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Status and Opportunities of Manufacturing Photovoltaic Components in Europe

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INTRODUCTION: WHY TO ACT NOW

With its *German Spanish Solar Initiative*[1], the German-Spanish Chamber of Commerce strongly supports the European Solar Manufacturing Council's (ESMC) plead to **relaunch a European PV Industry**.

To implement the European Solar Strategy, adopted in May 2022, of installing a total of 600 GW of photovoltaics ("PV") by 2030[2], Europe must **immediately take action to recover the domestic manufacturing it lost 10 years ago**. It should not depend on imports from one dominant country as supply might be disrupted and there is full exposure to price risk. Security of energy supply is of utmost importance. Available tools for the EU range from specific regulation (see "Chip Act") to IPCEIs (see H_2, batteries). It is thus logical that the European Solar Strategy is substantiated by the "EU Solar PV Industry Alliance," which endorses the objective of 20 GW of solar PV manufacturing in Europe by 2025.

Within the EU, there is still sufficient know-how and entrepreneurial power to recover the industry. However**, to challenge foreign dominant competition, large scale initiatives are also needed which can best be promoted by the EU**.

We thank Agere Energy and Infrastructure Partners for their collaboration elaborating this paper.

1 EXECUTIVE SUMMARY

Photovoltaics is the conversion of light into electricity using semiconducting materials. In the late 1950s solar cells found practical use in earth orbiting satellites. With cell efficiency of around 14% and high production cost, PV was not attractive for other applications at the time. However, in response to the oil crisis of the 1970s as well as nuclear accidents, research in the US, Germany and Japan continued and by the 1990s some countries had launched incentive schemes for the installation of solar panels on buildings. It was in the early 2000s that the deployment of PV picked up considerable momentum following the promulgation of a law in Germany that guaranteed a 20-year feed-in tariff for the electricity generated by PV panels.

Historically, the **world market grew** from a yearly installation of **0.3 GW in 2001** to 1.5 GW in 2005, to 17.5 GW in 2010 and **168 GW in 2021** (approx. **600 times more than in 2001**). Going forward, according to EU targets, 37 GW per year must be installed by 2025 and 56 GW by 2030; other areas of the world have exponential growth targets. Thus, the world market will amount to more than **380 GW** per year **in 2030,** which is **a fourfold increase over 2021**.[3] On a global scale, sufficient production capacity is available and expected to satisfy the demand.

Thanks to economies of scale and automation, capital expenditure for PV installations came down massively. This, in turn, led to a **cost of electricity produced by PV panels (Levelized Cost of Electricity "LCOE")** of as low as **30 €/MWh in the case of large generation plants in Southern Europe and around 100 €/MWh in the case of small residential installations in Northern Europe**.

[1] https://www.ahk.es/es/german-spanish-solar-initiative
[2] European Commission
[3] IEA

This "production cost" of electricity compares to average **consumer prices** (including taxes and levies) in 2021 of **119 €/MWh for large, industrial consumers and 237 €/MWh for residential.**[4] The comparison, without even contemplating the current disruption of European electricity markets, leads to the conclusion that **consumers pay a multiple for their electricity supply versus the LCOE of PV**.

Fabrication of a PV panel requires silicon, which is transformed through ingots into wafers, from which cells are manufactured, which are then assembled to fabricate a panel. The full production chain was developed in Europe, together with equipment for its automation. In 2009, Europe still had a market share of around one third of the world's production[5]. In 2011, when Chinese producers sold components at around 50% of their production cost, Europeans halted manufacturing.

As of 2022, with an installation target of around 37 GW for 2023 according to the **EU PV Strategy**, European manufacturing capacity of ingots and wafers is 1.4 GW (3.8% of the 37 GW target), of cells 0.8 GW (2.1%) and of modules 8.3 GW (22.4%). Consequently, the EU PV Strategy is **fully reliant on imports**.

More than 90% of the world's manufacturing capacity of ingots (around 200 GW), wafers and cells (almost 500 GW) is in **China**, concentrated in just a few companies. In 2020, imports from China created an EU trade deficit of around €6.2bn, which will grow to more than €15bn yearly if the target of up to 56 GW of newly aggregated capacity p.a. is to be achieved.

Beyond the drain of cash and the ensuing trade deficit, dependence on imports from a single country creates further **risks** such as exposure to **price, jurisdiction, geography (natural disasters), trade restrictions, inability to manage pace and scale of growth and financial health of the producers**.

Given the above, in order to (i) facilitate EU consumers' recovering control over their electricity costs, (ii) ensure availability of solar panels for the roll-out of up to 56 GW yearly, (iii) avoid €15bn of trade deficit and (iv) recover certain control over supply chain and technology, thus reducing the risk of concentration on just a few globally active players, it is **highly advisable for the EU to recover domestic manufacturing**.

One possible route is by individual action of some large players that might still have inhouse expertise and sufficient liquidity. While they might be successful, they would be challenged by the need to reduce production costs with high economies of scale to defy the pricing of imported competition, the need for R&D to increase panel efficiency, dependence on critical materials in the value chain, and access to financing, as EU-made modules are currently no longer "bankable". In addition to all this, they would be exposed to the risk of havoc which could arise from renewed aggressive pricing policies from Asian competitors similar to the ones experienced 10 years ago, with no decisive action taken by EU institutions at that time.

To overcome these hurdles, a useful tool of the EU could be the creation of an **IPCEI.** This is presently already supported by various countries including Spain, which has expressed interest in leading the IPCEI. Germany has not yet pronounced its interest, although it has been invited by relevant actors to do so. It would (i) provide the political framework to **overcome the total market failure** of being exposed to a quasi-monopoly of one Asian supplier, (ii) **encourage industrial players to return** to the sector which they abandoned as victims of unfair

[4] **Eurostat**
[5] **Fraunhofer**

competition, (iii) help to get **access to financing**, be it from public or private institutions, and (iv) **recover technological leadership,** with the framework of the IPCEI (partially) covering the technological risk inherent in product innovation (see chapter 5).

Another tool might be a "**PV Act**", like the Chip Act, a draft of which was released in February 2022. The draft sets out three measures: **Support for R&D, State Aid exemption for manufacturing, and monitoring of supply chains**.

Beyond the necessity to recover control over electricity cost, EU manufacturing would also strengthen the EU's **resilience against any disruption of fossil fuel supply**.

2 HISTORY OF MANUFACTURING OF PV COMPONENTS AND CURRENT STATUS

Photovoltaics is the conversion of light into electricity using semiconducting materials. In the late 1950s solar cells found practical use in earth orbiting satellites. With cell efficiency of around 14% and high production cost, PV was not attractive for other applications at the time. However, in response to the oil crisis of the 1970s as well as nuclear accidents, research in the US, Germany and Japan continued and by the 1990s some countries had launched incentive schemes for the installation of solar panels on buildings. It was in the early 2000s that the deployment of PV picked up considerable momentum following the promulgation of a law in Germany that guaranteed a 20-year feed-in tariff for the electricity generated by PV panels.

The PV production process can be schematically divided into the steps shown in Figure 1:

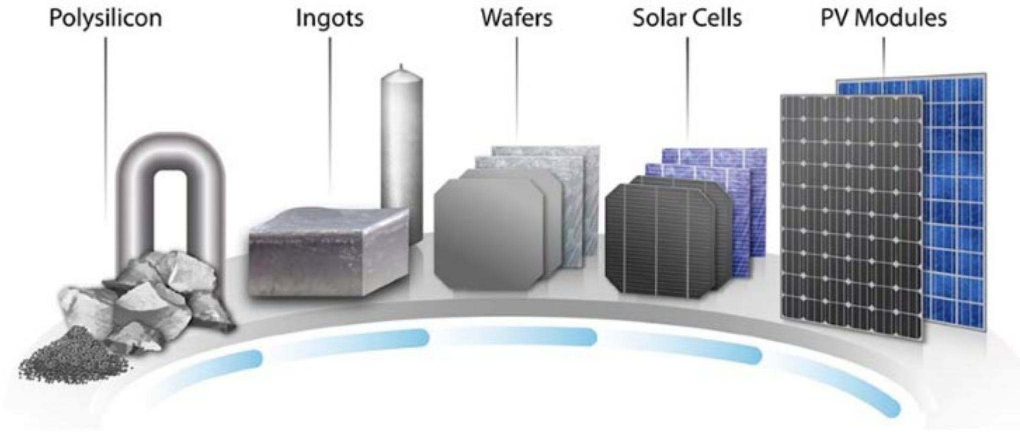

Figure 1 – Steps of PV production

2.1 European Leadership up to 2010

The world market of installed panels per year grew from 0.3 GW in 2001 to 1.5 GW in 2005 and 17.5 GW in 2010. The full value chain of practically all modules was covered by European and

Japanese producers. Triggered by high feed-in tariffs, module demand was high, which, in turn, stimulated the expansion of production capacity. It was only then that Chinese players gained interest in the sector.

