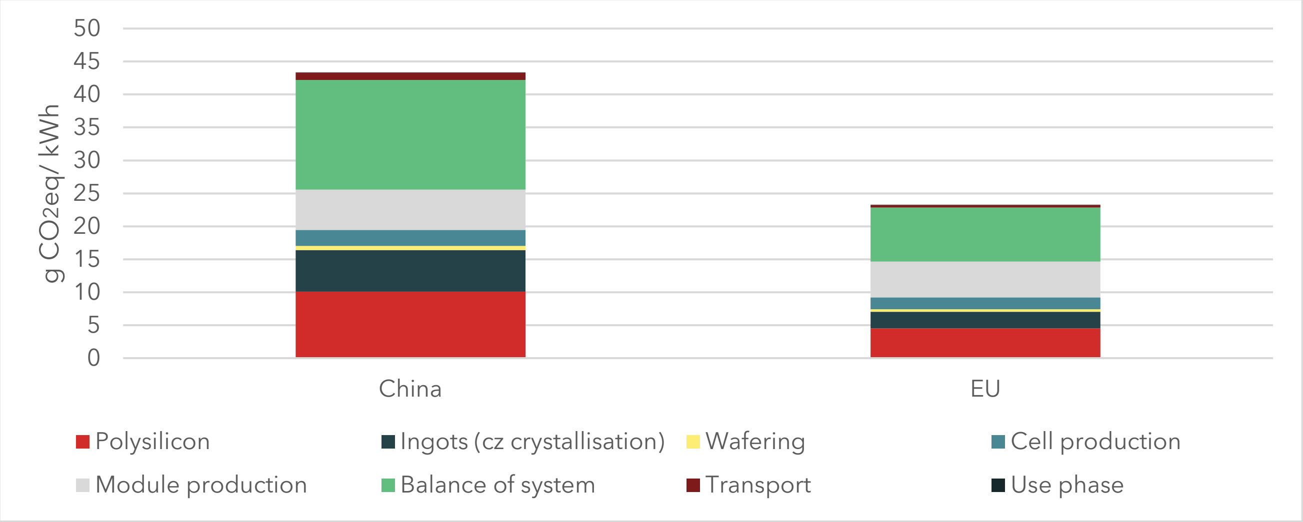
As stated in paragraph 3.1.2, the CO_2 footprint for PV systems produced in China is 43 g CO_2 eq/kWh. Figure 4.5 shows the CO_2 emissions per production step for passivated emitter and rear contact cells (PERC) in China and in Europe. Producing the same system in Europe would use approximately 23 g CO_2/kWh. Electricity usage accounts for 89 per cent of solar PV industry emissions. As a result, the energy mix of a country is a major factor in the CO_2 footprint for solar PV systems. Figure 4.4 gives an overview of the fossil fuel intensity of electricity production per geographical area. The graph entails all areas that currently hold a share in the solar PV production capacity. This graph shows that the use of European electricity instead of Chinese electricity would reduce the electricity's fossil fuel intensity in 2021 from approximately 66 per cent to 42 per cent.

Figure 4.4 Share of electricity production from fossil fuels



Source: SEO (2023), based on Our World in Data (2022)

Figure 4.5 CO2 emissions per production step for solar PV systems in China and Europe



Source: Fraunhofer Institute for Solar Energy Systems (2021)

The IEA (2022) calculated hypothetical solar PV manufacturing emission intensity for certain countries. Countries with a relatively high renewable energy capacity, such as Norway or Spain, can significantly reduce manufacturing emissions. Next to the source of electricity used during the production process, the use of more advanced technologies and end-of-life treatment also contribute to supply chain efficiencies. The next section briefly addresses end-of-life treatment. More attention to advanced technologies will be given in the paragraph 4.3.

From all the Waste from Electrical and Electronic Equipment (WEE) categories, solar panel materials currently hold the lowest value in their end-of-life stage (TNO 2021). It is important to reconsider the value of these materials as the abundance of these materials is questionable. While silicon is one of the most abundant materials on earth, pure raw silicon, purified from quartzite is rather scarce. The same holds for glass (SiO_2), which has to be obtained from relatively pure sand with low iron content. New technologies, such as perovskite solar panels, require rare earth materials like tellurium, indium, and gallium. As a highly conductive metal, silver is used for the busbars and contacts in solar panels. Thus, especially n-type technologies such as TOPCon or heterojunction require much silver. Even with conventional technologies, 85 to 98 per cent of global silver supplies would be depleted by 2050 (Hallam et al. 2022). It is important to note that while more efficient technologies decrease energy payback time, they also pose challenges in terms of utilising scarce resources. A whitepaper of TNO suggests more specific criteria for recycling solar panels, also regarding its long product lifespan (TNO 2021).

4.3 Advancing solar PV technologies

CO_2 emission reduction can also be achieved by cells with higher efficiency that decrease the energy payback time. Advancing solar PV technologies can play a key role in achieving the RePower Europe goals and differentiating from conventional market leaders.

4.3.1 Promising technologies

Currently, silicon is still the most used material, holding a market share of 95 per cent. These cells reach an efficiency of 29 per cent in laboratory conditions, which is just a few percentage points from the obtainable maximum. The challenge lies in obtaining the same percentages under large-scale production (TNO 2021). Currently, this is possible to up to 22 per cent. To address efficiencies in the application of solar cells, perovskite cells with a 25 per cent efficiency have been developed in just a few years (TNO 2021). The thin films can harness solar energy on more surfaces and from a wider range of angles than merely on rooftops. Equally promising are tandem cells, which form a combination of silicon bottom cells and thin perovskite top cells. These cells already surpass the efficiency of the other technologies with efficiencies of 30 per cent or more (TNO 2021). Tandem perovskite cells are still in the development phase. They could become commercially viable within the next few years (Clean Energy Reviews 2023).

PERC (Passivated Emitter and Rear Cell) belongs to one of the recent technologies already commercially viable. These cells have an advanced cell architecture using additional layers on the rear side of the cell to absorb more light photons, reaching an efficiency of about 23 per cent in 2023 (Clean Energy Reviews 2023). TOPCon (Tunnel Oxide Passivated Contact) solar cells have a more advanced N-type silicon cell architecture, also increasing efficiency. First introduced by Fraunhofer Institut (2014), it reaches efficiencies of 25 per cent in 2023 (Clean Energy Reviews 2023). TOPCon cells' efficiency is similar to heterojunction cells, which use a crystalline silicone base layer with additional ultra-thin-film layers of amorphous silicon on either side. IBC (Interdigitated Back Contact) cells are in a later development stage and promise slightly higher efficiencies than previously mentioned technologies. Unlike traditional cells which have 5 to 6 large visible ribbon busbars and multiple fingers on the front side of the cell, IBC cells have a grid of 30 or more conductors integrated into the rear side of the cell (Clean Energy Reviews 2023).

4.3.2 Europe's and China's technology position

According to a TNO whitepaper (2021), Europe is a global leader in the knowledge of perovskite cells and has advanced production capacities in this area. Companies such as Meyer Burger or Enel are examples of leading companies developing heterojunction and tandem solar cells (McKinsey 2022). Spin-offs from DSM have specialised in developments such as backsheets, coatings, and polymers, which improve the efficiency of solar cells as well. Collaboration with research institutes is important for projects expanding a country's PV technology and production capacity. Important European knowledge institutes include TNO, Fraunhofer Institut, Amolf, CEA, EPFL, Instituto de Energia Solar, and ISC Konstanz. Knowledge institutes are often part of project consortia, such as in the Dutch

Groeifonds, a Dutch investment program to strengthen clean energy sectors and their role in the Dutch economy. Interviews confirm the perspective on relatively advanced European technologies.

Interviews with experts confirm that the strength of Europe lies in technological advances, whereas China outperforms Europe in manufacturing scale. This perspective also comes back to the historical development of China's PV industry. Manufacturing in China came with lower labour costs and was stimulated by government support and the rising global demand for cleaner energy. The technology transfer from Western countries, especially Germany, has been crucial in fostering China's PV industry (together with China's national permission of private enterprises in 1987 and the rising demand in Europe for renewable energy since the Kyoto Protocol in 1997) (Huang et al., 2016). The imported "turn-key" technology from Europe required relatively little technical expertise, as high-tech capabilities and knowledge were already embedded in the production lines and easily transferred (Huang et al. 2016). During the dawn of the Chinese PV industry (2004 to 2008), the connections between research institutes and the industry were still weak. The manufacturing sector hired Chinese PhD graduates from foreign universities for attractive salaries (Huang et al. 2016). Despite the effects of the financial crisis between 2009 and 2012, a Chinese domestic PV market began to form due to industry lobbies and a central government's stimulus to increase public expenditure and stimulate domestic demand. At the same time, the European market for solar PV started declining.

According to interviewed parties, China is estimated to take up technological advancements quickly. Companies such as Sunpower (U.S.), Canadian solar, REC Solar (U.S.), Panasonic (Japan), Belinus (Belgium), Futura Sun (Italy), and Meyer Burger (Germany) rank among the companies with the highest efficiencies in solar panels (with 22.8 per cent the highest by Sunpower). However, companies such as Trina Solar, Jinko Solar, Spic Solar, and Huasun are also in the ranking and employ technologies such as heterojunction, IBC, PERC or TOPCon. Whilst not having a place in the ranking in 2022, the Chinese company Longi Solar was even added to take second place in the ranking of 2023, with an efficiency of 22.6 per cent, after Sunpower (Clean Energy Reviews 2023). Huang et al. (2016) emphasise the ability of traditional machinery manufacturers to shift to the PV industry and take up the manufacturing of PV modules for a much lower price. Interviewed parties perceive China as less risk-averse than Europe and do not doubt the Chinese industry's ability to catch up to European technological advancements quickly. A company manufacturing automated production lines for back-contact PV modules experienced a knowledge take-up of five years between 2008 and 2013. Huang et al. (2016) show similar timeframes in their empirical study.

