PV MANUFACTURING LESSONS LEARNED IN EUROPE

2022 and 2010-2012 in comparison — how to turn market differences into opportunities?

The European Solar Manufacturing Council (ESMC) is the organisation representing the interests of the European PV manufacturing industry. The Council relies on key industrial companies, organisations and research centers active in the PV sector rooted in Europe. ESMC aims at promoting and supporting the PV manufacturing industry and its value chain at the European level.

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I. SUMMARY OF KEY MARKET DIFFERENCES

Global photovoltaic (PV) developments and the European PV manufacturing success story at the time around 2010-2012 turned into a period of great risks and shrinking margins, ultimately leading to a diminishing of European PV manufacturing industry during 2012–2014. **Now in 2022 the European PV manufacturing industry potentially is at the edge of a renaissance, due to several key differences. These differences of the situation today as compared to the situation a decade ago are critical for the trust in the re-establishment of PV production in Europe, including its long-term benefits. The differences between 2022 and 2010–2012 are the decisive factor for the actions to be taken to support PV manufacturing in Europe. ESMC is positioning this document as the summary of the structural factors which should be taken into account while the European Union and the Member States are developing the support instruments for the European PV manufacturing to be sustainable competitive. The European PV manufacturing industry has enormous growth potential, but without the operationalization of some support instruments without delay this potential could be irreversibly wasted. Consequently, these key differences between 2022 and 2010-2012 have potentially positive implications for European PV manufacturing, which could be realized through the proposed actions to benefit from these differences (Table 1).**

Table 1. The structural differences of the global and European PV deployment and PV manufacturing in 2022 vis-à-vis 2010-2012.

Market differences	Positive implications for European PV manufacturing	Actions to benefit from the difference
1. Global PV market expanded	Scaling-up potential — export	Investment incentives, credit guarantees
2. European PV market growing	Scaling-up potential — domestic use	Investment incentives, credit guarantees
3. EU's strategic autonomy and technological sovereignty became critical	Value chain potential	Investment incentives Regulatory incentives
4. European policy frameworks created (EU Green Deal, Renovation wave)	Investment potential Innovation potential	Regulatory incentives

5. The sustainability, carbon neutrality, eco-design, foreign subsidies check principles emerged	Competitiveness potential Investment potential Innovation potential	Regulatory incentives
6. The cost of solar electricity dropped extensively	Competitiveness potential Investment potential	Long-term investment incentives such as credit guarantees
7. Industrial PV production in Europe starting to be cost-competitive	Competitiveness potential Investment potential Scaling-up potential	Long-term investment incentives such as credit guarantees
8. Competitive advantage of European PV integrated systems emerged	Competitiveness potential Investment potential Innovation potential	Regulatory incentives
9. Europe's leading positions in PV technology innovation – industrial manufacturing base necessary	Competitiveness potential Investment potential Innovation potential	Investment incentives Regulatory incentives
10. PV deployment more attractive due to growing demand for green hydrogen and decreased costs of battery storage systems	Competitiveness potential Investment potential Innovation potential Scaling-up potential	Investment incentives such as credit guarantees

II. GLOBAL PV MARKET AND EUROPEAN PV MANUFACTURING IN 2022 AND 2010-2012 IN COMPARISON – WHAT IS DIFFERENT?

Comparing with 2010-2012 and today, we are in a completely different situation along the full value chain, from polysilicon and wafers to cells, modules, systems and finally integrated PV solutions while the global and European markets are under constant accelerating positive changes:

1. The global market has expanded dramatically, and there is a better global and European balance between production and demand of PV modules.

In 2010-2012, the annual Global PV market was 16.5 GW, 31.7 GW and 28.8 GW, respectively. For the same years the module manufacturing capacity was, 106%, 67% and 94% higher. This module overproduction capacity was a key issue in 2010-2014 and led to an unhealthy price pressure on a global scale.

In 2022, the global PV market currently absorbs about 140-160 GW per year, and the effective global module production is about 180-200 GW, so the overproduction of modules is less of a problem in the current rapidly growing global market.