Figure 2 illustrates how PV installations in China reached only negligible amounts until 2010:

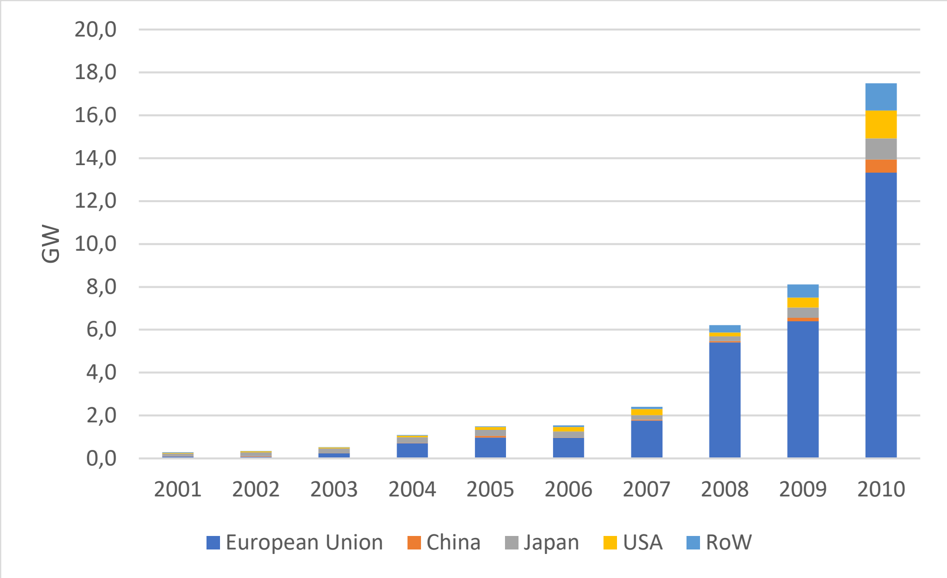

Figure 2 - Global PV installed capacity by year (2001-2010)

Of the accumulated 40.3 GW of PV capacity installed globally in 2010, more than 75% was in Europe, with negligible installations in China (3%), Japan (6%), USA (7%) and rest of world.[6] This proves that it was **Europe where the technology was developed and European citizens who paid for its cost**.

2.2 Reason for the Decline of European Manufacturing

The European PV industry was formed by rather small companies with only a few exceptions (e.g. Siemens, Bosch, Sharp, Sanyo). The small pioneers came from an R&D driven background. While they handled growth rates of 50% and more year by year, they could bring down production cost only in line with technological progress and amortization of previously made capital expenditures. When in 2008, with Spain constituting almost 50% of the world's installation of 6 GW that year, a lavish feed-in tariff in Spain fell away, the industry quickly adapted to other upcoming markets. It was also then, in 2008, that China declared the solar industry a central industrial strategy cornerstone of its XI five-year industrial plan. When in the second quarter of 2011 Chinese players started to dump their products onto the market, however, accepting up to 50% loss per unit sold, European players could no longer compete as they had limited access to capital. Therefore, during 2011 and 2012 practically all European producers stopped manufacturing. Many filed for bankruptcy. Some were taken over by international players. Others were simply liquidated.

[6] **IRENA**

Chinese producers, whose significant financial losses were evidenced in their financial statements, received public grants and loans, and could thus continue even though market prices did not cover their production cost.

2.3 A New Opportunity? European Solar Strategy (5/2022)

From 2010 to 2021 yearly global PV installations grew from 17.5 to 167.8 GW, respectively, resulting in an annual growth rate of 21%. Of the 167.8 GW installed globally, only 14% correspond to Europe, 4% to Japan and 16% to the US, while 33% were installed in China and 34% in other countries such as India and Turkey.[7]

This trend of continued exponential growth, diversified by countries, is illustrated in Figure 3:

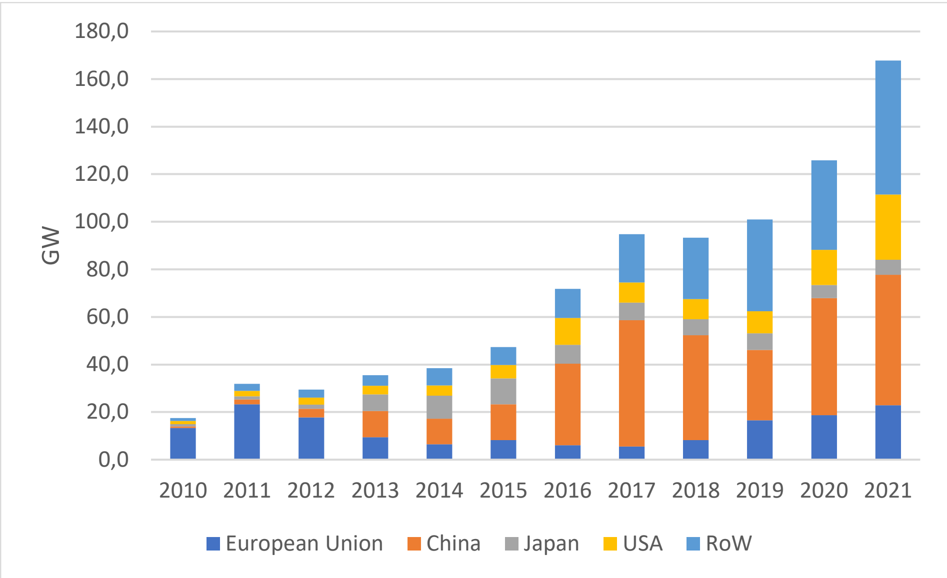

Figure 3 - Global PV installed capacity by year (2010-2021)

At the same time **module selling prices came down from 1.6 US$/W (2 €/W) to less than 0.4 US$/W (0.4 €/W)**. Large manufacturing facilities created important economies of scale allowing a partial cost reduction, which, in turn, increased demand and thus induced further capacity expansion. As shown in the chart below, global PV manufacturing capacity grew from less than 50 GW for silicon, wafers, cells and modules each to values of 400, 350, 300 and 220 GW, respectively. The chart indicates that (i) **silicon is still the bottleneck** with the lowest

[7] **IRENA; EurObservER**

capacity, (ii) **module manufacturing has significant overcapacity** more than doubling demand and (iii) **further significant capacity expansion** is underway.

Figure 4 shows demand versus manufacturing capacity and module price development.

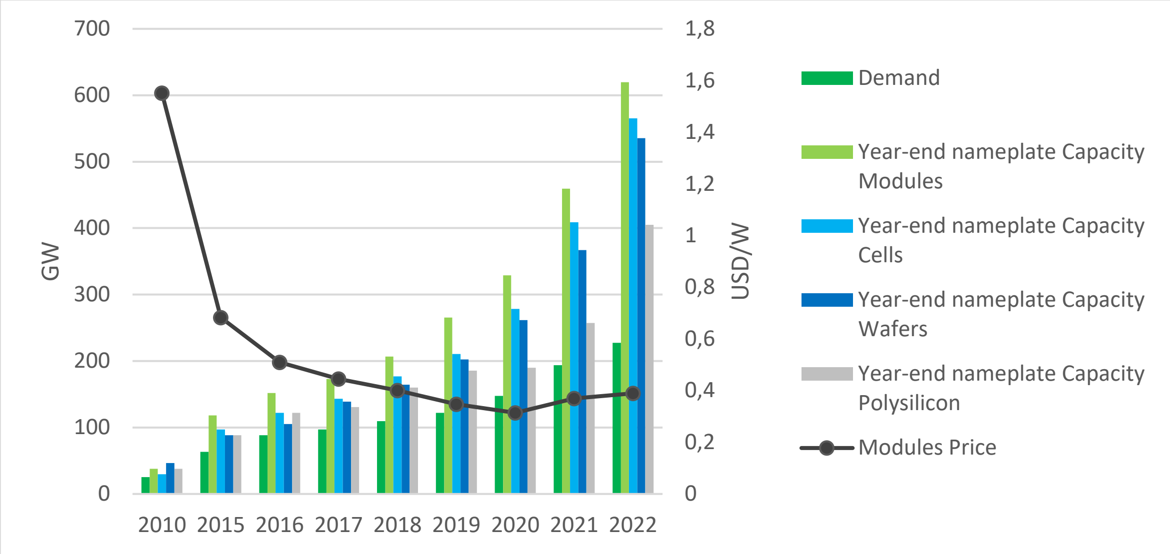

Figure 4 - Manufacturing capacity and module demand[8]

