The European Technology and Innivation Platform for Photovoltaics

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White Paper -
ETIP PV Industry Working Group

PV Manufacturing in Europe: Ensuring resilience through industrial policy

ETIP Photovoltaics

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The European Technology & Innovation Platforms (ETIPs) have been created by the European Commission in the framework of the new Integrated Roadmap Strategic Energy Technology Plan (SET Plan) by bringing together EU countries, industry, and researchers in key areas. They promote the market uptake of key energy technologies by pooling funding, skills, and research facilities. The European Technology and Innovation Platform for Photovoltaics (ETIP PV) mobilizes all stakeholders sharing a long-term European vision for PV, helping to ensure that Europe maintains and improves its industrial position, in order to achieve a leadership position within the global PV market.

The experts of the ETIP PV Working Group on PV Industry jointly contributed to this publication. They represent leading European research institutes and industrial actors in the PV community, and work to further the objective of an efficient, highly innovative European PV industry with a positive environmental and social impact.

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Contributors:

ETIP PV Industry WG

Peter Fath (RCT Solutions), Bianca Lim (ISFH), Ralf Preu (Fraunhofer ISE), Rutger Schlatmann (HZB), Jutta Trube (VDMA), Michael Bünnig (Wacker), Nabih Cherradi (Desert Technologies), Chris Case (Oxford PV), David Moser (EURAC), Philipp Krazert (SolarWatt), Fabrizio Bizzarri (Enel GreenPower), Roch Drozdowski (IPVF), Puzant Baliozian (VDMA), Kaan Ahizer (RCT Solutions), Ivona Kafedjiska (HZB)

Editing & Layout:

ETIP PV Secretariat

Thomas Garabetian (SolarPower Europe), Hanna Dittmar (SolarPower Europe), Rania Fki (WIP Renewable Energies), Johanness Stierstorfer (WIP Renewable Energies), Melanie Kern (WIP Renewable Energies)

info@etip-pv.eu

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Introduction

The ETIP PV Working Group on the PV industry is proposing an update of its White Paper on the *PV Manufacturing in Europe: understanding the value chain for a successful industrial policy* published in May 2023. In merely 6 months, the global landscape for PV manufacturing has transformed profoundly at various levels, with the adoption and the announcement of new support framework for PV manufacturing globally.The PV sector continued its swift adoption of new technologies, with the mainstreaming of TOPCon modules and the renewed focused at an industrial level on innovative photovoltaic materials such as perovskites. Besides, the global PV sector continued deploying an ever-larger amount of PV capacity every month as the world intensified its switch towards renewable energy sources as a resilience tool against future energy price crises or expected fossil fuel prices spikes in the winter of 2024.

Throughout a busy year for the global PV industry, a new challenge emerged for companies in the European PV sector seeking to implement the European objective of PV supply chain resilience outlined in the European Solar Strategy and pursued by the European Solar PV Industry Alliance (ESIA). As pointed out by the ETIP PV in the May 2023 White Paper on PV manufacturing, research and innovation for PV relies on a robust and healthy PV industry to be able to bring innovation to market rapidly and deliver innovation at scale – and pace. Collapse of the global prices of PV modules driven by massive overproduction accelerated ongoing trends (e.g. the market shift away from PERC) and presented new major challenges for European manufacturers that are unable to compete with the low-priced modules arriving on the market. The collapse of prices throughout the PV value chain is a direct threat to many manufacturing EU PV companies, notably SMEs that constitute the core of the European industrial basis for PV. News of bankruptcies and companies interrupting production have had an impact on the short to medium term perspectives of the PV industry, despite a rather positive – although nuanced – beginning of the year 2023 following the implementation of ESIA and positive policy signals at the European and national level.

On the back of an eventful year, this update of the ETIP PV White Paper on PV manufacturing published in May 2023 will seek to evaluate how the policy and regulatory framework has evolved for European companies in the PV sector, also considering the evolution of key global markets with a strong focus on industrial policies for the photovoltaic industry. Beyond this assessment of policies, regulatory frameworks and support measures, this document will explore the question of the resilience of the European PV value chain, and notably the long-term economic impact of these measures on the price of energy in Europe as a major feature of the social license of PV technologies is the promise of plentiful, cheap energy on the long term. Finally, this paper will focus on the role of innovation in the growing wave of industrial policies in Europe, to better understand how to capitalise on Europe's broad landscape of research institutes and innovative companies as a component of long-term competitiveness and resilience for the European PV industry.

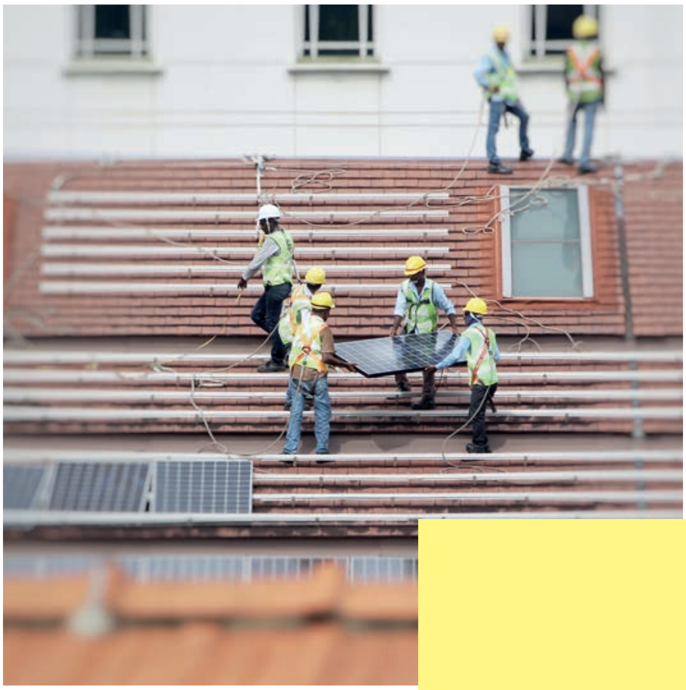

Photo: Justin Lim, Unsplash.com

1.
Updates on National Schemes – Feedback & analysis on industrial policies introduced or proposed in the second half of 2023

1.1
European countries

Europe is undergoing a structural shift in the way it approaches renewable energy policy. Moving away from an approach primarily focused on boosting demand, the European Union and European Member States are building the premises of an industrial strategy for photovoltaics. The European PV industry and research and innovation communities appreciate such announcements, as they are involved in an increasingly competitive global landscape. Over the second half of the year 2023, European Member States, as well as the European Union have fleshed out in more details policies to support the re-industrialisation of the PV value chain.