> *"Knowledge and mass production are closely connected. Usually, it takes about 5 years for knowledge to transit towards the area where mass manufacturing takes place."*
>
> *Bram Verschoor, CCO Eurogroup*

4.4 Market failures

The current European demand and supply in PV are vulnerable to supply chain disruptions such as price increases and geopolitical conflicts. Initiatives such as RePower Europe are directed at reducing the exposure to these vulnerabilities. In 2022, approximately 241 GWp out of 1570 GWp production capacities came from outside China. More than half of this capacity (approximately 54 per cent) is European. Especially ingots, wafers, and cells are not sufficiently produced in Europe, although these are critical supply chain components. Equipment over the supply chain is also highly dependent on imports. Interviews and literature confirm that exporting stable and reliable production equipment to countries with lower production costs has decreased European manufacturing capacity. Industry parties, such as Meyer Burger, Norwegian Crystals, and Wacker, have concluded that Europe has no resilience against potential supply chain disruptions (Fraunhofer, 2023). In contrast to China's central government's macroeconomic policy stimulating the growth of the solar sector, Europe's vision of a strong solar industry was less clear during the financial crisis in 2008 and 2009. Interviewed parties state that the governance and ambition of China or the U.S. are clearer and more proactive than Europe's. This has also manifested itself by companies such as Enel, Meyer Burger, and Futura Sun choosing GW production in the U.S. and China over Europe.

The relocation of mass production to countries outside Europe has led to a dependence on less environmentally friendly manufacturing processes, resulting in a CO_2 footprint twice as large compared to production processes with a more sustainable (European) energy mix. Moreover, importing from countries outside Europe also increases transport emissions. Furthermore, polysilicon production relies partly on unethical labour conditions. These market failures are still insufficiently addressed. For example, there is no price internalisation of the environmentally higher costs of producing PV systems in China. Initiatives such as Ecodesign or Energy labelling are still works in progress, and efforts to enforce the procurement of products that fully respect human rights are ongoing. The U.S. has banned the import of any goods made wholly or partly in the Xinjiang Uyghur Autonomous Region. India has enforced import tariffs to safeguard "made-in-India" products.

According to a joint statement of industry parties and the Fraunhofer Institute (2023), European companies have high business risks in establishing a more local solar upstream manufacturing chain, making positive investment decisions difficult. The main reason for the increased business risk is high CAPEX expenses, long payback times, and higher labour and material costs. At the same time, reducing CO_2 emissions and establishing human rights standards also increase operational costs. According to a report by McKinsey (2022), solar PVs manufactured in Europe for every stage of the value chain will have a 20 to 25 per cent disadvantage against the lowest cost levels of 2022, not yet accounting for the recent hike in power prices. European solar panels cost 0.33 USD/W, whereas Chinese solar panels cost about 0.24 USD/W. Higher cost differences are also enhanced by an unlevel playing field when comparing China and the U.S.'s power prices and electricity market mechanisms. Furthermore, the IRA strongly subsidises U.S. companies, leading to a competitive disadvantage for European production. Including other American incentive programs, the direct production support will be 12 to 20 c/Wp until 2030, after which the support through the IRA will reduce by 25 per cent per year.

On top of that, the U.S. already uses import tariffs on cells and modules made in China. All this support will make solar PV from the U.S. the cheapest in the world (McKinsey 2022). With significant import tariffs of 10.7 c/Wp and incentives of 2.1 c/Wp, India has also managed to reduce its import dependency from China, becoming one of the world's lowest-cost regions for solar PV. Occasional European grants (like the EU Innovation Fund) only have a relatively small impact of 0.1 c/W.

Dutch government intervention

Government intervention is a way to correct some of the above-mentioned market failures. The viewpoints of the interviewees suggest that the existing instruments do not adequately address the vulnerability of the Dutch solar manufacturing market.

Company representatives and scientific experts have expressed their concern that the current financial instruments regarding solar PV do not have enough budget for technology demonstration and system development. The time gap between fundamental laboratory research and implementation of technology is perceived as too wide. One Dutch subsidy that targets pilot and demonstration phases is the DEI. In order to determine the amount of subsidy, it requires a reference of an alternative Dutch production process and its CO_2 emissions. Consequently, the resulting subsidies are sometimes low, as Dutch production processes are already relatively CO_2 friendly. According to interviewed parties, the requirements of such financial incentives are sometimes too strict for the respective investment. Generic instruments, such as the WBSO or the Innovation Box (for the employment of R&D and R&D staff) are more effective in that sense.

To further upscale production, interviewees agree that there is insufficient seed capital or funds, let alone for an entire solar cell manufacturing plant. Innovation in silicon cells and perovskite tandem cells is hard to finance. On this point, many interviewees start comparing the Dutch and European programs to the more generous stimulus programs in India or the U.S. (the IRA).

In order to reduce some costs, it could be beneficial for (Dutch) solar companies to jointly purchase their bulk materials from European suppliers. According to a solar panel company representative, there is currently little collaboration between solar companies. Collaboration is also lacking between European governments. Discussions with neighbouring countries and European institutions in general is experienced as rather slow and risk averse, compared to China or the U.S., for example.

Another shared opinion is that the current subsidies target rapid expansion of rooftop solar but do not address issues such as the congestion of electricity nets or smart storage solutions in order to use the harvested energy as efficiently as possible.

5 The Dutch solar PV industry

Developments of the Dutch solar PV industry closely followed the European solar PV industry. However, in time, the Dutch industry will focus more on a niche market with aesthetic, thin-film, flexible solar panels that are suitable to integrate into buildings to expand solar capacity while saving space.

The Netherlands' potential does not lie in large scale production, but rather in mass customisation and light-weight panels. At the same time, experts and companies underline the environmental benefit of Dutch solar panels versus large-scale produced panels from Asia. Not only are light-weight panels better suited for Dutch rooftops, the Netherlands can also play a pioneering role in further developing BIPV and VIPV and contributing to European module technology. Dutch knowledge institutes like TNO or AMOLF are responding to that role, also in international cooperations, such as Solliance or Interreg. These knowledge institutes and specialised companies in the field of solar panel integration are participating in the Nationaal Groeifonds program to realise GWp production lines of Dutch efficient and circular solar cells.

5.1 Dutch solar PV companies

In 2022, installed solar PV capacity in the Netherlands reached 18.2 GWp. Solar Power Europe's trend report (2022) shows projects of 11 GWp more in the pipeline. 46 per cent of the growth in 2022 in installed capacity can be attributed to residential rooftop solar, 30 per cent to solar on commercial buildings' roofs, and 24 per cent to ground-mounted or floating solar. As briefly highlighted in Chapter 1, the SDE subsidy contributes to expanding Dutch solar capacity. Challenges constitute limited grid and land availability for solar deployment. Despite these challenges, the target of 27 MWp of installed solar capacity by 2030 is projected to be reached in 2025.

Table 5.1 gives an overview of Dutch companies specialising in different value chain segments. For this research's scope, companies specialising in heat pumps or solar boilers are not considered here. The first column represents companies that deliver essential production equipment, such as semiconductors, module testers or nanostructures and microstructures. The material suppliers in the second column provide module producers (in the last column) of materials such as back sheets, resins and compounds, coatings and glass or adhesives. As there are many materials being manufactured by a wide range of companies, the companies in the second column serve as a few examples. Finally, companies for junction boxes, converters or inverters and companies for substructures are represented in the third and fourth columns.

Table 5.1 Dutch solar PV companies per industry segment

Machinery/production equipment	Material suppliers	Junction-box/ converter/inverter	Sub-structures	Mg-Si/-polysilicon/-ingots/wafers/ cells	Modules/ integral Solar PV systems	
Smit Thermal Solutions	Endurans	Taylor	Valk Solar systems		Exasun-Wienerberger	Kameleon Solar
Levitech	Sabic	Solned	Solarstell		Energyra	Lightyear
Tempress	Scheuten	Delta	Esdec		Solarge	Im-efficiency
Solmates	Yparex	Sofar Solar	Easyfix solar		Solinso	Mito Solar
Mat-tech	Akzo Nobel	Solar Edge	Alius		Elsun	FlexSol
Morphotonics	C Coatings	Sungrow			HyET Solar	Solar Visuals
Eternalsun Spire	Resin BV.	Huawei			Oceans of energy	Zigzagsolar
VDL	RGS Development				Solar Duck	Studio Solarix
Eurotron	SPG Prints and Yparex				Escom	Wattlab
	DSM				Gosse Boxhoorn	Robisol
	Flexipol Composites				Duramotion	GSE Integration
	Compoform				SMA Solar Technology	Viridian Solar
	Taylor Technologies					Hanover Solar Brite Solar
						Hermans Solarglaz

Source: SEO (2023), based on RVO (2023), Holland Solar (2023), SolarNL (2023)

Note: This table of companies is not exhaustive

Similar to the broader European picture, most Dutch equipment and material manufacturers have shifted their production or gone out of business. Instead of embracing the momentum of high-quality equipment development between 2004 and 2008, many companies started to export their production to Asia for solar cells to be developed there. Nowadays, the remaining companies are still exporting to Chinese countries. EthernalsunSpire (although not owned by a Dutch company anymore) and Eurotron are examples of Dutch companies still active in this value chain section. On the other hand, the Netherlands does not house any companies that produce metallurgical and polysilicon ingots, wafers and cells. Europe's capacity for silicon is eight per cent of the global capacity. For ingots, wafers and cells, this is about one per cent and mostly concentrated in Norway, Germany or Italy. More Dutch companies are active in the module segment, although they do not contribute largely to European bulk production. Instead, Dutch module companies focus more on specific niches, while sourcing their bulk material (mostly) outside Europe. These niches address the demand of a densely populated country, seeking to optimise space and energy return while expanding solar capacity to reach national climate goals.