By 2030, according to the International Energy Agency (IEA), accumulated capacity on a worldwide level is expected to reach 4,000 GW, as shown in Figure 5:

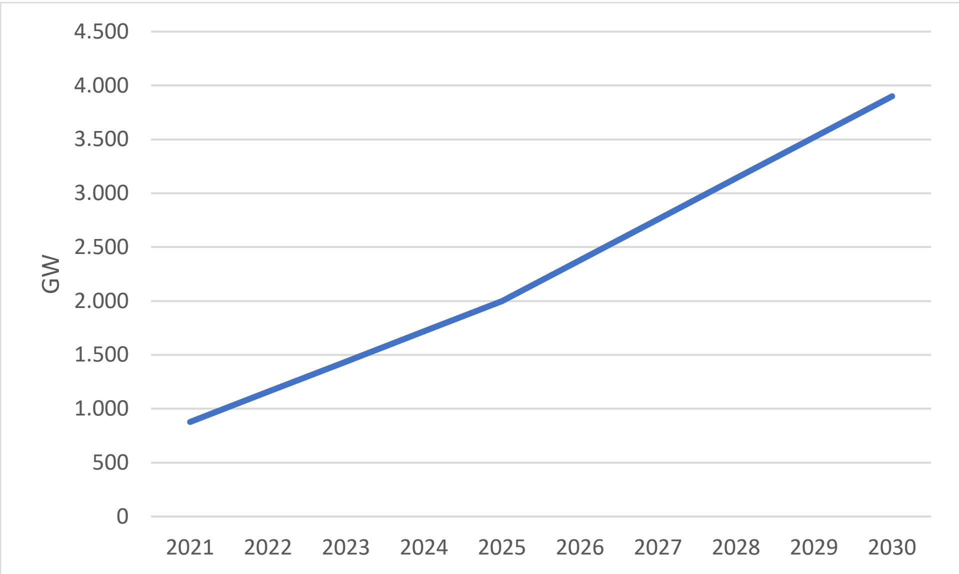

Figure 5 - Projection of Global PV Installed Capacity[9]

[8] IEA
[9] IEA

This projection is almost linear. While it is based on the IEA's data, and is therefore well-founded, attention must be drawn to the fact **that historically growth has always exceeded forecasts**, the only exceptions being years with changes in remuneration schemes in two European countries.

While **global manufacturing capacity should suffice to meet demand over the years to come, there are still strong economic arguments in favour of a recovery of PV manufacturing in Europe:**

Putting the EU's PV strategy in relation to global manufacturing capacity, an installation target of 37 GW for 2023, with another 56 GW per year by 2030, should be perfectly achievable. However, this installation target is **heavily reliant on imports** as European manufacturing capacity of ingots and wafers is only 1.4 GW (3.8% of the 37 GW yearly target), of cells 0.8 GW (2,1%) and of modules 8.3 GW (22,4%)[10].

Having to purchase practically the entire supply for a technology that is key to the transition from fossil to renewable energy further creates a **total technological dependence** and inhibits innovation which is not directly implemented by the few remaining manufacturers.

More than 90% of the world's manufacturing capacity of ingots and wafers and 80% of cells lies with just a few companies in China. This constitutes a **high concentration** with corresponding risks, from jurisdictional and geographic to financial, market and trade.

In 2020, imports from other countries (with China accounting for 75%) created an **EU trade deficit** of around €6.2bn[11], which will grow to more than €15bn yearly if the 56 GW target is to be achieved. This deficit might even worsen, as the **dynamic of module price reduction reverted in 2020**, as illustrated by Figure 6 below:

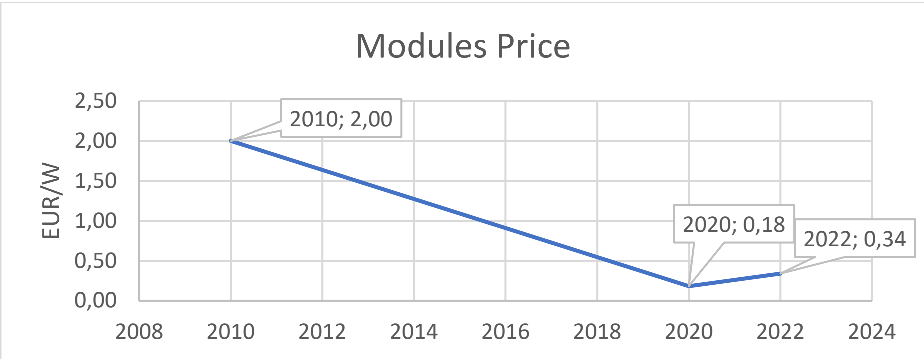

Figure 6 - Evolution of Modules Price (2008 - 2022)

Given the absence of domestic manufacturing, Europe is **fully exposed to price risk**: Historically, the price of modules dropped drastically from 2010 to 2020 (-91%). However, this trend has reversed in the past two years and **prices are up 87%** due to supply chain disruption and competition for supply, as worldwide demand is growing rapidly. Regarding the US market,

[10] **Fraunhofer**
[11] **Eurostat**

quotes for modules have even reached 0.43 €/W, also due to import duties on products from countries such as China[12].

It is up to Europe to overcome the paradox that, now that PV, originally developed by European players, has proven to be a reliable, cheap, and predictable technology to generate electricity, no manufacturing is left in Europe. It seems advisable that the European strategy, adopted in May 2022 in order to end European dependence on imported fossil fuels and establishing targets of installing 320 GW of PV by 2025 and 600 GW by 2030, should be substantiated by the recovery of domestic manufacturing.

3 ELECTRICITY MARKETS WITH PV AS A COST COMPETITIVE SOURCE

Until around 10 years ago, electricity generated from PV panels was not cost competitive with other sources. This has changed, with PV now being fully competitive. PV is no longer dependent on feed-in tariffs guaranteed by law which increase consumers' electricity bills. The motivation to include this chapter in the report is to prove this statement and illustrate that PV is highly beneficial for consumers.

Consumers benefit most when they directly consume the electricity produced as no grid charges and taxes apply. Also, power purchase agreements (PPAs), i.e. bilateral contracts between the producer and consumer, allow significant savings when other technologies, such as gas and coal, set the price at electricity wholesale markets.

The goal to ensure these savings further stresses the necessity to secure access to PV components and reduce dependence on foreign dominant suppliers.

The analysis of competitiveness differentiates between different applications (residential, commercial and large-scale), each having its own metrics.

3.1 Applications of PV Installations

Applications of solar PV can be differentiated in four segments:

- **Residential systems** (typically systems up to 20 kW on individual buildings/dwellings);
- **Commercial systems** (typically systems up to 1 MW for commercial office buildings, schools, hospitals, and retail);
- **Utility scale systems** (starting at 1 MW, mounted on buildings or directly on the ground);
- **Off-grid applications** (varying sizes). Examples are telecommunications units, remote communities, and rural electricity supply.