Photo: ameenfahmy, Unsplash.com

As of the end of 2023, the Net Zero Industry Act is entering the last phase of the legislative process – trialogues – which are expected to start in December and continue in the first quarter of 2024. The European Council and European Parliament have both reached agreement on their general approaches. European Council keeps the reference to strategic net zero technologies and suggests non-price and prequalification criteria to be applied in 20% of all auctioned volumes per year per Member States. The European Parliament widens the list of Net Zero technologies, even scrapping the category of strategic net zero technologies, and includes pre-qualification criteria based on resilience, excluding imports from countries non signatories of the GPA agreement (Government Procurement Agreement). None of the three proposals (COM, EP & EUCO) include a reference to new specific finance mechanisms to support the manufacturing of NZ technologies, calling instead for a coordination of already existing funds. The outcome of the final legislative process on NZIA, expected in March 2024, will amount to a compromise position between the different European co-legislators.

The following table assesses industrial policy developments for PV in the May 2023-December 2023 period.

Country	Policy scope	Delivery/conditions	Assessment
EU	Beyond the Net Zero Industry Act, the Adaptation of state aid guidelines via the **Temporary Crisis and Transition Framework**: making it easier for EU countries to fund PV manufacturing projects. **Critical Raw materials**: Recycling targets increased from 15% to 25% of the EU's annual consumption, aluminium has been added to the Strategic Raw Materials list, projects to substitute SRM can be considered strategic projects and large companies exposed to shortages of SRM for strategic technologies will have to regularly conduct assessments of their supply chain to individuate vulnerabilities.	TCTF: CAPEX support only, limited to 40% support. Most of the delivery has to be channelled by national programmes. Long and uncertain application processes for EU funds (Innovation Fund...) Lack of transparency for funding allocation at the national level (e.g. RRF)	Despite high-level political support, the European Framework is defined by a lack of a consistent and clearly defined pathway for investors in PV manufacturing capacity, with fragmented support at the national level and complex application procedures at the European one. Moreover, manufacturers are calling for an improved OPEX support framework.
Germany	Build-up of 10 GW production capacity along the value chain and focus on upscaling innovative technologies. Focus of the support scheme on CAPEX	Initial call for projects concluded in August 2023 High requirement on innovation components in projects for eligibility (e.g. >24% module efficiency)	First round of call for applicants to the scheme was successful in attracting interest from the industry. The outcomes of the scheme are yet to materialize as of the end of 2023.
France	France 2030: High-level objective to multiply by 10 the installed capacity for PV in France and dedicate up to 1 billion EUR to industrial renewable energy projects (e.g. PV manufacturing). High-level policy announcements favourable to PV manufacturing and bilateral support to specific industrial actors with large manufacturing projects. France expressed interest to implement a scheme within the framework of the TCTF.	Case by case delivery of support, notably through the national Energy Agency ADEME, despite the lack of a streamlined industrial policy tool to direct support to PV manufacturing in France. France 2030 Plan: proposes calls for projects covering the entire value chain, from research to industrialisation.	A number of projects have already been funded and others are currently under appraisal. PV companies in France have announced a series of large-scale manufacturing projects with high-level political backing from their inception.
The Netherlands	No specific measures targeted at upscaling PV production or manufacturing. SolarNL: large scale public/private industrial partnership with 312 Million EUR of public support.	SolarNL: Support allocated through the National Growth Fund via various vehicles, including loans.	SolarNL is an example of a proactive use of national funds to support the industrialisation of PV and consolidate the industrial value chain which could be replicated in some European countries.

1.2
Non-European countries

1.2.1
India: Comprehensive programme that demonstrates adaptability to market conditions

India's main policies to support the growth of its domestic PV manufacturing include Basic Customs Duty (BCD), Approved List of Models and Manufacturers (ALMM), Modified Special Incentive Package Scheme (M-SIPS), Production Linked Incentive Scheme (PLI) Tranche I & Tranche II.

Thanks to this diversified and thorough legislative arsenal to support the establishment of a robust domestic PV supply chain, including notably financial support and demand creation for domestic products, India is attracting significant interest from investors. The India framework is structured around market creation for a domestic industry by creating a specific framework for domestic manufacturers that mixes provisions ranging from barriers to competitors on specific market segments, tariffs, CAPEX and OPEX support.

The variety of tools available in India is proving attractive to domestic investors (with major national conglomerates as well as domestic PV manufacturing companies investing in new capacity) and foreign companies alike. India PV manufacturers, driven by the structure of the support framework and global competitiveness factors are also investing in new technologies, for instance with the acquisition of the REC group by Reliance.

The aspect of protecting domestic manufacturers through trade measures has however been put on halt, as evidence emerged that tariffs had a negative impact on deployment rate in various segments of the Indian economy. This was due to a lack of a sufficiently robust domestic industry to step in to fulfil the high demand. The ALMM scheme was therefore relaxed until 2025, notably emphasising the lack of high-power modules from the list of ALMM manufacturers to satisfy the needs of utility scale projects in the Indian market. This did not prevent the Indian PV sector to significantly expand its PV manufacturing capacity during the year 2023, notably filling in some technological gaps within the domestic supply chain. The country already boasts a module manufacturing capacity of 37 GW at the end of 2023 and 6 GW cell capacity (expected to grow to 25 GW by 2025, reflecting a significant number of investments currently in construction).