In the EU countries, the total installed capacity of 165 GW at the end of 2021 need to reach 660 GW until 2030 if EU should be able to reach its 40% renewables target and climate goals.

2. The European market is now expanding on a much more solid basis.

In 2010-2012, Europe had a market at the same level as now and installed the record value of 23,2 GW in 2011. However, the market was back then heavily dependent on generous feed-in-tariff subsidies in a few countries such as Germany, Italy and Spain. When these subsides decreased, or even were cut and retroactively changed (like in Czech Republic, Spain and Italy) the market decreased substantially and shrunk to about 10 GW/annum. The shaky European PV deployment market was not a good environment for an emerging PV manufacturing industry.

In 2020, 20.6 GW of PV capacity was installed in Europe and in 2021 the PV installations grew to 26 GW. Forecasts show that in the EU the PV annual installations could double in 2-3 years — according to a High scenario reaching 40-45 GW annual installations in 2023-2024. Today, the prices for modules and ultimately turnkey PV installations has decreased to such a level that no or very little governmental support is needed to reach profitability. The dramatic decrease of European PV installations, as in 2013-2018, cannot be expected to happen again in the future, as the sustainable policy frameworks, growing electricity prices, the increased competitiveness of PV power, and the growing awareness of the dangers of irreversible changes in the global climate system are driving the deployment. A PV market that is no longer dependent on subsidies or confined to the budget of specific countries are a much more robust market for the PV manufacturing industry.

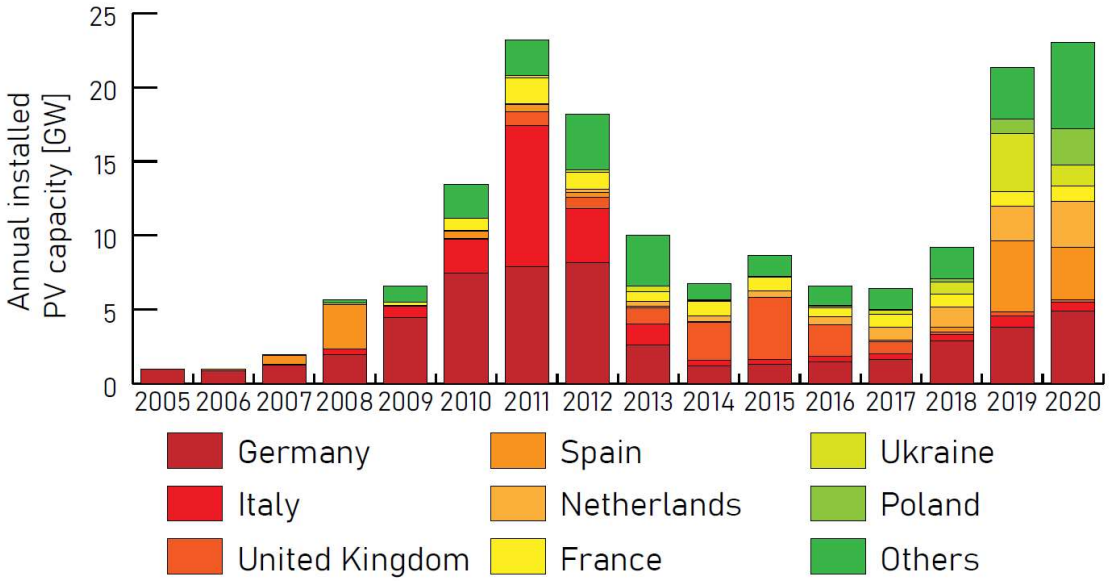


Figure 1. Evolution of annual PV Installations in Europe (Source: IEA PVPS).

3. The EU's strategic autonomy and technological sovereignty.

In 2010-2012, electricity from PV grew from 0.3% of the total electricity consumption in 2010 to 1.8% to 2012, according to the IEA. At the beginning of the decade, PV was thus a promising technology, but not of strategic importance for the European energy system and balance.