The share of market segments is changing significantly over time, with commercial systems gaining a relatively larger share, as shown in figure 7.[13]

[12] **Agere, actual quotes of recent transactions**
[13] **IEA**

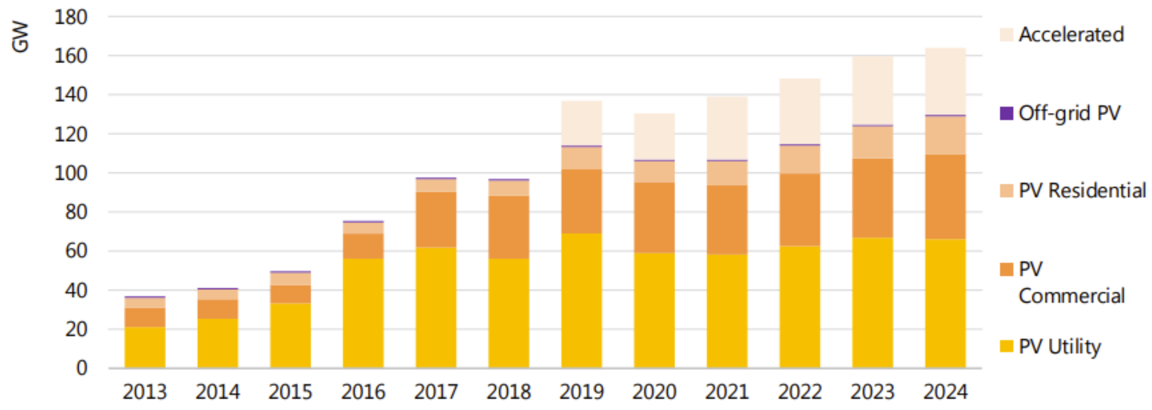

Figure 7 - PV generation by segment

3.2 Market Size, Generation Capacity and Electricity Prices

In 2020 Europe's total installed capacity in relation to all technologies was 881 GW, with only 110 GW of PV (12%)[14]. Given PV's low load factor, a 12% capacity share translates to a mere 5% share in generation (gross electricity generation 2,781 TWh, 139 TWh thereof from PV).[15]

As shown above, penetration of PV is still low, and targets marked by the EU PV Strategy of an increase to 320 GW by 2025 and 600 GW by 2030, replacing natural gas and other sources, fit in the overall production mix and are necessary to meet consumption.

This raises the question of the security of component supply and the dominance of foreign suppliers and supports the possible relaunch of a European manufacturing industry.

Household consumers are defined as medium-sized consumers with an annual consumption between 2,500 kWh and 5,000 kWh.

Non-household consumers are defined as medium-sized consumers with an annual consumption between 500 MWh and 2,000 MWh.

Industries are defined as consumers with an annual consumption between 20,000 and 70,000 MWh.

Prices presented here include taxes, levies and VAT for household consumers, but exclude refundable taxes and levies for non-household consumers.

3.2.1 Household Consumers

The weighted average of the most recent data for electricity by household consumers (second semester 2021) was €0.2369 per kWh or **237 €/MWh**.

[14] Eurostat

[15] Eurostat

They were highest in Denmark (€0.3448 per kWh), Germany (€0.3234 per kWh), Belgium (€0.2994 per kWh) and Ireland (€0.2974 per kWh). The lowest electricity prices were in Hungary (€0.1001 per kWh), Bulgaria (€0.1091 per kWh) and Croatia (€0.1313 per kWh).[16]

Figure 8 illustrates price levels of households:

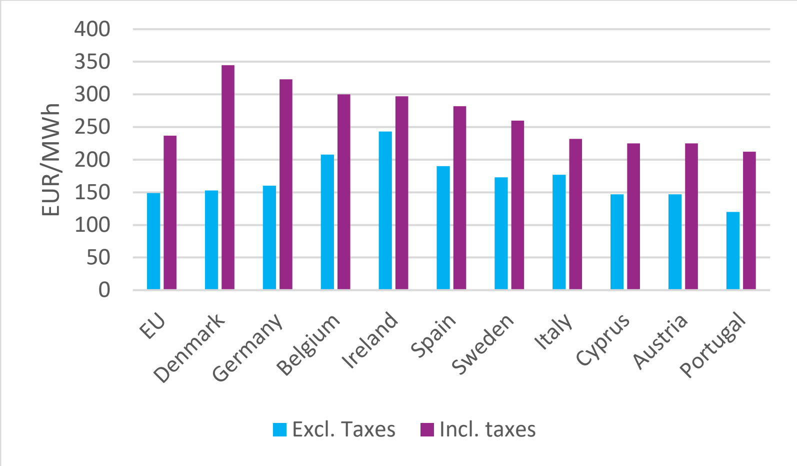

Figure 8 - Electricity prices for household consumers 2021

3.2.2 Non-household Consumers

The EU average price in the second semester of 2021 for non-household consumers was €0.1445 per kWh or **144 €/MWh**. Prices were highest in Greece (€0.2238 per kWh) and Cyprus (€0.1946 per kWh). The lowest prices were observed in Finland (€0.0800 per kWh) and the Czech Republic (€0.0905 per kWh).[17]

Figure 9 illustrates price levels of non-household consumers:

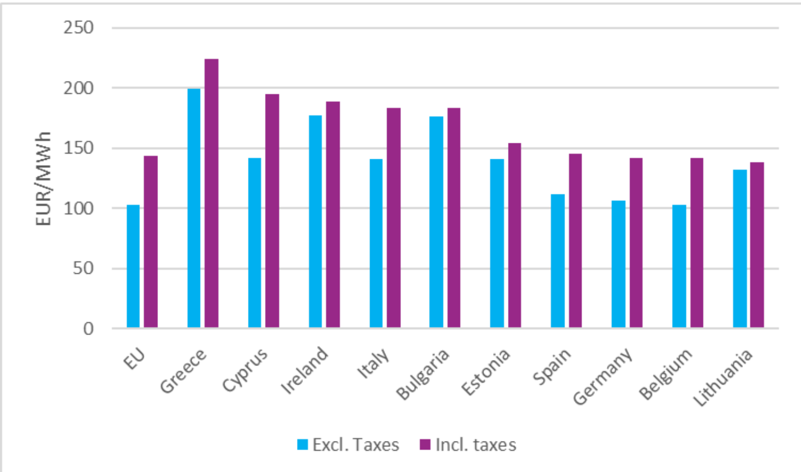

Figure 9 - Electricity prices for non-household consumers 2021

[16]Eurostat
[17]Eurostat

3.2.3 Industries

The EU average price in 2021 for industries was €0.119 per kWh or **119 €/MWh**, with the highest prices registered in Cyprus (€0.203 per kWh) and Germany (€0.169 per kWh) and the lowest in Luxembourg (€0.0800 per kWh) and Sweden (€0.0905 per kWh).[18]

Figure 10 illustrates price levels of industrial consumers:

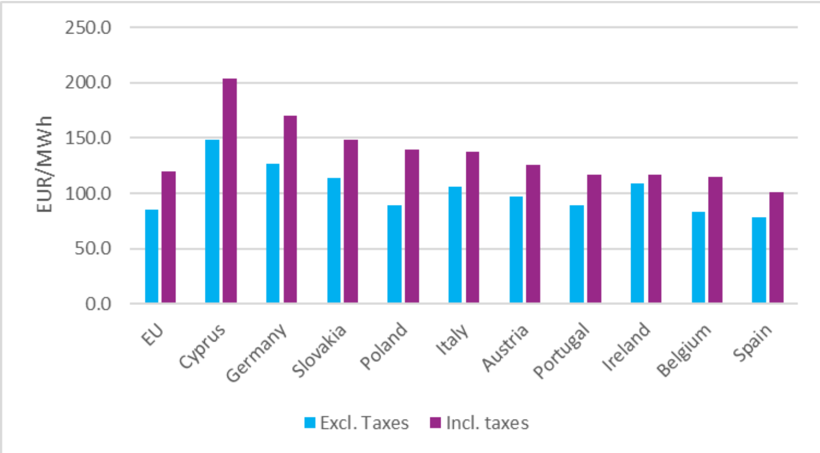

Figure 10 - Electricity prices for industries 2021

From the consumers' point of view, the price they pay to their utility, including all non-refundable taxes, levies and grid charges, is what has to be compared to the all-in cost of electricity generated by PV. Consumers cannot buy at prices of the wholesale market, which only represent a part of consumers' final bill.

3.3 Levelized Cost of Electricity Generation with PV Installations, Economic Viability

To assess the economic viability of electricity produced by PV modules, prices to be paid by consumers must be contrasted with the cost of generating the electricity. This cost is calculated as "levelized cost of electricity" (LCOE), taking into consideration the initial capex and opex over time.