1.2.2
USA: A major support framework that redefines investment flows for the global PV industry

Since the introduction of the Inflation Reduction Act (IRA), over 210 GW of new manufacturing capacity have been announced across the solar supply chain in the Unites States, representing nearly 21.000 potential jobs and nearly $12 billon in announced investments across 66 new facilities or expansions according to the Solar Energy Technologies Offices (SETO) of the U.S. Department of Energy. As the U.S. solar supply chain scales, SETO provides support for the very beginning of ideas all the way through to those who have developed their technology and are looking to development pilot manufacturing projects at scale. The office helps prepare new technologies to be ready to apply for loans from the DOE loan programs office to help scale up into full production and accelerate the market uptake process.

The Inflation Reduction Act allocates $369 billion to the effort of decarbonizing the U.S. economy. Under the IRA, PV manufacturing projects can benefit from significant tax reduction (see table below) as OPEX support through a simplified procedure. The ease of implementation of the support scheme as well as the sheer scale of support leads the IRA to be widely acknowledged as the most attractive scheme globally by PV industry stakeholders. The scheme also supports state of the art & innovative projects through additional incentives.

Moreover, alongside the IRA, the U.S. have introduced a strict ban on forced labour products, specifically targeted at products originating from China. The ban has a significant impact on the capacity of several manufacturers to access the U.S. market, rendering local manufacturing more attractive for many developers, including those that may be targeted by forced labour limitation on the export of their products.

The Inflation Reduction Act (IRA) offers the following solar manufacturing production incentives:

Component	Tax Credits
Solar cells	$ 0,04/watt
Wafers	$ 12/m³
Polysilicon	$ 3/kg (must be 99,99999% pure)
Backsheets	$ 0,40/m²
Modules	$ 0,07/watt
Inverters	Varies
Torque tubes (trackers)	$ 0,87/kg
Structural fasteners	$ 2,28/kg

Due to the implementation of manufacturing production tax credits and the inclusion domestic content adder, the solar manufacturing industry in the U.S. solar manufacturing is significantly growing. The reason solar manufacturing and investments in solar manufacturing were so low prior to 2021 was due to higher PV manufacturing costs for labour, electricity, land acquisition, permitting and environmental burdens in the US market. However, the tax credits provided by the IRA offer a chance to significantly reduce those costs and progress towards competitiveness through building a domestic industry on a large scale.

U.S. solar manufacturing announcements boom following IRA:

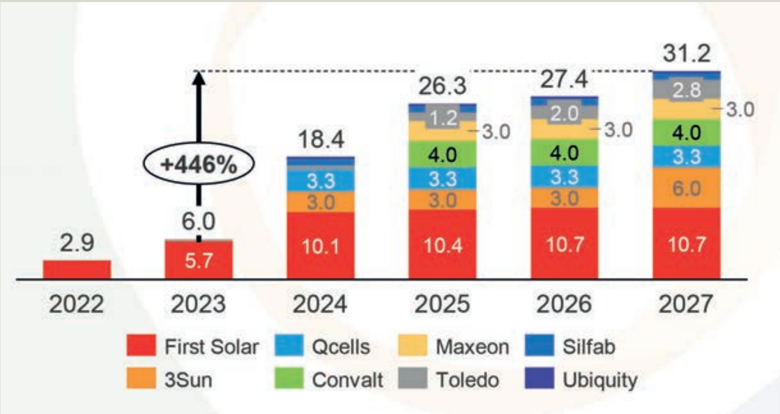

Figure 1:
U.S. announced solar cell production capacity in GW[1]

[1] *CEA - Clean Energy Associates, Analysis PVCellTech October 4th 2023*

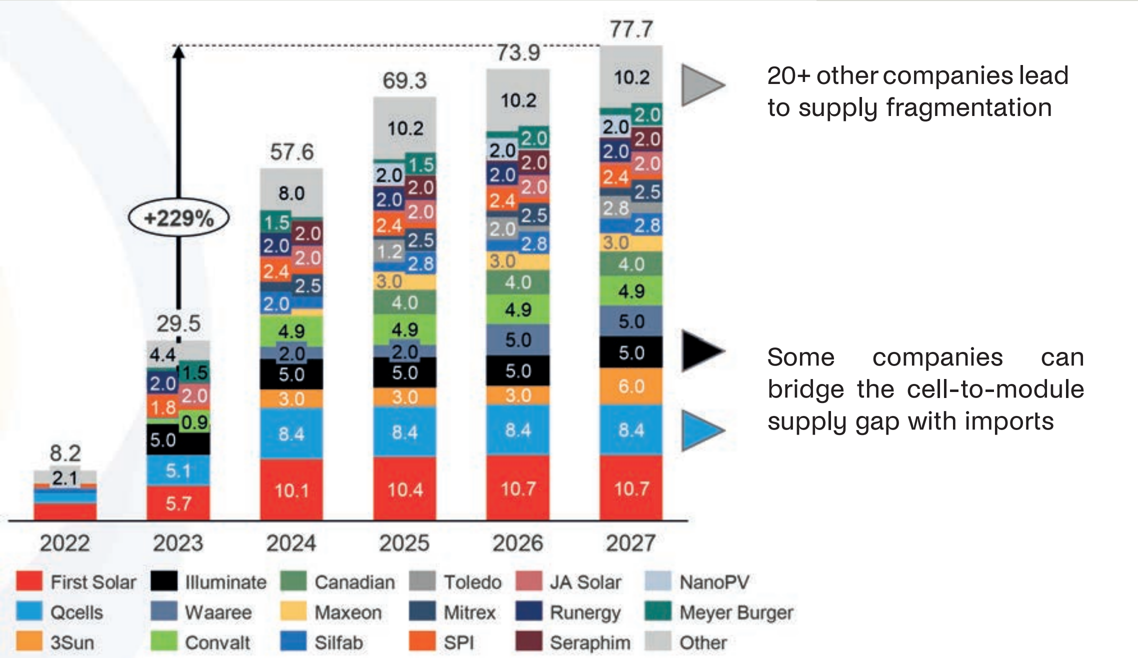

Figure 2:
U.S. announced module production capacity in GW[2]

However, the U.S.' solar manufacturing sector remains highly imbalanced, and many gaps need to be addressed before the country's industry reaches a high degree of resilience. Despite the announcement of significant new solar cell and module production capacity, upstream PV supply remains inadequate compared to module assembly. There are for instance challenges for polysilicon where no new investments into solar polysilicon have been publicly announced, and ingot/wafer capacity expansions remain uncertain given the newcomer status of many new suppliers active in the market. The IRA is not proving successful along the whole value chain. The incentives will help to ensure that solar cell factories already planned come online and are competitive. Nevertheless, the expansion of polysilicon, ingot and wafer production capacity needs to be accelerated.