5.2 Strengths of the Dutch solar PV industry

Apart from significant machinery and material suppliers, the Netherlands' production capacity of solar PV panels is relatively limited. The biggest producer (Energyra) currently has a production capacity of 200 MWp. Other producers have capacities smaller than 50 MWp or are still on the way to full commercialisation. According to interviews with scientific experts and industry partners, the Netherlands' competence is present in manufacturing production equipment and in embedding solar cells in panels but not in silicon, ingots or wafer production. With the largest share of Europe's silicon, cell and wafer production capacity in other countries than the Netherlands, Dutch production focuses more on a niche market and less on bulk production. Interviews with Dutch companies in the solar industry show that this niche market has been characterised by a focus on the integration of solar panels in infrastructure and transport. Unique selling points of Dutch companies are flexibility, aesthetics, and sustainability.

Mass customisation and lightweight solar panels

Mass customization here refers to flexible solar panels in specific tailor-made sizes and shapes, which are well suited to be applied on different objects, such as buildings, cars or floating structures. The integration of these panels often comes with the need for light and thin solar panels. IM Efficiency, Lightyear, and Wattlab are examples of integrating solar cells on trucks, cars and boats respectively. These solar cells are lighter than conventional cells and, in the case of cars or boats, are capable of harnessing solar energy from a wider range of angles. Furthermore, lightweight solar panels are often more fitting for roof top installations in Europe and especially the Netherlands, as the mechanical load of standard panels is too heavy.

> *"The Dutch industry has a pioneering role in innovating PV modules for integration in the built environment."*
>
> *Arthur Weeber, Program Manager Solar Energy at TNO,*
> *Professor Applied Silicon Photovoltaics at Delft University of Technology*

Producers of flexible or lightweight solar modules are Mito Solar, HyEt Solar or Solarge. Many of these companies make use of Dutch material suppliers. For example, Solarge uses polymers of Sabic to produce lightweight solar panels. Lightweight solar panels are Energyra's foremost product as well. Energyra uses the back sheets of Endurans. Flexible and lightweight solar panels address an important component in realising European and national renewable energy ambitions: since the Netherlands has limited space in expanding solar PV, mass customisation is critical to optimise the installation of solar PV. Therefore, building integrated (BIPV) and vehicle integrated PV (VIPV) represent an attractive way to apply solar panels in the Netherlands.

Aesthetics

An often important requirement for applications on walls, vehicles, and roofs is aesthetics. Companies such as Zigzag Solar, Solarix, Solar Visuals, Solinso, and Kameleon Solar focus on solar panels' aesthetics (and multiple applications). Kameleon Solar and Solar Visuals even deliver solar panels in different colours and patterns to make them more compatible with the design and appearance of buildings. Also, international companies, such as Hanover Solar or Brite Solar Technologies on Brightlands Campus, have established a company in the Netherlands to facilitate the integration of solar panels in the built environment by substituting glass in greenhouses, for example. This is also taken up by Hermans Solarglaz. A supplier of substructures to integrate solar panels seamlessly into roofs is Alius. Alius' mounting structures can be fully integrated into the roof by making the transition between roof tiles and solar panels seamless and thereby contributing to the roof's aesthetics.

The organisation BIPV Nederland increases the product and market of building integrated PV. Established in 2018, it has recently joined Holland Solar as one of its working groups to promote BIPV in the Netherlands (BIPV Nederland 2022).

Sustainability

Sustainability is a major unique selling point for Dutch solar PV producers. This has also been emphasised during the interviews with Dutch solar panel companies. To begin with, equipment (such as SABIC's) often entails bio-based polymers that are fully recyclable. For example, this contributes to the full recyclability of Solarge's solar panels.

Another sustainability concern is the use of toxic chemicals. Endurans' back sheets do not rely on fluor polymers for protection but are toxin free and fully recyclable at their end-of-life stage. Similarly, Energyra refrains from the use of materials containing fluor. Companies like Energyra, Exasun, and Solarge state to avoid PFAS (and thus fluor) and/or lead in general.

Despite their dependency on Chinese components for their modules, some companies already source some of their materials from European countries to contribute to fewer transport emissions and a more sustainable supply chain. In some cases, polysilicon is sourced from Norway, polymers from Italy and the Netherlands, glass from Liechtenstein. This can make up 50 per cent of the production process and save on transport emissions. In addition, the lighter weight of these solar modules also reduces transport emissions. However, a large share is still imported from China, mostly due to the scale by which these products can be obtained rather than their costs.

BIPV project risks

Studies have been carried out to analyse successful business models for BIPV and the risks in realising BIPV projects. The following box addresses some of the risks and bottlenecks. It is out of the scope of this study to conduct a detailed risk assessment. One example of a risk assessment framework for BIPV is Zhou and Gao (2022), in which interviews with sector experts and a mathematical four-dimensional risk model led to a systematic risk estimation. More qualitative approaches can be found in studies from Liu et al. (2009), Jing Yang (2015), Vroon et al. (2016) or in IEA's Photovoltaic Systems Power Programme, Task 15. Knowing the risks of realising BIPV projects can help to introduce policies and collaboration to foster an attractive investment climate for BIPV.

Innovative business models for BIPV face economic, technological and social risks and bottlenecks for. Natural environmental risks (such as solar energy resources and climatic conditions) do also play a role, but are generally not very different for solar PV projects.

Technical aspects such as the panels' lifespan and its guarantee, aesthetics, flexibility and implementation procedures of integrating the panels in the building represent a major bottleneck in the realisation of BIPV projects (Zhou and Gao 2022, IEA 2018). Based on a research involving interviews and questionnaires, Vroon et al. (2016), found that over 40 per cent of the bottlenecks can be attributed to technical aspects. The reason for technical bottlenecks is a lack of standardised products, a lack of defined maintenance procedures and a lack of data on degradation and performance (IEA 2018, Jing Yang 2015). The lack of international standards is influenced by a complex regulatory environment. Since architects need to know where they can integrate BIPV, more clarity on specific BIPV standards and codes that fit well within the building codes are necessary (Jing Yang 2015, IEA 2018).

Approximately 23 percent of the bottlenecks in the realisation of BIPV projects is due to financial infeasibility (Vroon et al. 2016). In Zhou and Gao (2022) and Prieto et al. (2017), they also play an important role, together with lacking government support. Factors influencing the financial risks are the uncertainty about the valorisation and the total cost of ownership of BIPV. Here again, the lack of knowledge and awareness of standards, regulation, and the market itself undermine investors' confidence in making financial decisions (IEA 2018). For example, there are restrictions in different countries about where BIPV can be placed on buildings (Jing Yang 2015). Uncertainty in costs can defer bigger potential players from entering the market. Social barriers such as a lack of awareness of BIPV and a lack of knowledge of the construction sector add to the financial risks (IEA 2018).

Another barrier is the collaboration with the construction sector. Construction projects are awarded to contractors by a price-driven tendering process, which follow certain rules, regulations, and selection criteria. Often, these processes and the technical aspects are less well grasped by non-sector stakeholders. Apart from many technical and environmental barriers from the design to the operation stage, the importance of integration, communication, and knowledge-sharing between stakeholders is an important conclusion (Jing Yang 2015).

In the end, addressing the knowledge gaps and uncertainties by integrating the stakeholders of the solar- and construction sector can make a difference to reduce the risks of investing in BIPV. Additionally, clear regulations and optimisation of technological aspects and the construction process play a positive role in choosing BIPV for innovative construction projects.

5.3 Dutch knowledge institutes

Private and public institutes and research institutes closely collaborate in the Netherlands (RVO 2014, TNO 2021). Since 1989, ECN has been conducting research on solar cells and panels. TNO started to conduct research in this field in 2000. Their research is mission-driven, aiming to contribute to realising the ambitions to reduce emissions (inter)nationally. The research is concentrated within two main programs: large-scale application of solar energy by developing new and improved applications, and innovations to apply and integrate solar systems in the environment. The latter includes solar energy for infrastructure, water, land, and buildings. In addition, they collaborate broadly with international knowledge institutes, manufacturers, and suppliers (TNO 2021).