For **utility-scale systems** (capacity greater than 1 MW), LCOE in the EU-27 (mean values) have dropped by 81% since 2010[19]. According to the investment bank Lazard, in 2021 the average LCOE for utility-scale was as low as **30 €/MWh**. This means that, even adding the additional cost for transmission, PV electricity is significantly cheaper than the **119 €/MWh** that large consumers paid in 2021[20].

[18] **Statista**
[19] **IRENA**
[20] **Lazard**

For **solar rooftop PV** (capacity lower than 1 MW), power generation costs in the EU-27 have dropped almost 80% since 2008. In 2021, the average LCOE of residential rooftop solar PV was **63 €/MWh**.[21] This compares very favourably to the price of **237 €/MW** paid by consumers in private households and is also below the average **of 144 €/MW** paid by commercial customers.

In the wake of the market disruption in 2022, consumer prices have climbed to more than 180 €/MWh for industry and more than 290 €/MWh[22] for households. The comparison leads to the conclusion that **consumers pay a multiple for their electricity supply versus the LCOE of PV**.

This creates a severe financial burden for consumers, which can be avoided by using PV. Applying electricity prices of 2021, the excess paid can be quantified as **174€/MWh** for households and **89 €/MWh** for industrial consumers.

Conclusion: At consumer level PV is fully cost competitive and its massive deployment is therefore beneficial for consumers. To **ensure such deployment, securing the supply of components is essential, which further strengthens the call for a relaunch of European manufacturing**.

4 PROSPECTS FOR A FUTURE EUROPEAN PV INDUSTRY

In a market that is expected to multiply by four, from a worldwide installation demand of 168 GW in 2021 to 630 GW by 2030 (IEA), with a currently highly concentrated production capacity of 180 GW (ingots and wafers), and practically none thereof in Europe, the recovery of a European PV industry to partially cover its own consumption of 56 GW yearly, according to forecasts, is highly recommendable.

Before moving on to options for a potential recovery, special emphasis is made on security of supply:

4.1 Security of Supply

As outlined in detail in the Special Report of Solar PV Global Supply Chains, published by the International Energy Agency (IEA) in August 2022[23], the solar PV supply chain is highly concentrated in terms of jurisdictions, geographies, individual facilities and companies. This concentration makes the supply chain vulnerable to many types of disruptions, some of them experienced recently, such as natural disasters or a pandemic; some still ongoing, such as war or a country's individual decision; as well as technical failures or a company's decision.

All these risks, resulting from high concentration, may cause delay, price increase or even non-availability of components. **Contrary to what is currently experienced with gas, Europe shall not risk becoming dependent again on supply from third countries when it comes to vital technology.**

[21] **Lazard**
[22] **European Commission**
[23] **IEA**

Figure 11 further facilitates a more detailed overview of relevant vulnerability factors:

Principal security-of-supply vulnerabilities and risk exposure

Vulnerability factor	Consideration	Potential associated supply chain disruption risks
Jurisdictional concentration	To what extent is the share of production concentrated in one single jurisdiction?	• Domestic policy changes • Geopolitical events
Geographic concentration	To what extent is the share of production concentrated in one single geographic area?	• Natural hazards such as earthquakes and fires, and extreme weather events such as drought and flooding • Technical failures of electricity, gas grids or other infrastructure
Facility concentration	To what extent is the share of production concentrated in one single facility?	• Above risks, plus: • Onsite equipment failure
Market concentration	To what extent is the share of production concentrated in one single company?	• Risk of collusion, price fixing and dumping
Pace and scale of growth	Are material supplies and production harmonised with demand?	• Long lead times for mining capacity and manufacturing facilities • Non-substitutability of some materials • Low labour and skills availability
Financial health of the PV sector	To what extent are manufacturers and integrated companies exposed to financial and bankruptcy risks?	• Bankruptcy risk from volatile prices • Changes to subsidies or other market changes
Trade restrictions	How globalised and dependent on international trade and trade policies is the PV supply chain?	• New or changing trade policies restricting the free flow of solar PV materials

Figure 11 - Vulnerability factors

4.2 Options

To recover domestic PV manufacturing, it is necessary to consider a wide range of options which complement each other. All efforts need to start with the aim of minimizing production cost and consumption of critical materials and energy, or, preferably, a replacement of critical materials. **Thus R&D keeps playing a fundamental role.** Further, as ramp-up of desirable GW factories will not be possible overnight even though this should be the goal to be reached as quickly as possible, reverting to some small players for downstream activities (modules) or manufacturing equipment (automation) is a first step with low entry barriers. Large scale silicon, ingot, wafer and cell production will have higher lead times and require significant capex. It is therefore advisable to leverage on existing initiatives and active players all over Europe and aim at the incorporation of large corporates.

4.2.1 R&D

Innovation needs to be headed in two fundamental directions: **Reduction of cost and replacement of critical materials**.

On the one hand, cost reduction is in line with the efforts undertaken over the last two decades: Reduce energy consumption in the production process, foster automation to reduce necessary labour while stabilizing product quality and leverage on economies of scale.

On the other hand, the focus on critical materials has not been so present, for example, with fossil fuels: Oil and gas have been at the heart of global energy security discussions over the past 60 years with extensive monitoring of their availability. In the light of the transition of energy supply to non-fossil sources, though, different materials constitute the centre of interest, need to be monitored and, should their availability be limited, need to be replaced. Significant R&D effort is required in the field and Europe, which still has PV R&D facilities and experts, must take an active role in this field.

Among the critical materials for PV manufacturing are silver, copper for connections, tin and zinc. Aluminium is required for frames, tellurium for thin film, etc.

Despite the almost complete shutdown of EU manufacturing, R&D has continued, which is evidenced by patent registrations (2012 related to PV 334), private spending of around €400m per year[24], public spending of only €150m and the yearly releases of the International Technology Roadmap for Photovoltaics by the VDMA (Verband Deutscher Maschinen- und Anlagenbau e. V.)[25].

While a large share of today's market is served by PERC cells with a maximum efficiency of 23%, next generation heterojunction "HJT" or TOPCon cells, with efficiencies of 25% (almost 9% more), are gaining market share. Major challenges are the high silver consumption for both technologies and high breakage rates in the case of HJT. R&D efforts therefore tend to focus on reducing or replacing silver and reducing breakage in HJT automation.

R&D is a viable option for Europe to keep an active role in PV manufacturing.

4.2.2 Small Scale Module Assembly

In 2012, according to a market survey amongst the producers, there were around 150 companies in Europe producing modules with a capacity of around 8.8 GW. While practically all of them went out of business, production facilities – albeit technologically obsolete – as well as some staff and know-how are still available.

Module assembly is less challenging than other steps of the production chain. Therefore, it does not generate significant margins and is the step with the most competition. Current overcapacity is around 100%.

However, for certain niche applications, revamping some of the sites, equipping them with new machinery that can handle bigger cells and bigger frames compared to the market standard 10 years ago, might be a small first step. Should local module assembly not render lowest cost,

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[24] MDPI
[25] VDMA

there might still be a market for residential applications. **Consumers might prefer local modules**, this being a voluntary decision without any regulatory background.

A second argument for European module production is transportation cost: While cells are still very compact and **transportation cost** is not significant, modules, with glass and frames, occupy significant volume which makes the overall price go up.

Small scale module assembly might thus be an option to meet consumer preference and reduce transportation costs.

4.2.3 TOPCon and Heterojunction Cells, Disruptive Technologies

Today's widely spread PERC cells with a market share of more than 85% seem to reach their power conversion efficiency limit at around 23%. Therefore, PV researchers are looking for other cell architectures to continue boosting the efficiency of industrially viable Si solar cells. Two types are being investigated, these being TOPCon and HJT.

TOPCon (also known as passivated contact) solar cells are touted as the next generation of solar cell technology after PERC with a maximum cell efficiency of 25%. The architecture was introduced by researchers at Fraunhofer Institute for Solar Energy Systems in Germany in 2013[26] and is currently in the phase of industrialisation. The TOPCon cell can be upgraded from current PERT lines and therefore requires less capital investment for existing manufacturers. It is currently in the stage of industrialisation, with some challenges still ahead that require significant innovation and R&D in relation to the significantly higher consumption of silver compared to PERT and the six different approaches to manufacturing which carry a technological risk upon deciding how to design and operate the cell line.