In 2020, PV electricity contributed to about 6% of the European Union's electricity demand and is therefore now one of the key components in the electricity mix. With the proposed EU 40% renewable energy target by 2030, may be even 55% as currently discussed, PV needs to stand for about 30-40% of the electricity production.

COVID-19 have clearly demonstrated dramatically the problems that follow after losing important value chains for important and strategic products and services. As PV are about to become a major cornerstone in the European electricity mix, PV manufacturing becomes an important issue of EU´s strategic autonomy.

The first steps of the acknowledgement of the need for the strategic autonomy and technological sovereignty has been done in May 2021 in the updated EU New Industrial Strategy and accompanying documents, by recognising that building a sizeable EU PV manufacturing industry would also reduce the supply disruptions and quality risks.

4. **European policy frameworks for the long-term development of renewables created.** European Green Deal and Renovation Wave built confidence and trust for investors and developers that the European PV market will experience further rapid growth during and after this decade.

5. **The sustainability, carbon neutrality and eco-design principles, together with concrete criteria under consideration have emerged, including the recently announced measures to address distortions in the EU market by foreign subsidies.** These principles became the driving force of the EU transformation towards green and innovative energy systems and economies. The increasing concern of all customers on the CO_2 footprint will have structural consequences for the PV manufacturing industry. PV modules produced in Europe using power and resources with favourable CO_2 balance and avoiding long-distance transport can show much better eco-design parameters than current Asian products, and this aspect will increase in importance in the coming years.

6. **The cost of solar electricity dropped extensively – solar electricity becoming the lowest-cost electricity.** The cost of PV systems readily installed has fallen well below € 1/Watt – depending on size prices down to € 0.6-0.8/Watt, resulting in levelized cost of electricity (LCOE) of PV electricity in sun-rich areas (more than 2000 hrs of sunshine per year) below 2 ct/kWh. The cost of solar electricity is rapidly approaching 1 ct/kWh, the lowest-cost electricity to be generated on earth! Consequently, the low-cost PV is attractive worldwide for decentralized green power production.

7. **Industrial PV production in Europe starting to be cost-competitive.** Recently, the price difference between European and Asian products has diminished due to the production and transportation costs and the significant increase of delivery time for the Asian products. European PV manufacturing could be price competitive on two conditions – GW-scale PV manufacturing capacities and complete manufacturing value-chains in Europe. EU needs to keep complete value chains at least for part of our needs available without imports, notwithstanding the fact that imports will of course remain an important factor.

8. **Potential competitive advantage for European PV manufacturing emerged due to new ways to deploy PV in integrated systems.** A great variety of innovative solutions are being developed and growing rapidly in various sectors, including the Building Integrated PV (BIPV), Vehicle Integrated PV (VIPV), Floating PV (FPV) and Agricultural PV (APV). European PV manufacturing companies could benefit from the specific European and local requirements as the integrated systems are more demanding for the individual customized solutions.

9. **Europe still has leading positions in PV technology innovation, but this can only remain so if an industrial manufacturing base will exist.** The traditional Aluminium back surface technology of solar cells (Al-BSF) with 18-22% energy conversion efficiency is currently being replaced by passivated emitter and rear contact (PERC) technology and its variants, which allows to achieve higher efficiencies of 20-24%, with only a moderate cost improving the production lines. The next step to third-generation high-efficiency PV cells will allow even higher efficiencies of 23-26%, based on heterojunction, HJT, or TOPCON technologies. These can be produced today at similar cost to PERC cells, in the 20-30 ct/W_p price range, resulting in competitive or even lower LCOEs of solar electricity due to the higher efficiencies of the more costly premium modules. There are further technology improvements possible down the road, from Perovskite-Si tandem cells with more than 30% efficiency. These technology advancements are still spearheaded in Europe, paving the way for worldwide deployment of Terawatt-scale PV.