TNO works on developing and industrialising technology for producing and using silicon-based solar panels via an expertise group in Petten and close collaboration with the TNO Solar Technology and Applications' group in Eindhoven. The latter has a focus on the manufacturing and integration of thin-film solar cells. In general, TNO's research focuses on:

- Photovoltaic applications and system integration
- Panel technology
- New production technology
- Hybrid tandem technology

The Solar Technology and Application Group is part of a partnership between research institutes, universities, and industrial partners, called Solliance Solar Research. TU Delft, TU Eindhoven, University of Twente, and Rijksuniversiteit Groningen are (technical) Dutch universities that are part of this partnership. International research institutes that joined the partnership include Imec (Belgium), Forschungszentrum Jülich (Germany), and University

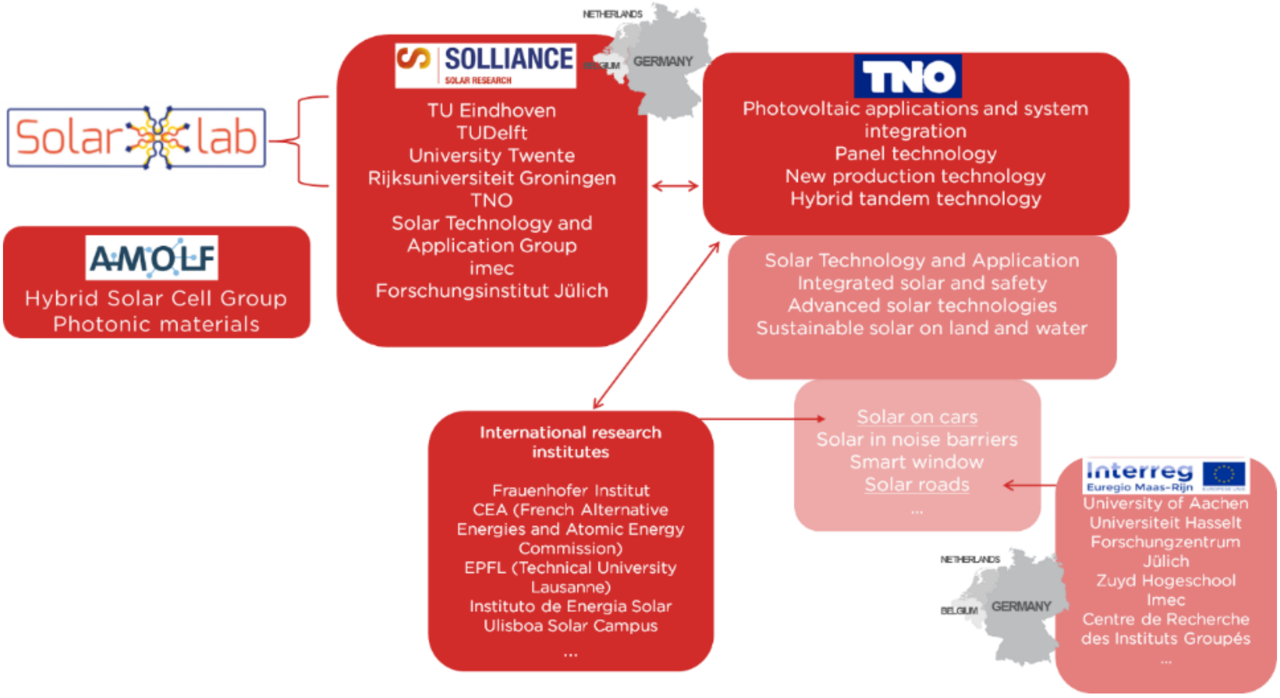
Hasselt (Belgium). This partnership focuses on the "seamless integration of solar technology on every surface". Surfaces include infrastructures, buildings, and transport.

Next to the Solar Technology and Application Group are programs related to Integrated Solar and Safety, Advanced Solar Technologies, and Sustainable Solar on land and water. Examples of topics addressed are solar on cars, solar in noise barriers, smart windows, and solar on roads. Interreg Europe, a European program for regional and national collaboration and development, supports solar on roads. Its project Rolling Solar pursues solar energy integration with thin solar panels on roads between Germany, Belgium, and the Netherlands. Partners of this project are the University of Aachen (Germany), Imec, University Hasselt, Solarge, and the Centre de Recherche des Instituts Groupés (CRIGS) (Belgium). Dutch applications for solar on cars have become renowned in events such as the World Solar Challenge, in which TU Delft's team has won seven times and TU Eindhoven's team two times.

Another independent research institute is AMOLF, dedicated to fundamental research on the physics of complex forms of matter – several of their research programmes concern solar PV. For example, the hybrid solar cell program develops an understanding on materials such as metal halide perovskites. The photonic materials program addresses light management in PV. TNO is also collaborating with AMOLF on the Dutch Joint Solar Program III, together with several universities and industry partners Shell, Tempress, Levitech, Exasun, and Eternal Sun to reach tandem devices with 30 per cent efficiency.

In 2016, a consortium of Dutch knowledge institutes was launched under the name Solar Lab. It brings together more than 50 research groups active in solar PV, supervising more than 150 PhD students and postdocs and 60 technology researchers at TNO. Solar Lab consists of the technical universities of Delft, Groningen, Twente, Eindhoven, and TNO and AMOLF, as well as the universities of Nijmegen, Amsterdam, and Utrecht. Solar Lab aims to lower the cost of PV and increase their power per unit area and implement PV into the landscape and infrastructure seamlessly (Solar Lab 2023). Figure 5.1 shows the different knowledge institutes in the Netherlands that address solar PV technologies and challenges. It highlights the research groups, the topics the technologies can be applied to and their relation to other (inter)national knowledge institutes. Furthermore, research on solar is complemented by other organisations, such as the Dutch Polymer Institute or Brightlands Chemelot Campus, which are not included in this figure.

Figure 5.1 Dutch solar energy knowledge institutes, programs and collaborations



Source: SEO (2023)

5.4 Ambitions for the Dutch solar PV industry

Despite having a very small share in bulk solar panel production and no share in silicon, ingots or wafer production, all interviewed Dutch solar PV chain companies have expressed their ambition to contribute to a more independent European solar PV supply chain. An example of this is Solarge's announced project of 100 MWp with an expected expansion of 400 MWp in 2024. Climate neutrality in 2050 entails an expansion of Dutch-installed solar PV capacity from 18 GWp to 100 – 250 GWp in 2050.

Building up more production capacity comes with a significant need for finance. Currently, subsidies in the Netherlands are not shaped to cover this need sufficiently. In addition, subsidies need to be approved by the European rules for State aid. By many industry stakeholders, the PV IPCEI is perceived as another possibility beyond subsidy categories and state aid rules. As every contribution to the necessary expansion in European PV capacity is welcomed, industry stakeholders have advocated for this initiative. So far, only Austria, Lithuania, Luxemburg, Poland, and Spain have committed to this initiative. Despite a broad interest from Dutch solar companies, the Netherlands has not yet committed and has gotten approval to start discussions with the European Commission. According to one interviewee, one reason for this is the number of parallel initiatives, such as the European Solar Strategy or the Green Deal.

For 2021 to 2025 the Nationaal Groeifonds has been introduced. It is a fund providing 20 billion euros to projects that foster economic growth in the long term. In at least three rounds, finance is to be allocated to projects that are deemed to contribute to the sustainable earning capacity of the Netherlands and entail knowledge development, research or innovation. One of the 27 projects proposed in the third round aims to develop and industrialise three innovative and competitive solar PV technologies. These technologies contain heterojunction silicon cells, with a high energy return, flexible perovskite foils and tailormade solar PV products for integrations in buildings and transport. Each technology and its respective product is supposed to be circular.

With regard to the Nationaal Groeifonds and RePower EU, a consortium of Dutch companies and industry stakeholders has been launched under the name of SolarNL. SolarNL is a national research, innovations and industrial investment program striving to bring back PV manufacturing to the Netherlands and Europe. The program’s total budget is 898.3 million euros, of which 65 per cent is privately financed. The National Groeifonds would cover the remaining 35 per cent. HyET Solar, Solarge, Compoform, Exasun, Energyra, IM Efficiency, Lightyear, and Taylor Technologies are participating companies. TNO, TU Delf, and AMOLF are significant participating knowledge institutes.

6 The future of the Dutch PV industry

Given the challenges and uncertainty underlying the development of a Dutch PV manufacturing industry on the one hand and the development of the geopolitical context on the other hand, a scenario analysis can shed light on future goals and possibilities.

In short, this scenario analysis reveals that in the short and middle term, the expected contribution of the PV industry to the Dutch economy is projected to remain minor. However, if the Dutch government successfully implements measures to promote local PV panel manufacturing, the long-term impact could be more substantial. These measures include financial incentives like grants, subsidies, tax breaks, and low-interest loans to enhance competitiveness and offset initial costs. Policies supporting the production of locally manufactured PV panels can boost demand of PV panels produced in the Netherlands or the EU, while vocational training programs can address shortages of skilled employees. Import restrictions, such as tariffs on non-EU PV panels, can level the playing field. Collaboration and partnerships between research institutions, universities, and PV manufacturers foster knowledge transfer and technological advancement.

The scenario analysis also demonstrates that a subsidy of about 5 cents/Wp is required for European-made PV panels to compete with other global PV manufacturers, amounting to a total 177 to 266 million euros of subsidies over the period 2023-2030. However, beyond financial incentives, it is crucial to consider and support other elements of a healthy PV industry ecosystem. This includes strong leadership, cooperation with European industry partners and knowledge institutes, enabling institutions, local demand, and a supportive infrastructure (including energy storage solutions). By addressing these factors, the revival of a robust PV ecosystem can be facilitated.

6.1 Scenario analysis

A scenario analysis starts with taking extreme (sometimes improbable) endpoints. This provides insight into the bandwidth of the possibilities for the future. The situation that usually is realised will be more nuanced and situated somewhere between the extreme outcomes. A matrix consisting of two dimensions and four quadrants, which represent the potential combinations of high or low outcomes of the two dimensions, is then used to develop the scenarios. This will ultimately give insight into how the dimensions could influence and possibly steer the development of the PV manufacturing industry in the Netherlands and Europe. Since the Netherlands has but a tiny share of the global PV manufacturing market, it has to rely on European collaboration to rebuild the Dutch PV industry. The interviews have widely confirmed this perspective, and the scenarios are therefore strongly European-focused. In this analysis we consider the timeline from now until 2030, corresponding to the year in which part of the Klimaatakkoord should be realised to become carbon neutral in 2050.