HJT is the acronym for hetero-junction solar cells. Introduced by the Japanese company Sanyo in the 1980s, then acquired by Panasonic in 2010s, HJT is considered another successor to PERT cells. Due to HJT's lower number of cell processing steps, and much lower cell processing temperatures, this architecture has the potential to simplify solar cell manufacturing. As with TOPCon, though, high silver consumption needs to be resolved. Moreover, high wafer breakage constitutes a challenge for mass production. Finally, process automation requires sophisticated equipment which is not easily available.

Even though PERC is expected to remain the dominant technology with a market share of more than 70% through 2032, other cells are gaining importance and will eventually replace PERC if they turn out to be more efficient.

Given that no large-scale PERC facilities currently exist in Europe, **production automation for new cell types is another option to catch up with cell production**, more so if no existing installations need to be amortized first.

26 Fraunhofer

The above considerations refer only to innovation of current state of the art, they do not refer to disruptive steps that might lie ahead **with perovskite cells, organic PV or the use of graphene**. While Europe lost out on optimizing silicon technology, it must urgently reengage and lead the way into the next generation.

4.2.4 Silicon, Ingot and Wafer Production

Silicon production, even though mostly metallurgical, is still present in the EU. However, wafer and cell factories are practically absent with Europe covering only 3.8% of its demand.

Special emphasis must thus be put on ingot and wafer production. This will be a major challenge as capex, know-how and energy consumption are high. On the other hand, though, know-how is available in Europe as currently evidenced in the even more challenging semiconductor industry.

With 97% of global wafer manufacturing concentrated in China, it is of vital importance for Europe to put a counterweight against such dominance.

In analogy to the **semiconductor industry, this requires large players with access to technology, capital and stable electricity supply**, contrary to module assembly that might ramp up on a small scale.

4.2.5 Vertically Integrated Facilities

Segmentation of the production process among various players, each being best-of-class in their segment, might be a strategy. In order to avoid supply chain disruptions and improve the traceability of components as well as the ability to give full product warranty, integrated facilities, manufacturing from silicon to module, can be an attractive option.

4.2.6 Manufacturing Equipment Producers

Finally, the manufacturing process requires sophisticated equipment, from silicon and wafer cleaning to crystal growing, ingot slicing, cell production and module assembly. Raw and ancillary materials need to be treated, which also requires automation.

Europe still has **specialised firms, able to design, adapt, upgrade and produce such equipment**. It is another viable option for Europe to recover lost ground in PV manufacturing.

4.3 Drivers

There is a broad range of drivers that contribute to the possible recovery of European manufacturing. Two very prominent ones that did not exist a decade ago are social acceptance, i.e. a consensus that electricity generated by PV is proven technology and forms part of the solution to implement the transition from fossil to renewable energy, as well as economic viability. While these drivers do not require further enhancements, others do require political and administrative support, entrepreneurial initiatives, visibility of product off-take, access to financing and coverage of technological risk.

4.3.1 Social Acceptance and Economic Viability

Several factors have contributed to an unprecedented awareness of Europe's energy dependence, the latest being the cut of Russian gas supply. This opens a window of high social acceptance for initiatives that help overcome such threats. Not only is social acceptance high for PV installations, above all residential and commercial, but reindustrialisation is also welcome in many European areas where jobs have been lost with the relocation of production facilities to Asia or elsewhere.

Social acceptance is especially high for rooftop applications, where no impact on habitats of species occurs. In the case of large, ground-mounted PV parks, extensive permitting procedures ensure that negative impacts will be avoided. Thus, installations that will finally be constructed will enjoy full social acceptance, more so if schemes of participation of local investors or local consumers are implemented.

Furthermore, social acceptance is high as electricity generated by PV can compete at the consumer level with electricity purchased from the grid.

Having learned these lessons, and adding the negative impact of disrupted supply chains, exposure to price risk given a quasi-monopolistic production sector, and the loss of local jobs during the collapse of the European PV sector, the European public is in favour of recovering domestic production.

4.3.2 Political Support at European Level (IPCEI, "PV Act")

One possible route to overcome the European manufacturing shortfall could be by individual action of some large players that might still have inhouse expertise and sufficient liquidity. While they might be successful, they will still be challenged by the need for R&D to increase panel efficiency and reduce cost, by access to financing and by the difficulty of placing their product, as EU-made modules are no longer "bankable".

To overcome these hurdles, a useful tool of the EU could be the creation of an **Important Project of Common European Interest** "IPCEI". Various initiatives to launch an IPCEI are presently underway, supported by various countries including Spain, which has expressed interest in leading the IPCEI. Germany has not yet pronounced its interest, although it has been invited by relevant actors to do so. According to the EU's definition, an IPCEI would (i) provide the political framework to overcome the total market failure of being exposed to a quasi-monopoly of one Asian supplier, (ii) encourage industrial players to return to the sector which they abandoned as victims of unfair competition, (iii) help to get access to financing, be it from public or private institutions and (iv) (partially) cover the technological risk inherent in product innovation.

During her speech at the "Foro Solar" in Madrid, Spain, on October 6, 2022, State Secretary Sara Aagesen once again announced Spain's leading role in this initiative.

At the international level, a group of around 50 European manufacturers, the European Solar Manufacturing Council "ESMC" (see 5.3.4) is heavily pushing for the launch of such an IPCEI, having already created five taskforces to address various fields, from cell production to PV integrated solutions and circular PV production.

Another tool might be a "**PV Act", in analogy to the Chip Act**, a draft of which was released in February 2022. The draft sets out three measures: Support for R&D, State Aid exemption for manufacturing, and monitoring of supply chains.

4.3.3 Administrative Support

Should any initiatives be undertaken, local administrative support will be of the utmost importance: Deployment of manufacturing installations is extremely slow in the EU with permitting and construction taking up considerably more time here than in China.

Below, Figure 12[27] shows lead times for PV manufacturing investments by segment and region. It evidences that lead times in the EU are more than double those in China:

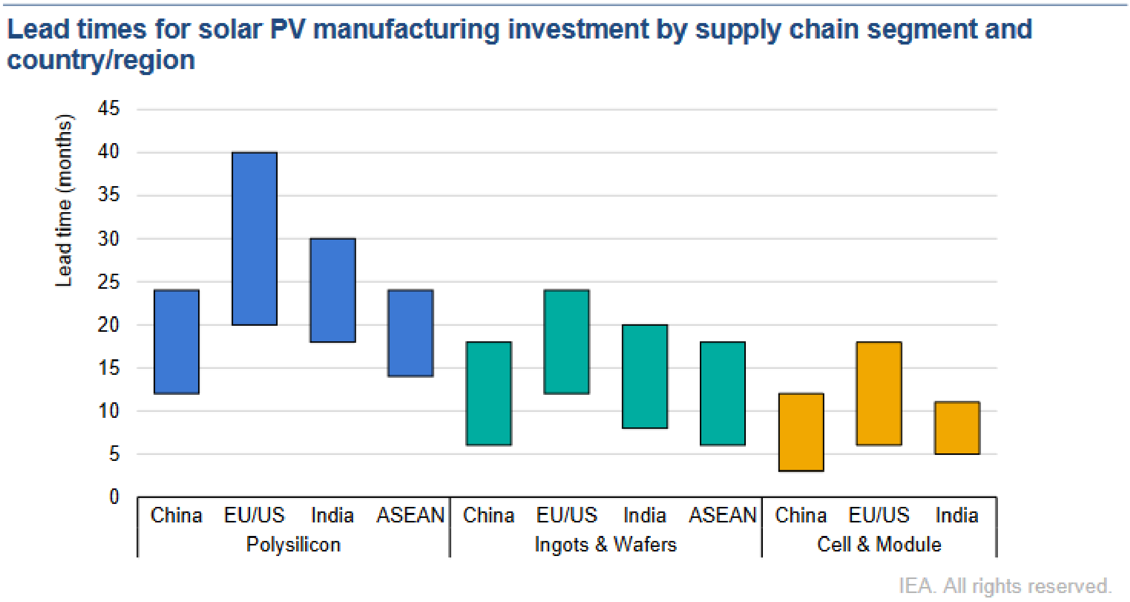

Figure 12 - Lead time for solar PV manufacturing investments

Based on the above, a very important driver for any potential recovery will be **administrative support, reducing lead times of manufacturing investments**.