[2] *CEA - Clean Energy Associates, Analysis PVCellTech October 4th 2023*

1.2.3
China: Domestic competition bolstering the exponential growth of a dominant national industry

China has been prioritising solar PV in successive five-year plans since 2001 (11th, 12th, 13th, 14th plans) and had over the past 20 years a long-term industrial strategy to support domestic PV manufacturing expansion. The programme was structured on national and provincial grants, low-cost loans and innovation funding to start a market that targeted export. Various tools, including grants and tax incentives used to import PV manufacturing equipment from the EU and U.S., enabled the start of the industrialization process, with a first phase on wafers, solar cells, and modules, followed by an increased focus on polysilicon. Following the establishment of a domestic industry, the Chinese government supported the consolidation of its PV manufacturing sector through incentives for domestic consumption, via a FiT from 2011 and utility-scale auctions since 2019. More recently, key programmes such as the Golden Sun programme - subsidised demand linked to installation of highly efficient technologies – and the Top runner programme – which incentivises manufacturers to target the most efficient technologies – have allowed global leaders in the PV industry to emerge. The country is now shifting from an export-focused market driven by technology acquisition from abroad, to a highly innovative market with a split focus on domestic and global supply, and an objective of maintaining a significant market share.

The Chinese industry is defined by large scale and a high degree of integration of the value chain, enabling structural factors that deliver a low OPEX environment (integration of value chain, water & energy costs...). The Chinese PV industry, which aims to maintain its market share on domestic and export, is greatly expanding its manufacturing capacity, driven in particular by internal competition among Chinese manufacturers to secure or expand their respective market shares along the value chain. Major investments into new production capacity, driven by this competition between Chinese manufacturers, has led to a situation of major oversupply of PV modules and other components of the value chain on the global market, inducing a global collapse of prices at levels far beneath production costs for European manufacturers. This short- to medium-term situation of oversupply is a major threat for the viability of many companies primarily active along the PV industry value chain globally. As of the end of 2023, the tensions linked to oversupply of modules are leading to plant closures or reduced production rates for small/medium size producers in the country[3].

1.2.4
Other key markets looking to expand their contribution to the PV supply chain

- Türkiye: The Turkish market implemented a local content premium as part of the FiT for deploying PV modules in the country, based on domestic added value (stimulating domestic module assembly from imported components) in 2013. From then on, the country has been steadily focusing on expanding domestic manufacturing, notably with a 2017 tender for 1 GW manufacturing capacity for all components from wafer to module. Investments have led the Turkish industrial value chain for PV to grow steadily in recent years, with 5,6 GW of manufacturing capacity in 2021, 7,9 GW of manufacturing capacity in 2022; and around 9,1 GW manufacturing capacity by the end of 2023.

- South Africa: The country stands as an emerging market for the energy transition and as the leader of renewable energy deployment on the African continent. South Africa is building an industrial strategy on PV deployment that aims to use its local market to support the establishment of domestic manufacturing. The country also aims to build trade relationship proximities to contribute to the PV value chain of key markets such as the European one. The key tool (2016) supporting South African PV industrialisation is local content requirements, notably for mounting structure, module frame, DC combiner boxes and to a lesser extent for inverters and PV modules[4]. Government procurement and local content requirements have been crucial in structuring a South African PV industry that is still burgeoning.

[3] https://www.pv-magazine.com/2023/12/08/china-module-prices-slide-to-new-record-low-manufacturers-cut-production/

[4] State of South African Manufacturing, its potential and resources required for further development of PV Value Chains, GIZ, 2023

Photo: Evgeniy Alyoshin, Unsplash.com

2.
The cost of resilience policies for European consumers

The question of the introduction of resilience requirements within European tendering for solar photovoltaics projects is a major topic for the entire sector, as the NZIA is entering the final steps of the legislative process at the end of 2023. The core challenge for policy makers and stakeholders from the PV sector is to understand how to effectively implement resilience requirements. Additionally, they need to consider the impact of such measures on both new investments in European manufacturing capacity and the cost of new PV projects in Europe.

The European Solar PV Industry Alliance (ESIA) proposes detailed "Effective and practical implementation of non-price criteria in specific public procurement, public auctions, and residential market segments for solar PV systems" in a November 6, 2023 paper. These recommendations notably include a "resilience auctions corridor" growing from 5 GW in 2025 to 30 GW in 2030, aligning with the EU manufacturing objectives laid out in the European Solar Energy Strategy. According to PV Magazine estimates, this corresponds to an estimated additional cost (i.e. subsidy) ranging from 600-900 million EUR/year in 2025, and 3,7-5,6 billion EUR/year in 2030, assuming a 10-15 cEUR/Wp additional cost from "resilience" for EU made modules and inverters[5].

To explore the question of the cost of resilience into greater details, it is notably crucial to consider different PV technologies when analysing the impact of resilience measures on the cost of ownership of a PV system. Newer technologies, such as HJT, TopCon and IBC are rapidly gaining market share because they promise higher efficiency than PERC, the mainstream technology on the market up to 2023. Beyond efficiency, several factors – including output power, temperature coefficient, performance degradation – are considered by investors when developing a PV project. Through the rapid industrialisation of innovative manufacturing processes however, TopCon modules have already reached costs expressed in EUR/Wp that are very close to PERC and is rapidly gaining market share.

Even more than technology, the location of manufacturing affects project costs. When assessing different technologies production in several countries, we can estimate a variation of the Cost of Ownership (CoO) in the range of 10 $ct/Wp for different technologies with production in China compared with the USA or Europe.

A representative CoO level comparison for a 10 GW integrated PV manufacturing factory is shown below.