The first matrix in table 6.1, consist of the two dimensions **'Dependence on imports from outside the EU'** and **'Diversity of trading partners'**. Where the former dimension regards the dependence on imports from countries outside the EU, the latter regards the diversity of those import partners. The first dimension will largely determine the price that will have to be paid in the Netherlands for PV modules. However, it will also affect the total CO_2 emissions (in addition to other ESG targets) released for PV modules installed in the Netherlands. The second dimension determines the vulnerability to geopolitical developments. For instance, a more diversified portfolio of import partners lowers the risk of lacking supply when one channel suddenly dries up.

Table 6.1 Scenarios for 2030 matrix I

		Dependence on imports from outside the EU	
		High	Low
Diversity of trading partners	Low	**A. China maintains dominant position** There is a **high dependence on imports from countries outside the EU.** This poses a geopolitical risk. This risk is exacerbated by the fact that **imports mainly come from one or a few countries** – with China as the main trading partner. Because the cost price per Wp is the lowest in China, the total investment required to achieve the PV energy production targets will also be the lowest relative to other scenarios. On the other hand, there are higher CO_2 emissions, mainly due to China's more polluting energy production. However, transport from China to the EU also adds to that. One uncertainty in this scenario is the effectiveness of the EU's yet-to-be-introduced CBAM. This may benefit the competitiveness of countries that produce PV modules by emitting less CO_2.	**B. Reshoring of the European PV industry concentrates in a few countries** There is a **low dependence on countries outside the EU.** Part of the production takes place in the Netherlands. However, **the majority of PV modules installed in the Netherlands are imported from one or a few other EU countries.** The share of renewable energy is higher in the EU than in China. This means that combined with the lower transport emissions, the overall PV value chain footprint for PV modules installed in the Netherlands will be lower. This comes at a price, however. The European PV industry does not have the economies of scale that Chinese PV producers have. On top of that comes the higher labour, material, and energy costs.
	High	**C. New competition on a global level** There is a **high dependence on imports from countries outside the EU.** In this scenario, China is a less prominent trading partner than it is now. **Products are imported from a diversified portfolio of countries and continents,** which reduces the geopolitical risk associated with high import dependency. There is a possibility that the U.S. will be able to attract part of the investments and production as a result of the IRA. Due to increased competition, prices may remain around the current level or fall slightly. As a result, there will be a higher focus on ESG.	**D. Reshoring of the European PV industry spreads across various countries** There is **a low dependence of countries outside the EU**. Part of the production takes place in the Netherlands. But the majority of PV modules installed in the Netherlands are **imported from a diversified portfolio of EU countries.** In this scenario, CO_2 emissions will be much lower than in a scenario in which the dependence on imports outside the EU is higher. The price will depend on the degree of economies of scale that can be achieved in Europe. However, prices will likely be higher due to more expensive labour, material, and energy.

Source: SEO (2023)

Although this matrix provides a good insight into the bandwidth of possible outcomes, these dimensions are less suitable for showing what potential policy options are available to policymakers and what their impact would be. One of the options is to support the reshoring of the PV manufacturing industry more directly through subsidies on energy, material, or labour, for example. An example of this is the generous subsidy in the U.S. from the IRA. Another option could be to implement import tariffs. At the European level, preparations for such a protectionist measure are already in an advanced stage. Although not (yet) targeted at products such as PV modules, on 1 October 2023, the Carbon Border Adjustment Mechanism (CBAM) will enter its transitional phase.

To provide more insightful perspectives for policymakers, a second matrix has the dimensions **'Dependence on imports from outside the EU'** and **'Import tariffs and subsidies'**. It thus provides insight into how support and/or protectionist measures can influence the development of the PV manufacturing industry in Europe and the Netherlands.

RePower EU and many other (inter)national government initiatives strive to come from a current situation, which is mostly reflected by scenario A to a situation such as scenario C. Scenarios B and C would be scenarios during the transition from scenario A to scenario D. Whether scenario B or scenario C is the better or more desirable scenario in this transition depends on political views (globally versus more European centred).

As discussed in section 4.4, the IRA in the U.S., but also the Indian government, is currently steering the market into the direction of scenario C. Interviewee's perspectives confirm this development.

The scenario in table 6.2 provides insight into how policymakers are able to nudge the development of the PV manufacturing industry into one direction or another. By for instance introducing import tariffs on PV modules originating from outside the EU and/or subsidising local production, a shift from quadrant A to quadrant C could be effectuated (movement I). Over time, this could then result in a shift from quadrant C to quadrant D (movement II). For such a dynamic to arise, we start from the current situation in which there are limited support measures for the PV industry within Europe and the Netherlands and no import tariffs (quadrant A). If support and/or protectionist measures (quadrant C) are introduced, the PV manufacturing industry in Europe becomes competitive and, on a somewhat longer term, a situation similar to quadrant D could be realised. The European PV manufacturing industry can scale up from here, which gradually leads to economies of scale and as a result support measures and/or import tariffs can gradually be scaled down again.

The Klimaatakkoord (2019) prescribes that by 2050 the Netherlands should reduce its CO_2 emissions by 95 per cent (with the introduction of the European Climate Law in 2021 this has become climate neutral) and reduce CO_2 emissions by 49 per cent by 2030 (55 per cent as of the introduction of the European Climate Law). One of the ways to reduce CO_2 emissions is by generating more renewable energy at the expense of non-renewable energy. The Dutch government has therefore taken on the goal to annually produce 35 TWh of renewable energy from wind turbines on land and large-scale solar installations. In 2022, the Netherlands produced 13.3 TWh with wind turbines on land and 9.4 TWh with large-scale solar installations (PBL, 2022). Hence, another 12.3 TWh needs to be produced in order to reach the 35 TWh goal.

Table 6.2 Scenarios for 2030 matrix II

		Dependence on imports from outside the EU	
		High	Low
Import tariffs and subsidies I	Low	**A. China maintains dominant position due to its persistent competitive advantage** The situation will largely remain as it is today. Government support from the Netherlands and the EU is rather sparse. In combination with the absence of import tariffs, dependence will remain high. Currently, there is little support (only about 0.1 c/Wp) for the PV manufacturing industry from the EU. Compared to the U.S. (with about 11-18 c/Wp subsidy from the IRA) and China (where capital, energy and labour subsidies add up to about 3.5 c/Wp) this is very low. If the current governmental support remains unchanged, dependence on China (and the U.S.) will remain high. Without support measures, the PV industry in the EU cannot compete with China nor the U.S.	**B. European PV industry thrives without much support** An unlikely situation in which the reshoring of the PV industry becomes a success despite the lack of support and/or protectionist measures. This is an unlikely scenario because without import tariffs and subsidies, the European PV industry will not be able to compete with China. The same applies to competition with the U.S. Given the heavy support from the IRA, the cost of PV module production in the U.S. currently is de facto cheaper than in China. With ±20 c/Wp for the U.S. and ±25 c/Wp for China. In Europe, the production of PV modules costs ±32 c/Wp.
	High	**C. China continues to dominate despite intervening EU** In 2030, China's position as a trading partner is still expected to be prominent. However, due to import tariffs (such as the CBAM) and the implementation of direct support measures, the European PV industry could become more competitive relative to China and the U.S. As a result, there could be a gradual shift from production and import from China to production in Europe. On a somewhat longer term, a scenario such as in D (bottom-right) could arise. In such a scenario, subsidies and protectionist measures could slowly be phased-out again, as the industry becomes competitive on its own.	**D. European PV industry bounces back due to intervening EU** This scenario is still unlikely before 2030. But on a longer horizon, this situation could arise from scenario C (bottom-left). Then, due to import tariffs on PV modules and substantial support measures from the Netherlands and the EU, the PV industry in Europe could become competitive. Ultimately, this could lead to a situation in which dependence on imports from countries outside the EU decreases. Due to the strong support for the PV industry resulting from the IRA, it is expected that, in addition to China, the U.S. will eventually become an important trading partner.

II

Source: SEO (2023)

Taking the scenario analysis in table 6.2 we can make some estimations regarding the total societal costs and CO_2 emissions that are associated with achieving the 35 TWh goal in 2030 for different scenarios. We first estimate the additional amount of renewable energy that needs to be produced in 2030 as compared to the most recent year we have data for, which is 2022. From that we draw the amount of additional solar power that still needs to be installed to meet the goal of 35 TWh of renewable energy. In our calculation we make the assumption that about half of the 35 TWh will be produced using large-scale solar installations, i.e., 17.5 TWh. Moreover, we assume that the ratio of large-scale to small-scale solar power remains the same as it is now. Currently, about 58 per cent of all solar power is generated by large-scale installation (>15 kWp) and the remaining 42 per cent is produced by small-scale installations (≤15 kWp).