27 IEA

4.3.4 Entrepreneurial Initiative

Europe is characterized by its entrepreneurial initiative with a lot of innovation being generated in rather small companies. In 2012, there were more than 150 companies actively involved in PV manufacturing in Europe. This number has decreased significantly by 2022.

One of the most active initiatives is a group of around 50 European manufacturers, the European Solar Manufacturing Council "ESMC"; a list of its members is included in Annex 1. It serves as a platform for technology transfer and mutual support and is pushing for the creation of an IPCEI. Among its members, five taskforces have been created to address various fields: (i) industrializing heterojunction cell and module technology to the Gigawatt scale; (ii) manufacturing TOPCon PV cells and silver paste; (iii) industrializing tandem PV technology to the Gigawatt scale; (iv) PV integrated solutions; and (v) circular PV production.

Figure 13 shows the current activity of the members, the country they are located in and, expressed by the size of the circle, their capacity.

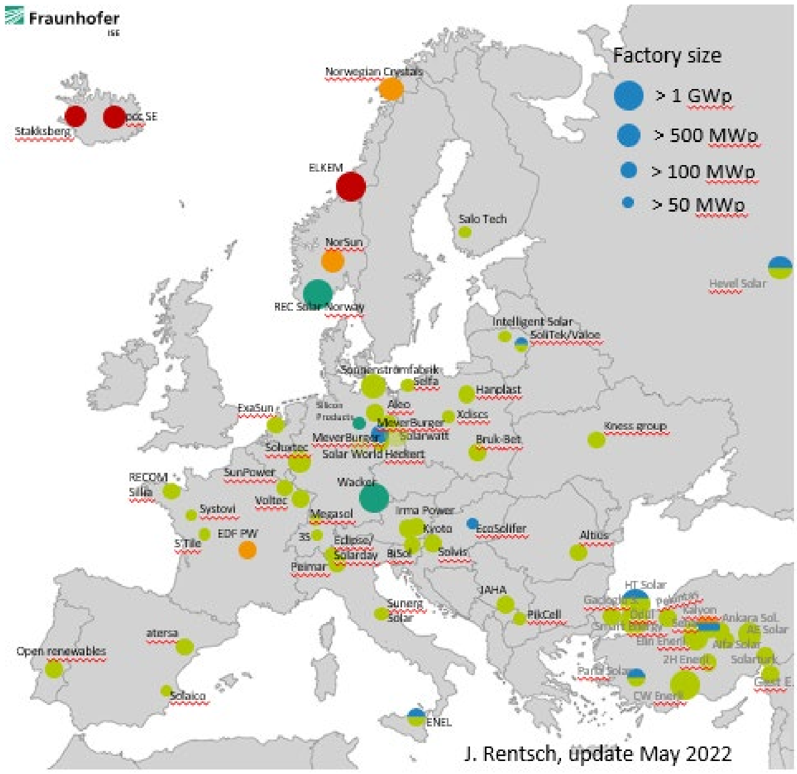

Figure 13 - PV factory size across Europe (red: metallurgical, dark green: poly silicon, orange: ingot and wafer, blue: cells, light green: modules)

Leveraging on these entrepreneurs going forward can be another driver for the recovery of PV manufacturing.

4.3.5 Visibility of Product Off-take

To motivate any investment in PV manufacturing, investors will require visibility of product off-take. Despite high existing production capacities and even a significant overcapacity of module production, the risk of not being able to place the product will limit investor appetite.

Consequently, schemes of "guaranteed" offtake are required. They can range from initiatives for public entities to install panels on their administrative buildings to consumer initiatives that voluntarily prefer "local content" and large-scale solar plants using the European products as a marketing argument. In short, **this is not necessarily a call for trade barriers or the like. It is an appeal to European consumers, public and private, to create visibility for PV made in Europe by buying locally**.

4.3.6 Access to Financing

Another fundamental driver of a potential recovery of PV manufacturing is access to financing. As of today, not even modules "made in Europe" are bankable as shown in the ratings in figure 14[28], published by PV-Tech and followed by most European banks:

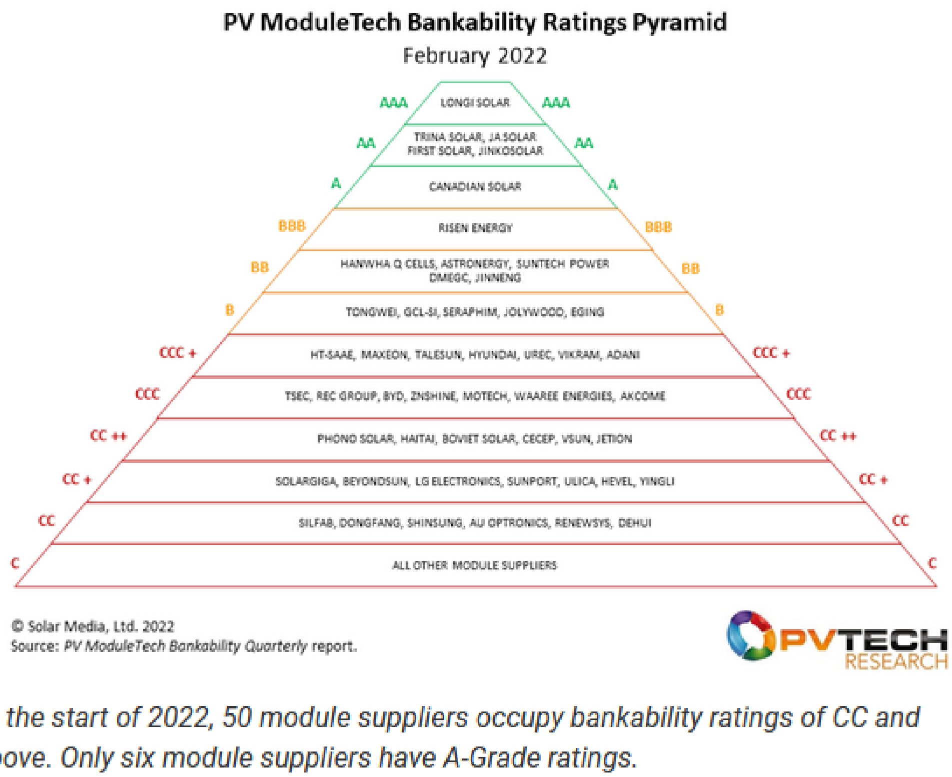

Figure 14 - PV Modules Bankability

[28] PVTech

Up to "quality" BBB, only Chinese module producers are listed. This means that even PV projects that use modules from other suppliers will find it difficult to get easy access to bank financing.

Consequently, access to financing will be even more difficult for PV manufacturing facilities that do not have a recent track record as they went out of business some years ago or for those who are new entrants.

It is therefore of the utmost importance that **entities like the German KfW, the European Investment Bank and others supply debt to or, at least, default guarantees for new manufacturing initiatives**.

4.3.7 Coverage of Technological Risks

To further reduce the cost of PV panels and replace critical materials, technological innovation is needed. However, intents to create innovation can fail and money spent might have to be written off.

The industry would therefore need coverage against such losses. Private risk capital will be available to a certain extent, just as it is still the case with R&D spending. But when it comes to large investments, **public coverage of technological risks** will be essential.

4.4 Positions of Germany and Spain

This final chapter contains some more details on historic capacity in 2012 in Germany and Spain, current capacity, and a high-level assessment of the countries' respective contributions in a possible relaunch.

4.4.1 Germany

In a survey conducted by the association EU ProSun in 2012, 36 companies participated reporting a 3.1 GW module manufacturing capacity in Germany with an actual production of 1.3 GW, and 1.5 GW cell manufacturing capacity with an actual production of 1 GW. This covered 38% of the country's module and 19% of its cell demand of 8 GW that year (Annex 2). Silicon, ingot and wafer production also reached significant levels of the demand.

As of 2022, while Wacker poly silicon production is still available, it is not viable economically with current electricity prices. No industrial ingot or wafer production remains. Meyer Burger is the only relevant cell producing company, which is just ramping up its new factory. There are still a few small active module producers with a production capacity of up to around 100 MW per year. However, they heavily depend on cell supply from abroad, basically Asia.