10. **PV deployment becoming more attractive due to growing demand for green hydrogen and decreased costs of battery storage systems.** Green hydrogen is needed not only for large scale short-term as well as inter-seasonal energy storage, and for transportation, but in huge quantities as well for the decarbonization of steel, concrete and chemical production. Therefore green, CO_2-free power is not only needed to replace fossil fuels, but in increasing amounts to produce green hydrogen by electrolysis. The existing gas infrastructure could be used as transport and storage facility. The cost of battery storage systems has as well decreased impressively, and is now falling below $ 200/ kWh, soon it will be $ 100/kWh and below, allowing to compensate the fluctuating nature of harvesting solar electricity. In addition, a rapidly growing market of second-life batteries from the emerging e-mobility sector will generate a continuous availability of low-cost batteries for stationary storage, where decreasing battery capacity can be easily compensated by adding battery systems.

III. FROM LESSONS-LEARNED TO NEW OPPORTUNITIES FOR THE EU

In 2022 **we are reaching a decisive crossroad** – in a world of rapidly increasing solar energy harvesting through photovoltaics we risk continuing the dependence on imports of a key component of the value chain and abandoning participation in this booming market. Or we can make sure to re-establish PV production along the full value chain, including **PV cell and module technology, in Europe, and put in place the policy instruments to make this happen**. Competing in existing technology would be difficult, however the onset of **production-ready third-generation high-efficiency crystalline-Si based technologies,** such as **HJT and TOPCON**, will allow us to produce in a pioneering and cost-competitive way right here in Europe, and serving our substantial European market.

For the European PV manufacturing industry, 2012-2014 was a period of great risk and ultimately demise due to worldwide production overcapacity and precipitated price erosion together with legislative insufficiency. In contrast, 2022-2023 is a period of opportunity to create new businesses and at the same time respond to the societal need of independence in low-carbon renewable energy sources. High-end PV technologies of European invention can now be produced in a cost-competitive way at GW-scale, serving a market that is set to further grow to unprecedented volumes in the years ahead. Strategic benefits include the creation of large-scale industrial employment and the preservation of EU autonomy and technology leadership in this major clean energy of the future. Solar PV is the most important basis of an entire new future-orientated energy system – by 2040 it is expected that around 60% of the global energy need will be provided by Solar PV for distributed energy system, like IRENA demands during it's 2020 Long-term Energy Scenario (LTES) gathering.

The rationale for the current window of opportunity lies in the fact that existing **large scale GW factories in Asia cannot be simply upgraded, especially to HJT.** Instead, entirely new factory systems will need to be built, which not only resets the competitive clock for the European industry, but effectively gives it a **head start as existing GW factories** must be amortised before major new investments can be made. This **window may only be 2 or 3 years**, such that time is of the essence. During this period, Europe can build a lasting competitive advantage through a bold scale-up, that will ensure lasting competitiveness in both scale and technology.

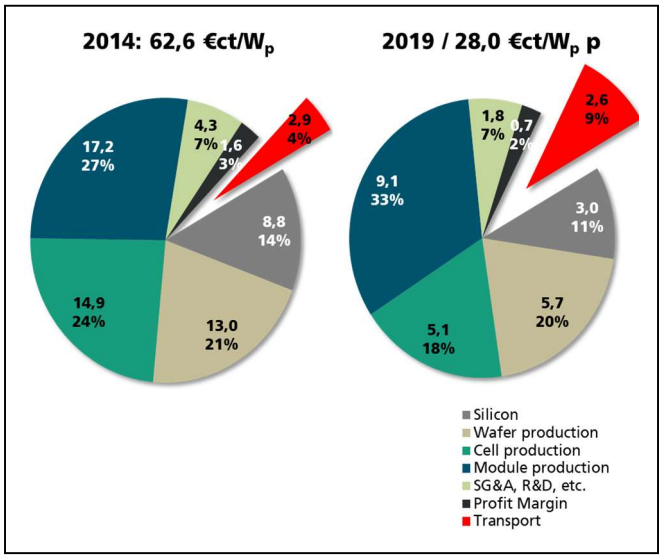
The economics of solar manufacturing are changing radically. The current environment represents a unique opportunity, which can only be fully monetised by a **fast and integrated response from the European solar supply chain, backed by effective policy initiatives**. If we

get it right, we will build a **strong and competitive industry serving this huge and emerging solar PV market.**

Along with the already experienced changes, three decisive factors still will be changing positively, impacting the competitiveness of European PV manufacturing. Accordingly, the policy, regulatory and financial measures should be dedicated for Europe to further enhance its competitive advantage.