Using these assumptions, we can estimate the amount of solar power that will be installed in the period from now until 2030, assuming as well that the 35 TWh goal will be achieved. Taking half of the 35 TWh goal as our expected amount of installed large-scale solar power, and using the ratio of large-scale to small-scale power, a total of about 30 TWh of solar power will be produced in 2030 (17.5 TWh or 58 per cent from large-scale PV and 12.5 TWh or 42 per cent from small-scale PV). Using an average conversion of kWh/Wp of 0.914[3], for the production of 30 TWh about, 32.82 GWp needs to be installed. With the current installed peak power of about 15.04 GWp[4], an additional peak power of 17.78 GWp has to be installed still. We take the difference of the currently installed PV peak power and the amount of peak power needed to realise the 35 TWh goal as the expected amount of peak power that will indeed be installed from 2023 until 2030.

Table 6.3 Share of production, total costs and CO_2 emissions for different 2030 scenarios

Dependence on imports outside the EU

High | Low

Import tariffs and subsidies

Low

A. China maintains dominant position due to its persistent competitive advantage (Dependence: High; Import tariffs and subsidies: Low)

	Share*	GWp*	c/Wp*	Cost*	CO_2*
China	80%	14.2	26.6	€ 3783.6	3698.3 kt
Europe	5%	0.9	32.6	€ 289.4	111.1 kt
U.S.	10%	1.8	21.9	€ 389.4	284.5 kt
Other	5%	0.9	28.7	€ 254.7	240.0 kt
Total			*26.5*	*€ 4717.1*	*4333.9 kt*

B. European PV industry thrives without much support (Dependence: Low; Import tariffs and subsidies: Low)

	Share	GWp	c/Wp	Cost	CO_2
China	40%	7.1	26.6	€ 1891.8	1849.1 kt
Europe	35%	6.2	32.6	€ 2025.6	777.9 kt
U.S.	15%	2.7	21.9	€ 584.1	426.7 kt
Other	10%	1.8	28.7	€ 509.4	480.1 kt
Total			*28.2*	*€ 5010.9*	*3533.8 kt*

High

C. China continues to dominate despite intervening EU (Dependence: High; Import tariffs and subsidies: High)

	Share	GWp	c/Wp	Cost	CO_2
China	67.5%	12.0	28.7	€ 3444.5	3120.4 kt
Europe	20%	3.6	27.6	€ 979.7	444.5 kt
U.S.	7.5%	1.3	23.7	€ 315.4	213.4 kt
Other	10%	0.9	30.6	€ 272.3	240.0 kt
Total			*28.2*	*€ 5011.9*	*4018.3 kt*
*Import tariff***				*€ -397.8*	
*Subsidies****				*€ 177.8*	
Total societal costs				*€ 4791.9*	

D. European PV industry bounces back due to intervening EU (Dependence: Low; Import tariffs and subsidies: High)

	Share	GWp	c/Wp	Cost	CO_2
China	40%	7.1	28.7	€ 2041.2	1849.1 kt
Europe	30%	5.3	27.6	€ 1469.5	666.8 kt
U.S.	20%	3.6	23.7	€ 841.0	569.0 kt
Other	10%	1.8	30.6	€ 544.7	480.1 kt
Total			*27.5*	*€ 4896.4*	*3564.9 kt*
Import tariff				*€ -302.3*	
Subsidies				*€ 266.7*	
Total societal costs				*€ 4932.0*	

Source: SEO (2023) with specific values based on IEA (2022) and McKinsey (2022) as indicated under explanation of '*' below.

*Share of production as percentage of total production, GWp: amount of peak power in gigawatt peak, c/Wp: cost of installation in cents per watt peak (IEA, 2022; McKinsey, 2022), cost of production in millions of euros, CO_2 emissions in millions of kilotons (IEA, 2022)

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[3] Annual average production from solar panels in the Netherlands according to SolarCare.

[4] Various sources (PBL, 2022; RVO, 2022; CBS, 2022; Ember 2023) report estimates on the amount of solar power produced (TWh) or the amount of solar peak power (GWp) installed. We take the average of these sources and where TWh is given instead of GWp, we convert this using the average conversion rate of SolarCare.

***Import tariffs on modules imported from outside the EU: China (3.0c/Wp), U.S. (1.5c/Wp), others (2.0c/Wp)*
****Subsidy of 5.0 cents/Wp on EU produced PV modules*

Table 6.3 summarises the results that are obtained after making some calculations on the basis of the scenarios presented in table 6.2. A first step in order to arrive at these results, is to make a prediction about the relative shares of production in the different regions considered. In quadrant A, a scenario in which no import tariffs nor support measures are in effect, China will continue to maintain its dominant position until 2030. In this scenario China still has an extensive, albeit slightly smaller share than its current share in production of all PV modules installed in the Netherlands. The dependence of imports from countries outside of the EU remains high in quadrants A and C. However, in scenario C the share of China is considerably smaller in 2030 due to the introduction of import tariffs and support measures. In quadrants B and D, the Netherlands becomes much less dependent on imports from outside the EU, with about one third of the PV panels installed originating from within the EU. In quadrant D, this is caused by effective import tariffs and support measures, while in quadrant B this happens without an apparent reason (or at least not due to an intervening European Commission or Dutch government).

Whether Europe and the Netherlands can become competitive in the market for PV modules critically hinges on the extent of supportive and/or protectionist measures such as subsidies or import tariffs. In our scenario analysis, import tariffs are based on the amount of CO_2 emissions involved in the production and transportation of PV modules from outside of the EU to the Netherlands. This makes that Chinese PV modules become less competitive compared to modules produced in the U.S. or Europe, resulting in a corresponding shift of the shares of origin in 2030 in quadrants C and D.

In 2018, the U.S. government put into place import tariffs on solar cells and modules. Under Section 201 of the trade act, the U.S. now raises about 3.1 cents/Wp of import tariffs on Chinese imported solar modules. Moreover, in 2022, the U.S. government passed the IRA that includes significant tax incentives for PV module manufacturers. Including also some more localised support measures, the total support for production in the U.S. adds up to about 11-20 cents/Wp. Globally, this currently makes the U.S. the cheapest producer of PV modules. In comparison with current support measures in Europe, which are negligible, this is significant and (in addition to the expected continued comparative advantage of China) makes for a geopolitical concern for Europe and the Netherlands.

In scenarios A and B, where no import tariffs are imposed, the price of importing PV modules from the U.S. is about 22.8 cents per Wp, which is 4.4 cents cheaper than importing from China and 9.3 cents cheaper than producing in Europe. This of course is under the condition that supply in 2030 from the U.S. and Europe would be sufficiently present, which at the moment is not the case. In scenarios C and D, however, Europe does impose import tariffs on PV modules originating from outside the EU. Ranging from 3 c/Wp on Chinese modules, 1.5 c/Wp on modules from the U.S. and 2 c/Wp on others, the rates of these tariffs is mainly based on the amount of CO_2 emissions that are involved in the production of PV modules in the countries of origin. In addition to the import tariffs, in scenarios C and D, a support program of 5 c/Wp is put into effect on locally (within the EU) produced PV modules.

The effect of these measures is that relative to China and the U.S., European produced PV panels will be better able to compete on price, which will attract investors to invest in the European PV manufacturing industry. On Chinese produced PV modules, the rate of import tariffs will be highest, 3 c/Wp, as the CO_2 intensity of production in China is also the highest at about 0.26 kg/Wp. For the U.S. in scenarios C and D, import tariffs amount to 1.5 c/Wp, as the CO_2 intensity of production in the U.S., about 0.16 kg/Wp, is about half of the CO_2 intensity of China. For other countries we take an average and impose import tariffs at 2 c/Wp. Imposing import tariffs at these rates, raises the cost of imported PV panels to 28.7 c/Wp for Chinese panels and 23.7 c/Wp for the U.S. However, as European produced PV panels cost about 32.6 c/Wp, only imposing import tariffs at these rates without further support measures is not enough to make European produced PV panels competitive. In scenarios C and D, we therefore introduce additional policy support in the shape of a subsidy programme for European produced PV modules, amounting to 5 c/Wp. This ensures a competitive price for European produced PV modules at 27.6 c/Wp, which should make Europe relatively more attractive for investors.

The total societal cost of installing an additional 17.78 GWp by 2030 can be approximated using the different scenarios. The societal costs include the cost of installation and any additional import tariffs or subsidies. The highest societal cost is expected in scenario B, with about 5,011 million. This is because of the large share of production in Europe, which, in the absence of a subsidy program, is rather costly. The lowest societal cost is expected in scenario A. In this scenario, for 2030, there are no substantial changes foreseen as compared to the current situation. China continues to dominate the market due to its competitive pricing. Although in this scenario the costs of meeting the 2030 goal of installing an additional 17.78 GWp is the lowest, it is also the scenario in which the dependence on imports from outside of the EU – and China in particular – remains very high.

While import tariffs raise the price of imported PV panels, it does also mean that tax income is generated. Tax income that can for instance be used to finance the costs of a European subsidy program, lowering the societal cost of the scenario. Scenarios C and D introduce both support measures and import tariffs. Where a subsidy that supports local production raises the societal cost in the short-term, import tariffs would generate a tax income and could to some extent alleviate the burden on government expenditure. This makes that the total societal costs of these scenarios are not hugely different as compared to the scenarios A and D.

Knowing the total societal costs in different scenarios and the least amount of subsidy required to make the European PV panel industry able to compete, allows us to draw a general insight into the extend of the financial stimulus that would be needed to make a move from scenario A to scenario C more likely. In the case that import tariffs are implemented, about 5 c/Wp of subsidy is required, amounting to a total of about 178 million in scenario C and to about 267 million in scenario D. In the absence of import tariffs, another 2-3 c/Wp of subsidy would be required, amounting to a total of about 285 million in scenario C and to about 427 million in scenario D. What this scenario does not account for is a likely cost reduction as an effect of a growing European manufacturing industry. Due to economies of scale, the cost to produce PV panels in Europe (currently about 32.6 c/Wp) will be lower. This means that the required subsidy over time, can gradually be scaled down.