5 https://www.pv-magazine.com/2023/12/09/weekend-read-europes-subsidy-conundrum/

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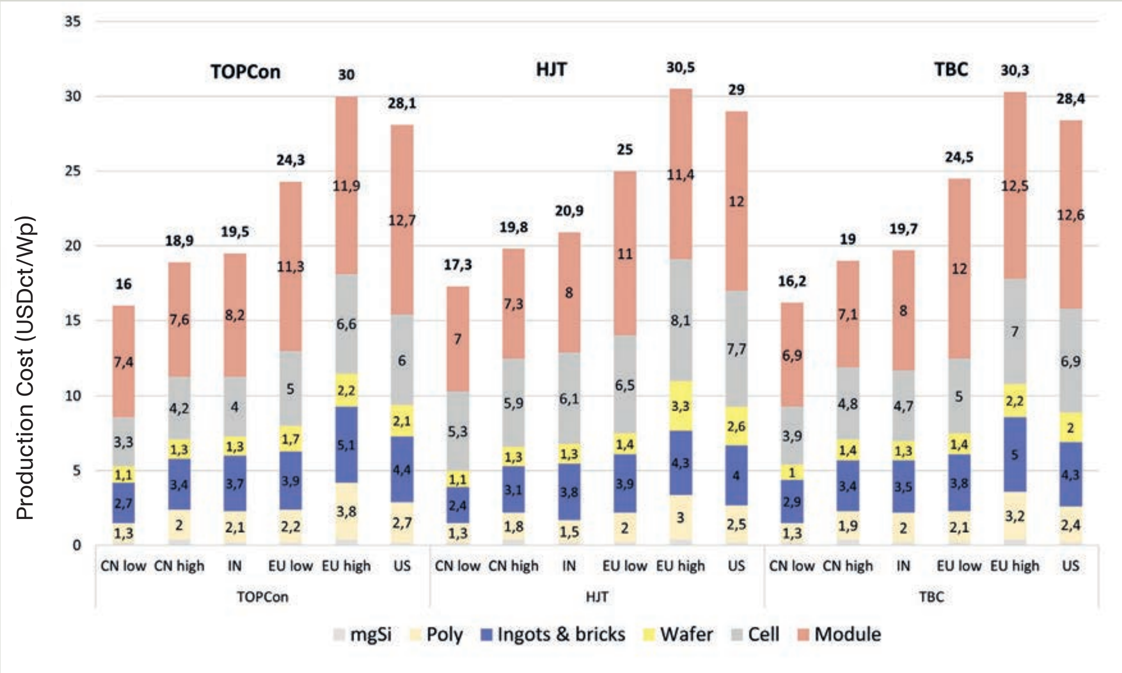


Figure 3:
Cost of Ownership (CoO) breakdown for different technologies for a 10 GW integrated PV factory. [6]

The cost variation in the manufacturing can notably be explained by the following factors:

- Significant variations in the material costs, labor costs and the equipment & building depreciation costs from one region to another
- Material cost differences can represent up to 30% premium, which results from shipment, economies of scale and import taxes in certain countries.
- Labor cost can vary by a factor of 8, while the electricity cost in Europe or the USA can be up to 5 times higher compared to China.
- Equipment CAPEX can be higher by 40% for western equipment including the imposed import duties.
- Building costs for a manufacturing plant are around 2 times higher in Western markets compared to China.

For different PV technologies, we see that there is little difference in the cost of ownership from one technology to another (up to 8,4% between HJT and PERC), and can largely be explained by different raw materials requirements, notably silver, and different cell production processes for innovative technologies. Newer, higher efficiency technologies however have a larger potential for cost-reduction through the introduction of new processes & materials, and further efficiency gains, on the medium term.

[6] *RCT solutions (rct-solutions.com)*

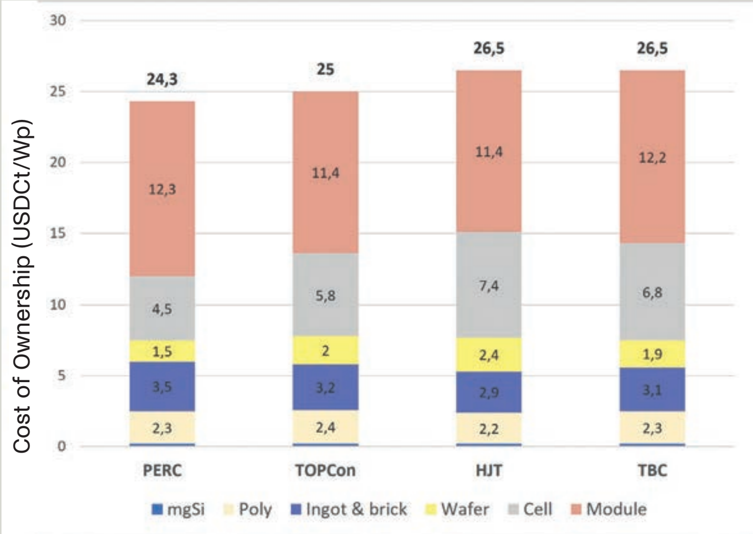


Figure 4:
Cost of Ownership (CoO) level comparison for different technologies in Germany [7]

Cost of resilience:

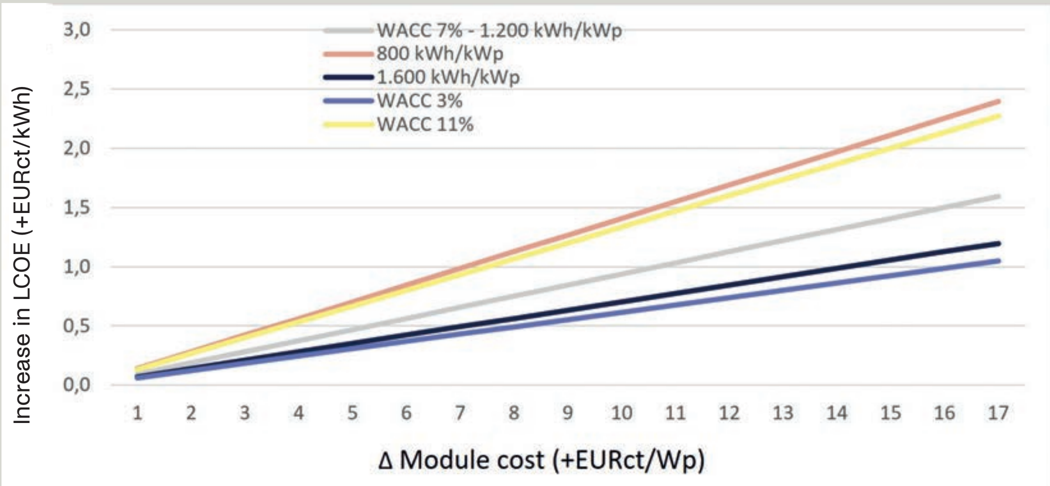


Figure 5:
Influence of higher module prices on LCOE at different locations (Irradiation) and with different capital cost (WACC) [Lifetime: 20 years; Depreciation and dept runtime: 10 years; Inflation: 2,5%; Degradation: 1 Year-2% 2. Year-0,5%; Tax Rate: 23,6% Dept: 80%]

Different factors contribute to shaping the impact of resilience measures on the economics of PV projects. The cost of capital and the capacity factor of the module (i.e. where the project is located) will have a significant impact on project development costs, on par with the location of the manufactured products. As the European economy is exiting a sustained period of low interest rates, the impact of interest rates will be felt much more by project developers and poses an additional challenge to the imperatives of resilience: In a context of very high interest rates (e.g. 11%), a utility scale product in a Northern European climate could be faced with projects whose LCOE is up to 25% higher for 'resilience' in the case of modules that are 15 cEUR/Wp more expensive to produce. This could have a significant impact on development rates. However, if the production cost difference is minimized (e.g. 5 cEUR/Wp) and interest rates remain moderate (e.g. 3%), resilience only carries a premium of around 5%.

[7] *RCT solutions (rct-solutions.com)*

To solve the resilience challenges, policy makers need to ensure they provide tools to minimise the production cost spread for PV manufacturers. While an important current focus of support policies in Europe lies on CAPEX, it appears clear from the cost structure of PV manufacturing (where electricity is a particularly impactful component for relative competitiveness) and the comparative success of countries opting for another approach (e.g. the US) that dedicated OPEX tools would also be relevant to consolidate the European PV industrial supply chain.

To support the transition of European PV manufacturing toward global competitiveness (i.e. narrowing the gap on the cost/Wp differential), various measures can be relevant as it is crucial to address different gaps in the value chain.

Resilience gaps in the European PV value chain:

<table>
<tr>
<td>Upstream manufacturing: Equipment availability and high energy costs for electricity intensive processes
Competitive electricity prices (renewable energy sources)
Non-Chinese equipment and raw materials availability: activities required</td>
<td rowspan="3">General
Level playing field, strategic long-term support as basis to achieve financing.
Pilot production lines for all parts of the value chain to accelerate developments for machine builders, manufacturers & institutes.
Purchase agreements (e.g. in public tenders through resilience auctions defined by NZIA)
Ensuring strong the respect of robust ESG criteria in the value chain to prevent environmental or social externalities.
Reliable, long-term financing</td>
</tr>
<tr>
<td>Solar Cell: The value of standardisation & accelerating the industrialisation of new technologies
Standardization (factory layout, wafer sizes, module sizes)
Differentiation through technological progress (e.g. perovskite / tandem)
Faster procedures (approval, financing)
Manufacturing in clusters</td>
</tr>
<tr>
<td>Modules: Highly competitive activities where relevant scale, integration to upstream and OPEX[8] competiveness are critical factors
Currently OPEX from German production is already above Chinese selling price.
Taxes for import on foreign components (wafers, cells, glass) is an obstacle for manufacturing in Europe</td>
</tr>
<tr>
<td colspan="2">Structural factors to reduce manufacturing costs
Economy of Scale (Equipment, Manufacturing and Supply Chain)
Highest degree of automation
Local supply chain integration (i.e. availability of all segments of the value chain at a relevant scale)
Energy supply by renewables to deliver a low cost of electricity to the manufacturing process</td>
</tr>
</table>

[8] *Module assembly also is an electricity intensive activity, moreover small competitiveness handicaps in sourcing various components (wafers, cells, glass...) add up to a significantly higher final module price on a EUR/Wp basis.*

3.
Technology focus: trends and the impact of industrial policies on R&I efforts, considering the role of manufacturing equipment

European photovoltaic machinery and equipment manufacturers have been historical drivers of the solar photovoltaics mass production globally. The expert competencies ranged from fundamental engineering understanding of systems up to the market-ready equipment for production lines over the entire PV manufacturing value chain. Many of these "hidden champion" mid-sized companies are market leaders in technologies that have revolutionized the industry, leading ultimately to the current status of solar PV. As an integral/irreplaceable segment of the solar PV industry ecosystem, the support of the European equipment manufacturer branch is of vital importance, especially in the currently highly competitive atmosphere. A sustainable and supply-resilient local European PV manufacturing capacity is dependent on the constant development of the production technologies and equipment manufacturers in Europe.