1. **Transport costs**

PV technology has become cheap! Module production cost for highest-efficiency modules are today around 25 €cents/Wp. In 2014 it was above 60 €cents/Wp.

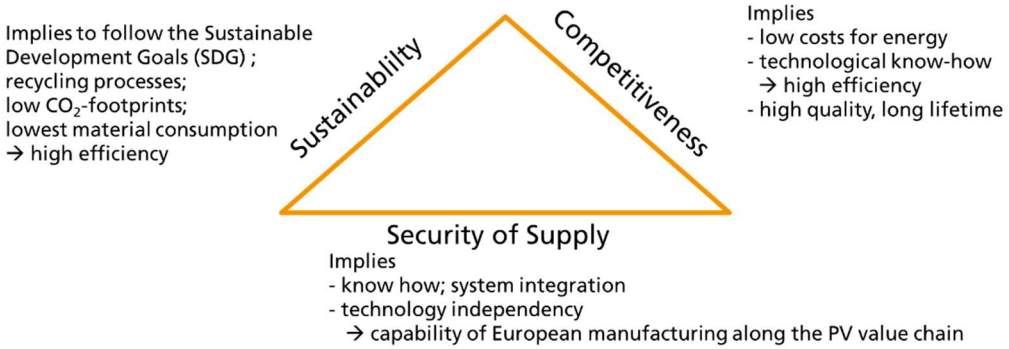


Lesson learned: the amount of logistic costs increases and becomes around 10 % of total module production costs!

- Local production along the whole value chain leads to 10%-plus margins;
- This favors European production for European demands.

2. **Security of Supply and Technology Sovereignty**

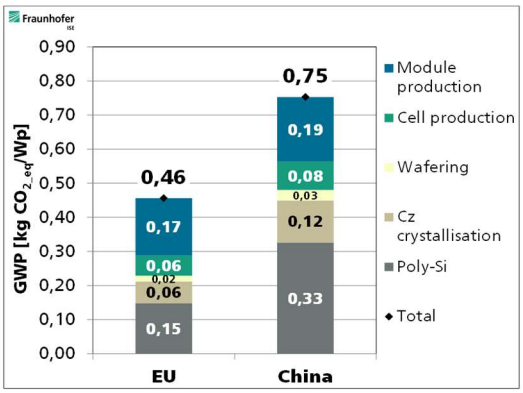
The COVID-19 showed that global dependency in a strategically important field is dangerous. The energy supply is certainly of strategic interest. If Asian countries control the PV market they control eventually the speed of the transformation process and the energy prices in Europe, which might negatively impact the economy.



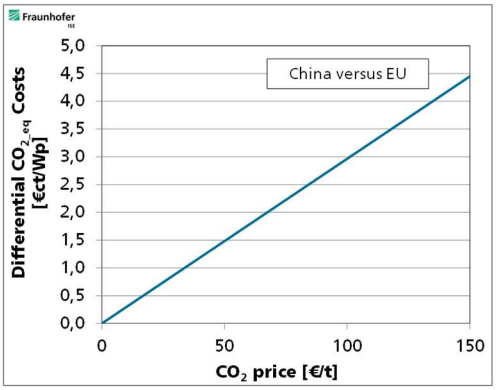
Lesson learned: security of supply, sustainability and competitiveness are guaranteed if the whole value chain for PV manufacturing is available in Europe.