It is important to note that these figures only include the direct subsidy of production, assuming the production capacity (such as factories and other infrastructure) is already present. The presence of a substantial production subsidy of PV panels will attract investors to invest in building production capacity in the EU and the Netherlands. However, further financial stimuli that are directed towards investments in production capacity may be needed.

Another aspect to consider is the CO_2 intensity or total amount of CO_2 that is emitted in each scenario. This includes the direct CO_2 emissions of production, but also the less direct emissions stemming from the electricity mix (natural gas, coal, nuclear, solar, wind, etc.) used for production and emissions stemming from shipping the PV modules to Europe and the Netherlands. The first step in the value chain, i.e., the production of polysilicon, is particularly energy intensive, consuming around 40 per cent of all energy used in whole production process of PV panels. This is an important explanation for the high CO_2 emission of scenario A, in which still a major share of production of PV panels stems from China. The electricity mix in China is less favourable in terms of CO_2 emissions as it is in the U.S. or Europe. Production of PV panels in China generates about 260 kg/kWp of CO2 emissions, whereas respectively in the U.S. and Europe this is about 160 kg/kWp and 125 kg/kWp.

Not only in terms of geopolitical risk would it be favourable to reduce the share of Chinese production, but also in terms of CO_2 emission (and, although not evaluated in this analysis, likely other ESG goals as well). If, for instance, from now until 2030 a move is made from scenario A (which approximates the situation as it is now) to scenario B, a significant reduction of 315 kilotons of CO_2 emissions is realised. A further reduction of 453 kilotons of CO_2 emissions can be realised if, after that, a move is made towards scenario D.

The scenarios presented do not make predictions regarding the share of the Netherlands explicitly. We can, however, make a prediction in terms of position of the Netherlands in the share of European production. This will give us some insight in the significance of reshoring part of the production for the Dutch economy. If, for instance, we take scenario C in which the share of European production is about 20% and we assume that one third of the European production takes place in the Netherlands, we see that the contribution of the production (1/3 of €980) to the Dutch economy would account to about 0.032%[5]. In an extreme case where all the PV panels installed in Netherlands that originate from inside the EU are produced in the Netherlands, and additionally the Netherlands exports an equal share of production, the contribution would account to about 0.189% of the GDP.

In these calculations we take a GDP figure of 2022 and the potential production over the years up until 2030. So, not the total production in 2030 but all production over the years from now until 2030. If we assume that the production of 17.78 GWp of PV panels is evenly spread over the years 2023 until 2030, the annual contribution to the GDP in the Netherlands would account up to about 0.005 per cent if one third of the European production in scenario C is produced in the Netherlands, and up to about 0.027 per cent in the extreme case where all of the installed PV panels are produced domestically.

6.2 Need for innovation, collaboration, and initiatives

The scenario analysis has highlighted the need for finance and stimulating governance measures. This paragraph brings the insights from the scenarios together with the insights of previous chapter to address the need for innovation, collaboration, and initiatives.

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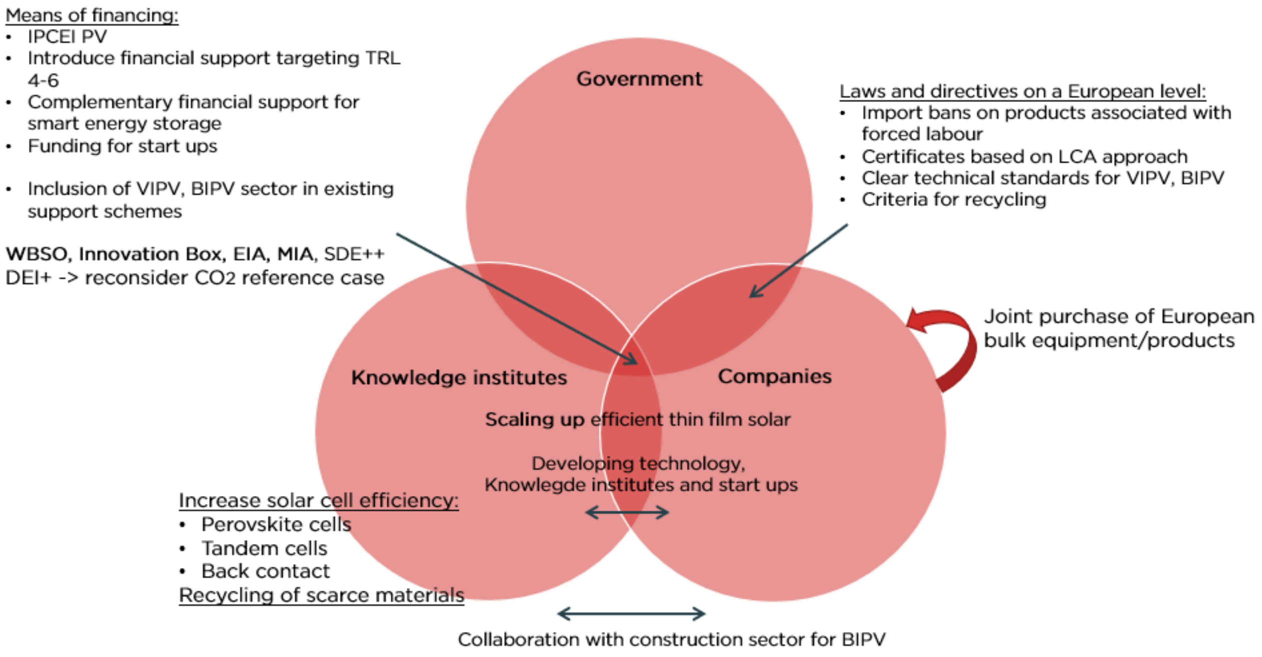
[5] We take the size of the Dutch economy to be 941 billion for this calculation (which was the GDP of the Netherlands in 2022).

Figure 6.1 Triple helix model



Source: SEO (2023)

Figure 6.1 shows the triple helix of government, knowledge institutes, and companies. Each of these play a vital role to enhance a more independent European and Dutch supply chain. Only sufficient policy-based and market-based instruments can realise a scenario such as scenario C or D.

The interviews have shed some light on how these instruments should be constructed. As the introduction and approval of subsidies is very much dependent on the state aid guidelines, the IPCEI PV represents a unique opportunity to support the Dutch solar PV industry and foster collaboration between European suppliers. As mentioned in Chapter 2, the hydrogen and battery sectors have already received public support, ranging between two and five billion euros. In a similar way, important contributions to the European manufacturing of solar cells could be supported.

Furthermore, subsidies that address the finance needed after the pilot phase of a project can make a difference as well. As explained in Chapter 4.4, existing subsidies such as the DEI could reconsider the requirement of the CO_2 reference case, which sometimes leads to little contribution in subsidising efficient solar PV projects.

With regard to which segment of the production chain should be supported first, interviewed parties have suggested to “go backwards” in the solar PV value chain: as it takes time to develop and scale up an entire value chain segment, European producers should first focus on scaling up their capacity of the value chain segment that comes after the one in which they are already relatively mature. Interviewees indicated a time period of three to four years to develop one value chain segment. Literature confirms the time it takes to develop a segment: summing up the time to build up all solar PV value chain segments, it can take 15 years or more (Mc Kinsey 2022, Hanson 2018, Huang et al. 2016). In the meantime, relations with reliable and, if possible, sustainable and ethical suppliers from abroad should be maintained. As shown in Figure 6.1, Dutch companies can reduce their costs by jointly purchasing European bulk equipment. Dutch companies’ position calls for a focus on mass customisation, lightweight solar panels, and cells in order to strengthen BIPV and VIPV. The government can emphasise this position as well, by including BIPV and VIPV in existing subsidies.[6] Introducing product and technology standards is important as well. For example, the selection criteria in tendering processes for construction projects could focus on aspects of BIPV. Additionally, companies and knowledge institutes should explore what information construction parties need in order to integrate solar PV in their buildings. There is a role for government and public authorities to provide technological and product standards for the BIPV sector. The construction sector should be integrated with the solar sector, from governance until actual installation.

At the same time, a competitive position can be maintained by increasing the efficiency of solar cells. The research which AMOLF and TNO are doing on (for example on perovskite cells and tandem cells) is promising in that regard. As put in whitepapers and interviews, the main challenge is to scale up these technologies. Another challenge is the compromise between efficient technologies and their use of scarce materials. For this, the collaboration between companies, especially start-ups and knowledge institutes is essential. Here, the government can also play a role by providing funds or backed loans to start-ups. According to interviewed parties, subsidies such as the WBSO, the Innovation Box or the MIAVamil are already forming an essential part of that support. Subsidies such as the SDE++ focus more on the mere expansion of solar installations. A valuable addition with regard to that could be a focus on energy storage, which is crucial for the broad expansion of solar PV.

If these things are taken into account, it is possible for companies, knowledge institutes and governments to meet in the middle and contribute to an independent European solar PV ecosystem. The facilitating role of the government is strengthened by European laws and directives. For the Dutch market, clear standards of BIPV and VIPV applications would be beneficial.[5] Furthermore, bans on products that are subjects of forced labour or environmentally harming processes can stimulate a global sustainable and ethical solar PV supply chain. With regard to environmental standards, certifications based on an LCA approach account for more of a product's environmental impact. Criteria and options for recycling of solar panels should be explored by the government, companies, and knowledge institutes alike.