Germany still has a strong R&D community which is frequently consulted by international players. Equipment for production automation is still being produced in the country. In addition, Germany has an industrial base with strong players like Bosch and Siemens, who both abandoned PV manufacturing in the past. Given the strategic importance of recovering protagonism in the energy sector, such large players should be motivated to return to the PV industry. Also, now that semiconductor production is being relocated to Germany, with the very active participation of companies located in Saxony's "Silicon Saxony" initiative and under supervision of the EU, boosting comparable initiatives for PV manufacturing is a must. **Knowhow and players are available, but without strong political backing, none of them will risk investments necessary for a meaningful relaunch**.

4.4.2 Spain

In the EU ProSun survey mentioned above, 16 Spanish companies participated reporting a 0.9 GW module manufacturing capacity with an actual production of 0.1 GW, and a 0.2 GW cell manufacturing capacity with an actual production of 0,05 GW (Annex 1). These low values are in line with the extremely low domestic demand of only 0.3 GW in 2012, which was a consequence of the "moratorium" on renewable energy and the insecurity created by the "impuesto al sol", a tax that was to be paid based on installed capacity.

Spain has never had its own poly silicon production. Cell production was concentrated in one historic player, Isofoton, which went out of business in 2012. There was one large wafer producer, Silicio Solar, and the smaller DC Wafer, which both ceased production in 2011. Atersa and Solaria, both companies still active, had certain activity in cell production, which they discontinued in 2012. Small initiatives by Cel Celis and Pevafersa were only ramping up in 2012 and ceased business.

The only active player with metallurgical silicon today is Ferroglobe. No ingots and wafers are being produced. According to Fraunhofer, as of 2022 only two cell producers remain with insignificant capacities. Other initiatives might be announced but have low visibility so far.

UNEF, the leading Spanish association for the PV sector, is presently coordinating industry initiatives destined to ramp up the Spanish PV manufacturing sector with the support of the Spanish Ministry for Ecological Transition and Demographic Challenge (MITECO), which has committed important funding to this issue under the umbrella of the European Next Generation Funds.

Spain's position is different from Germany's: While the domestic technological and industrial basis does not suffice for a relaunch of the full production chain, at the political level there is a strong consensus that such a revamp is of the utmost importance, which motivates Spanish players to support the European IPCEI and even offer to lead it.

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Annex 1

European Solar Manufacturing Council's Members and Task Forces

Task Force 1: Industrializing heterojunction cell and module technology to the Gigawatt scale
Task Force 2: Manufacturing of TOPCon PV cells and silver paste
Task Force 3: Industrializing Tandem PV technology to the Gigawatt scale
Task Force 4: PV integrated solutions
Task Force 5: Circular PV Production

#	Name of company	Country of origin	1	2	3	4	5
1	3S Swiss Solar solutions AG	Switzerland					
2	AGC group	Japan	x				
3	Applied materials	United States	x	x	x		x
4	Coveme	Italy	x				
5	Enea	Italy	x	x			x
6	Enel	Italy	x	x			x
7	Eurac research	Italy	x	x		x	x
8	Evolar AB	Sweden		x			
9	Fraunhofer	Germany	x		x		x
10	FuturaSun	Italy	x				
11	GIGA PV	Europe			x		
12	IEO	Poland			x		
13	Imec	Belgium		x			
14	INES - Institut National de l'Energie Solaire	France	x	x		x	x
15	Institute for Energy Technology	Norway	x				
16	IPVF	France	x	x	x	x	x
17	ISC Research for a sunny future	Germany	x	x	x	x	
18	KGHM	Canada			x		
19	LuxChemtech	Germany	x				
20	MCPV	Germany	x	x			x
21	Metsolar	Lithuania				x	
22	Mondragon assembly	Spain		x		x	x
23	Nexwafe	Germany					x
24	Norsun	Norway	x	x			x
25	Oxford PV	United Kingdom		x			x
26	Photowatt	France		x			x
27	Protech	United States				x	
28	RCT solutions	Germany			x	x	
29	Rec Solar	California					
30	Rise technology	Italy		x	x		x
31	SIEMENS	United Kingdom		x		x	x
32	Singulus	Germany		x	x		x
33	Sintef	Norway	x				
34	Smart energy	Lithuania	x			x	
35	Solarge	Netherlands	x				x
36	Solarwatt	Germany	x	x		x	
37	Solean	France				x	
38	Solitek	Lithuania	x			x	
39	Soltec	Spain		x			x
40	Standex	United States	x				
41	Team technik	Germany		x			x
42	Tecnalia	Italy				x	x
43	Ulbrich	United States					x
44	Valoe	Finland				x	
45	Vitronic	Germany					x
46	Voltec solar	France	x	x			x
47	ZS-Handling	Germany				x	x
48	H2GEMINI	Switzerland					
49	Halm	Germany		x	x		x
50	Von Ardenne	Germany		x			x

Annex 2

Module and Cell Manufacturing Capacity 2012 in Germany and Spain

Company	Country	Module Capacity 2012	Module Production 2012	Cell Capacity 2012	Cell Production 2012
alfasolar GmbH	Germany	40			
Algatec Solar AG	Germany	120	15		
Asola Solarpower GmbH (TUSAI)	Germany	45	40		
Astronergy Co., Ltd. (Chint Solar) (Conergy)	Germany	300	250		
AxSun Solar GmbH & Co. KG	Germany	20	5		
BaxThor GmbH	Germany				
Besco	Germany				
B-Solar Ltd.	Germany			50	
Centrosolar Group AG (Centrosolar Sonnenst	Germany	350	139		
Gss Gebäude- Solarsysteme GmbH	Germany	18	3		
Hanwha Q Cells GmbH	Germany	130	30	230	170
Heckert Solar AG	Germany	170	75		
Innotech Solar ASA	Germany			5	2
Jurawatt GmbH	Germany	50	23		
Mage Sunovation GmbH	Germany				
ML&S Manufactoring, Logistics & Services Gr	Germany	40	20		
no-vo GmbH	Germany	40	10		
Scheuten Solar Technology GmbH (Multisol)	Germany				
SGT GmbH	Germany	30	10		
SI Module GmbH	Germany	25	15		
Solarbau Süd GmbH	Germany	15	7		
Solar-Fabrik AG	Germany	210	103		
Solarnova Produktions- Vertriebsgesellschaft	Germany	30	20		
SOLARWATT AG	Germany	300			
Bosch Solar Energy AG	Germany	250	100	630	450
SolarWorld AG	Germany	500	275	300	300
Solon SE (jetzt Solon Energy GmbH / Microso	Germany	70	20		
SOLUXTEC GmbH	Germany	15	3		
Sovello AG	Germany			180	
Sunrise Global Energy (Aleo)	Germany	280	100		
SUNSET Energietechnik GmbH	Germany	40	5		
Sunware Gmbh	Germany	2	2		
Sunways AG / LDK / Blue Cells	Germany			100	30
Unimen	Germany				
Webasto	Germany				
WIOSUN Production GmbH	Germany	6	1		
Total		3.096	1.271	1.495	952

Company	Country	Module Capacity 2012	Module Production 2012	Cell Capacity 2012	Cell Production 2012
Aleo Solar AG	Spain				
APLICACIONES TÉCNICAS DE LA ENERGÍA, S.L.	Spain	144	20		
CEL CELIS, S.A.	Spain			35	21
Cuantum Solar, S.L.	Spain				
Eurener	Spain	45	15		
Fluitecnik Sunenergy	Spain	30	6		
HELIOS ENERGY EUROPE - HELIENE	Spain	45	6		
IATSO - INNOVACIÓN ALTA TECNOLOGÍA SOL	Spain	10	1		
Isofoton SA	Spain	230	15	150	15
Pevafersa S.L.	Spain	60	5		
Siliken	Spain				
SOLAICO - Unión Composites S.L.	Spain	40	10		
SOLAR WIND EUROPE, S.L.	Spain	10	2		
SOLARIA ENERGÍA Y MEDIO AMBIENTE, S.A.	Spain	250	25	50	15
Vidurglass, S.L.	Spain	2	2		
Yohkon Energía S.A.	Spain				
Total	Spain	866	107	235	51

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