Within the European PV industry, there are diverging forces in presence with regards to innovation as part of an industrialisation policy. The need for both rapid scale-up and future consolidation requires distinct actions in the present. To compete globally on introducing innovative technologies to the market, EU industrial actors focus on investing in R&I, while EU manufacturers adopt the relevant strategy of rapid manufacturing growth, which includes accessing imports of significant volumes of affordable equipment from Asia. The industry faces the challenge of the sheer scale of equipment, investments, production and delivery needed in such a short period of time. One of the key challenges that policy makers must address at the European and national level is finding a balance between the need of rapid scale-up of manufacturing capacity and reaching sufficient cost-competitiveness for the short-term resilience of the European PV industry, and the need to sustain competitiveness through innovation and high-quality products to reach the market at scale for the long-term resilience of PV European market. The question of availability of skills, resources, investment capacity and production scale up potential in Europe will need to be addressed for a successful implementation of the outlined industrial policy for PV. As highlighted in the previous ETIP PV White paper on the European PV industry, beyond economic, technical & regulatory barriers, the European PV sector will need to solve challenges linked to missing expertise (e.g. upstream segments) and the need to rapidly expand its qualified workforce to deliver products that are competitive on the basis of quality, reliability and performance with global best practices. Research and innovation in Europe are known to be of very high quality on the development of solar photovoltaic (PV) products. Nevertheless, keeping the technological excellence of European machine manufacturers on different technology readiness levels (TRLs), requires the continuous investments in development by a clear European research and innovation (R&I) strategy. With the lack of multi-GW scale integrated PV manufacturing in Europe and the increasing competition with Asian machine manufacturers, European equipment manufacturers are left with difficult research and development (R&D) investment choices. In worst-case scenarios, these machine manufacturers risk the development of tools that do not penetrate the market and won't generate turnover, despite the high R&D investments. It is clearly the case with equipment that target solutions for emerging photovoltaics technologies requiring machines offering solutions for new approaches that replace or adapt already established state-of-the-art technologies. So, a de-risking factor and the commitment of companies to invest in the further development of their products and services are necessary to enhance the position of European machine manufacturers and in turn the entire PV manufacturing industry.

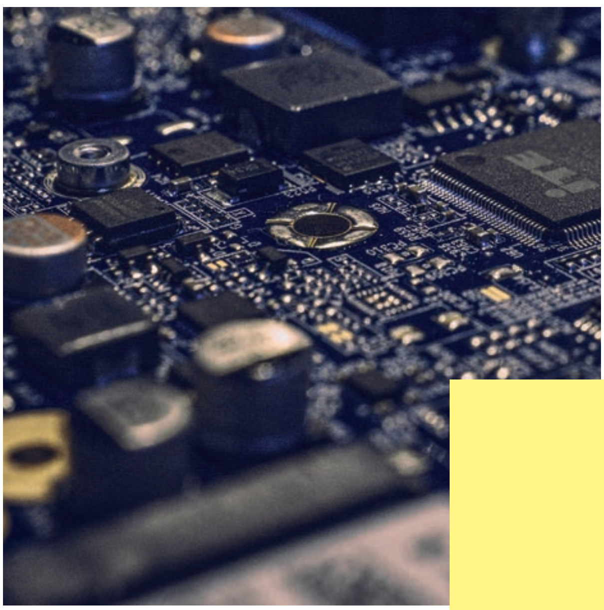


Photo: Alexandre Debieve, Unsplash.com

Topics of specific importance for machinery and equipment R&I, to name a few, include data-driven machine learning approaches, carbon footprint of the equipment, lower consumables use, high-quality results proven on product level. Moreover, a supportive European R&I strategy opens new possibilities leading to the diversification of cutting-edge technologies. In other words, working on specific solutions with high industrial potential, that have not yet been deeply explored. This would create an advantage gap of technological know-how that would further increase the competitiveness of European machine manufacturers. In cases of unexpected market disruptions (e.g., pandemics) and supply risks, having production-related innovative solutions and alternatives in face of such challenges is required. R&I would further support the resilience towards sudden interruptions of supply by broadening the scope of machine manufacturer's research towards solutions considering our European supply chain. The absence of European solar ingot pullers' supply is an unfortunate example of how the lack of incentives for companies also in R&I would create dependencies.

With a clear strategy to fund the R&I of European machine manufacturers, approaches to further reduce cost of ownership of equipment, by reducing not only operational costs of machines, but also the cost of manufacturing this equipment with advanced approaches lead to the reduction of the tools' cost. With the development of the PV manufacturing ecosystem, the top talents of the branch, particularly machinery and process experts, will stay in Europe. Machine manufacturing is supported in European and national programmes, notably with a focus on lower TRL R&I. However, in the perspective of building resilient supply chains for PV, it could be relevant to introduce programmes that have a stronger focus on turnkey supplies on the ground, thereby supporting the demonstration of innovation at scale and accelerating its market uptake. This would notably contribute to de-risking R&I investments of European companies, especially SMEs, that seek to initiate the manufacturing of innovative equipment to the service of the European PV manufacturing expansion. Meanwhile, it is also crucial to continue looking forward and supporting R&I projects on low TRL topics and consolidate the long-term resilience and sustainability of the European solar manufacturing industry.

Conclusion: A decoupling of R&I and industrial policies? How to reconcile at the European level for innovation at scale

In the race for building resilience in the European industrial value chain for photovoltaics, many stakeholders and governments may be tempted to focus primarily on copying global best practices and support investments targeted mostly at cost-competitive, mainstream products on the market. Given the numerous gaps in the European PV value chain, it is imperative to build up the capability of those market segments as well. However, a robust industrial policy cannot only focus on very short-term outcomes.

The PV technology cycle is quite short: The ITRPV report highlights the rapid rate at which new technologies emerge and become mainstream in the market. Within 5 years, a new PV technology can have moved from being considered highly innovative and reserved for high-cost applications to having become the market baseline. In Europe, this is the order of magnitude of the time needed to construct a new production facility for PV in the GW scale, which means that new investments are at risk of not being able to compete on performance soon after starting operations. While it is a challenge for PV companies, which need to rapidly scale-up and improve their scale and competitiveness in PV manufacturing, a proper coupling of research and innovation and industrial policies is something that policy makers can achieve at the European and national level.

A crucial challenge of the current industrial policy is to ensure the European PV sector will be able to ride the upcoming wave of innovative technologies, most notably with the emergence of new processes for emerging materials such as perovskites. A coordinated effort will be required to convert the years of European leadership in perovskites innovation into industrial competitiveness in the coming years, building the foundation of sustained resilience for the European PV sector, as a whole.

Upscaling manufacturing is an important step on the short term, in line with policy objectives. But providing the tools to bring new technologies to the market is also imperative since performance and technological leadership are a major component of competitiveness.