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[6] More details on the opportunities of BIPV and VIPV can be read on SEO's report "Solar Mobility – De kansen van een innovatieve sector". (2023).

7 Conclusion

1. How is the European value chain for PV products constructed now, and what developments are expected in the first 5-10 years?
Currently, the European value chain for PV products from polysilicon to modules is highly dependent on Asian products. China accounts for approximately 83 per cent of all solar PV manufacturing stages. Parts of these production processes rely on forced labour. On average, Europe holds about two per cent of all the PV manufacturing stages. Especially, capacity on wafers, ingots, and cells is scarce. Europe had an advantage in the knowledge of manufacturing in the past, which has been widely exported to Asia for cheaper mass production. The relocation of mass production has led to a dependence on environmentally harmful manufacturing processes, resulting in a CO_2 footprint twice as large compared to production processes with a more sustainable (European) energy mix. European research institutes are still well connected to the industry and contribute to advanced technologies. Promising developments are perovskite cells and tandem solar cells. In the laboratory, efficiencies already reach past 30 per cent. The main challenge is to achieve this level of efficiency on a commercial scale. Chinese companies are quick to take up knowledge and have already leading companies in efficient cell technologies such as PERC, TOPCon, and IBC.

2. What role can the Netherlands play in a future production chain?
The Netherlands' solar sector is not characterised by size and can only be rebuilt by relying on European collaboration. Scale is mentioned as one of the main reasons for Dutch companies to buy materials from Asian factories. Therefore, joint purchases of bulk equipment from European manufacturers can strengthen an autonomous Dutch and European solar PV production chain. Further, the Netherlands has a pioneering role in the development of mass customisation and lightweight panels. By building on that strength, they can gain a competitive international position in the integration of PV modules in the built environment. Furthermore, an integration of information and standards between the construction and solar PV sector should take place on all levels of the triple helix.

3. How far back in the chain must we go to take up a sufficiently safe position in the chain?
It takes about three to four years to develop and scale up an entire value chain segment. Going too far back in the value chain when other segments are not yet developed is costly and cumbersome. Therefore, the Netherlands should mainly focus on the niche market of BIPV and streamline its production with European producers. European producers should first focus on scaling up their capacity of the value chain segment that is closest to the one in which they are already relatively mature. Ambitions should take a step-by-step approach; focusing on value chain segments that are too far away from the domestic markets' strength does little in reducing dependence. In the meantime, relations with reliable and, if possible, sustainable and ethical suppliers from abroad should be maintained for the value chain segments that take too much effort and time to produce domestically for the moment.

4. Is it realistic that larger European ingot, wafer, and cell manufacturers will emerge? What are the preconditions?
Currently, more than 5.4 GW ingot/wafer, 8.5 GW cells, and 38.1 GW European module capacity have been announced; mostly to be operational between 2023 and 2025. This brings Europe's share from global solar PV manufacturing from about two per cent to five per cent. The success of new capacity addition beyond that time period is harder to predict. Dependence on countries outside Europe is therefore still inevitable. Preconditions for a more independent European supply chain are to lower business risk, CAPEX expenses, long payback times, and labour and material costs. This can be supported by financial incentives, such as subsidies and import tariffs. As seen

in the U.S. and India, these can already result in cheaper modules than modules imported from China. For the Netherlands, this translates into sufficient budget for TRL levels past the pilot stage, capital for start-ups, and inclusion of BIPV and VIPV in support schemes.

5. What is the financing requirement to build a Dutch PV industry?

Determining the exact financing requirement for developing a Dutch PV industry necessitates a comprehensive analysis of various factors, including the industry's current state, desired capacity, market demand, technological advancements, infrastructure needs, and associated costs. Given the uncertainties surrounding the global PV manufacturing industry and the geopolitical environment, conducting such an analysis exceeds the scope of this project. Instead, a scenario analysis gives us insight into the range of possibilities for the future and thus provides us with some guidance on the correct form and configuration of policy options.

Through the scenario analysis, we can gain valuable insights. For instance, to make the European PV panel industry competitive, the least amount of subsidy required can serve as a general indicator of the financial stimulus needed to successfully reshore the PV manufacturing industry. If import tariffs are implemented, approximately 5 cents per watt peak (Wp) of subsidy is required, totalling around 178 to 267 million euros. Without import tariffs, an additional 2-3 cents per Wp of subsidy would be necessary, totalling around 285 to 427 million euros. These figures only include the direct subsidy of the production process, assuming the production capacity (factories and other infrastructure) is already present.

Offering substantial production subsidies for PV panels can attract investors to establish production capacity within the EU and the Netherlands. However, additional measures and financial incentives may be required to encourage investments specifically in building production capacity. These include implementing support programs, grants, subsidies, tax incentives, or low-interest loans to encourage domestic manufacturing and stimulate industry growth.

Additionally, constructing manufacturing facilities, including land acquisition, building construction, machinery, equipment, and related infrastructure, is essential. Investing in vocational training programs, educational initiatives, and skill development is crucial to meet the industry's workforce requirements. Allocating resources to develop and implement supportive regulations, standards, and policies that facilitate industry development and create a conducive business environment is also important. Furthermore, investment in necessary infrastructure such as grid connections, transmission lines, and storage facilities is needed to support the integration and distribution of PV-generated electricity.

Summing up, while an in-depth analysis of the financing requirement is beyond the scope of this project, a scenario analysis provides insights into the necessary financial stimuli to support the development of a Dutch PV industry, considering factors such as import tariffs, production subsidies, and the attraction of investment in production capacity.

6. What are other preconditions to achieve a ‘healthy’ industry?

Achieving a healthy and self-sustaining PV industry in the Netherlands requires more than just financing. It requires a coordinated effort between policymakers, industry stakeholders, academia, and other relevant parties to ensure the necessary conditions are met. What preconditions need to be met to achieve a healthy and self-sustaining industry varies to a great extent and depends on various factors, including market conditions, economies of scale, and cost structures. Additionally, what is particularly important for the Dutch PV industry, is whether the Dutch PV industry can develop and sustain a technologically advanced position, relatively towards international bulk manufacturers.

Striving for a leading role in more knowledge and technology-intensive niches, such as BIPV and VIPV solutions, suggests a smaller size to become healthy, and seeing the current and historical existence of PV manufacturing in the Netherlands, this would also be a more feasible direction.

There are several factors that need to be considered and arranged properly in order to increase the likelihood that a 'healthy' and self-sustaining PV industry arises. Firstly, developing and fostering technological knowledge and experience, especially in niche areas such as BIPV and VIPV, is vital. For this, integration of information and collaboration between the solar and construction sector is important. Additionally, supporting the production of highly efficient solar cells, such as tandem cells and perovskite cells, can contribute to realising a competitive position and climate goals. Therefore, support should be targeted towards the demonstration and development of these technologies. At the same time, the options and criteria to recycle critical materials for these technologies should be explored. This requires collaboration with research institutions, universities, companies, and other industry associates. This could enhance product development that expands existing niches or allows to tap into new markets, while also driving process development to reduce costs and improve efficiency of the production processes.

Secondly, and related to the former, fostering a supportive industry ecosystem and leadership is crucial. This can be achieved by encouraging collaboration between the construction sector, manufacturers, research institutions, universities, industry associations, and the governments. Strong leadership is important as it sets the direction and vision for the industry. By adopting the triple-helix model, this can be achieved in an efficient and proven manner within the Dutch context. However, as the Netherlands has but a tiny share of the global PV manufacturing market and cannot reshore the whole value chain, European and international collaboration is essential.

Thirdly, and again somewhat related to the former, ensuring a stable and cost-effective supply of materials is important. Access to a diversified set of reliable and more sustainable import partners, along with a robust supply chain involving local and European suppliers, would lower the exposure of the Dutch PV industry to potential geopolitical unrest.

Fourthly, nurturing a talented workforce that possess relevant capabilities and knowledge is an important factor to meet the future industry's workforce requirements. High-skilled technicians, engineers, and researchers contribute to efficient production processes, product innovation, and continuous improvement. Introducing vocational training programs or certain educational initiatives that attract people towards technical studies and training is likely to have an effect. Another way could be to facilitate collaboration between the industry and educational institutions on the development of training programs tailored more towards the current and future needs of the industry.

The last precondition regards the presence of a supportive institutional environment that makes sure the rules are both clear and fair for all actors. Examples are product standards for BIPV, life cycle certifications, and criteria on recycling. Supportive policies in favour of importing and products with a low carbon footprint could also be used to promote domestic and ethical manufacturing. A clear regulatory environment fosters a favourable business climate and attracts investors. Stable and long-term regulations and policies provide potential investors with the confidence necessary to commit. This is important to develop a strong domestic market, which provides stability and opportunities for local manufacturers to scale up production and become more competitive in the process.

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Appendix A

Table A.1 Interviewed parties

Name	Organisation	Function
Arthur Weeber	TNO	Program Manager Solar Energy and Professor at TU Delft
Bram Verschoor	Eurogroup	Chief Commercial Officer
Gerard de Leede	Solarge	Chief Technology Officer
Hugo Schoot	Endurans Solar	Director Innovation and New Business Development
Menno Veldboer	Energyra	CEO, Owner
Pim van Leeuwen	Ministry of Economic Affairs and Climate	Senior Policy Advisor
Thierry de Vrijer	Groendus	Lead Product Developer Solar
Walburga Hemetsberger	Solar Power Europe	CEO

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