Annex I:
Assumptions supporting the Cost of resilience modelling

Assumptions for Cost of Ownership Breakdown

The Cost of Ownership figures presented in this paper reflect the findings of the Libertas project[9] and are shared by RCT Solutions. The assumptions considered for the various scenarios that are represented in the Figure 3 of this paper include:

The commercially available PV technologies based on silicon are PERC, TOPCon, HJT and IBC.

The module efficiency, output power and temperature coefficient of power degradation vary among the different technologies. High-efficiency technologies such as TOPCon, HJT and IBC have a lower coefficient of degradation compared than the PERC technology, which is still the work horse of the PV industry.

The simulation of production costs based on known costs of equipment and raw materials:

China Low	China High	EU Low	EU High
Building & Land provided by Government		Min 20% CAPEX Incentive for C-Regions	Non-incentivised
Electricity at 3.2 EURct/kWh[10]	Electricity at 9,1 EURct/kWh[11]	Electricity at 5 EURct/KWh	Electricity at 10 EURct/KWh
		Low-income country	Fully European Equipment · Poly and mgSi: + ca. +40% Equipment CAPEX · Ingot and Wafer: + ca. +100% Equipment CAPEX · Cell: ca. +30% Equipment CAPEX · Module: ca. +35% Equipment CAPEX
			High Income Country

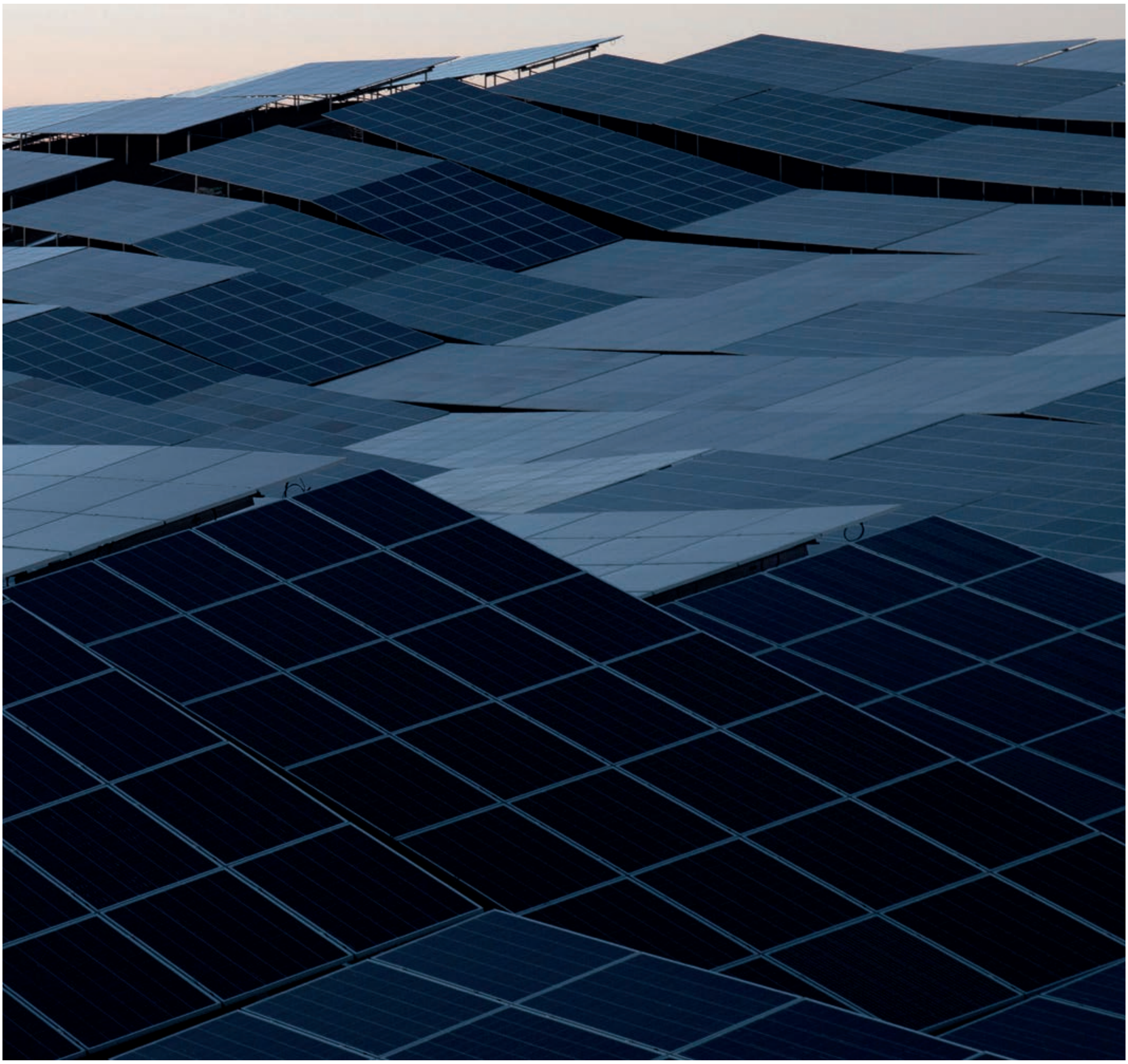
Chinese production costs assumptions:

China is able to produce PV modules at significantly lower costs than other regions. This notably results from a largely consolidated and integrated domestic supply chain, including local sourcing of material. Moreover, Chinese manufacturers can rely on low electricity rates (electricity being a central feedstock to most steps of PV manufacturing) and subsidised land and factory building.

Considering these criteria, the Libertas project estimates a production cost around 16,5 EUR/Wp for PV in China for vertically integrated manufacturing (i.e. production from ingot to module). When excluding the impact of incentives programmes, estimates for the production cost in China range around 0,19 EUR/Wp.

For non-vertically integrated manufacturers, the need to source components should result in higher production costs value compared to an integrated producer. Specific market conditions (e.g. overcapacity in upstream segments of the supply chain) may however punctually change this picture until adjustments occur throughout the value chain.

[9] *Libertas PV Feasibility Study (rct-solutions.com)*
[10] *3 USDct/kWh, conversion rate 0,93 USD = 1 EUR*
[11] *8,5 USDct/kWh, conversion rate 0,93 USD = 1 EUR*



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