3. **New Green Deal – lowest CO_2 footprint**

The ultimate goal is reducing CO_2 emissions as rapidly as possible. Since the PV market will grow rapidly, it is of importance that a cradle-to-cradle analysis is performed. High-tech production technologies in combination with highest PV efficiencies provide the lowest CO_2 footprint. If CO_2 prices will be introduced, European PV production will be favored! Moreover, sustainable, and high-tech employment are available.



Carbon footprint of a Cz PERC glass-backsheet module production*



CO_2 cost difference of a Cz PERC module production located in the EU compared to CN.

Lesson learned: highest CO_2 reduction is possible if European PV manufacturing is implemented. Green border taxes will lower the cost of local PV production compared to China.

PV manufacturing in Europe provides:

- Highest performance – technology know how and low-cost products
- Employment and prosperity
- Independency in the strategic field of energy supply
- Highest sustainability

IV. HISTORIC OVERVIEW

The extraordinary **PV revolution of 2008/2014** was a combined success story of Germany/Europe with China: The renewable energy law from April 2020 in Germany made the project to install PV systems bankable via the guaranteed feed-in rates for PV electricity. At this time there had been no cap on the volume to be installed. The numbers allowed RoR (rates of return, profits) of 5-15 %, guaranteed for 20 years. In this attractive market for PV installations, about 40 GW were actually installed by 2015, for an investment of more than € 60bn.

In China, starting with the 11th Five-years plan, the Chinese government declared **PV a technology of key strategic importance for China**, and provided cheap money via very important credit guarantees for a total of ca. $ 50bn for entrepreneurs proposing to establish PV manufacturing in China. A key feature was that the different regions of China acted in competition as to where the largest PV manufacturing capacity could be established, and this competition was widely unregulated.

A considerable share of this **$ 50bn was actually spent in Germany** and the EU to purchase the needed production equipment. This inflow of investment money helped to soften the catastrophic economic crisis 2008/9 after the Lehmann Brothers crash. By 2012, the world market had climbed to annual sales of 30 GW, but the global production capacity, at that time not only in China, was 60GW, double of what the world market could absorb.

Therefore, **prices dropped below production costs**, and below the long-term price experience curve. This 'PV Learning Curve' showed – since the 1980s! - a 20% decline of module prices for each doubling of the globally installed capacity. In 2012-14 all PV companies worldwide struggled to stay profitable in this cut-throat market situation, and only companies with sufficient capitalization and access to additional investment money could survive.

This was not the case for **the two large European (German) manufacturers Solarworld and Q-cells, they disappeared** (Solarworld) or were taken over (Q-cells, now Hanwha Q-cells). In the case of Q-cells, a key factor for their demise was that management in the early years, 2005-2008, did not really believe in the future of crystalline Si PV, and in a time of great profits invested large sums in at least 6 daughter companies, that pursued production of different thin film PV technologies. These failing companies had to be sold in 2012-2014 at great loss. This used up not only Q-cell capital, but created also large debts for the company, which ultimately lead to the insolvency.

In addition, a very serious attempt of an existing large and profitable company, Bosch, was ill-timed and ill-managed: **Bosch spent a total of about €2,7 bn**, first to buy 2008 a small start-up, ErSol, at a much too high price of about € 1bn, and then started to build up capacity just at a time of global overcapacity. Fundamentally, Bosch had the right approach, to go for cost-saving GW-scale production, but it was based on conventional me-too technology (Al-BSF), and ill timed. After a change of leadership, in 2013 the new Bosch CEO no longer wanted to support a money-losing business and pulled the plug on Bosch Solar.

Besides these specific economic reasons for a decline of European Solar Industry, some personal mismanagement decisions (Solarworld) have been as well noticed.

Overall we need to understand that the General legal setup for the different Feed-In-Tariff Systems had been dramatically deteriorated compared to clear and easy to understandable and usable system initiated be the fathers of the German Renewable Energy Act (EEG - Erneuerbare Energien Gesetz): late Hermann Scheer (SPD - social democratic party -died in

2010) and Hans-Josef Fell from the German green party. The main changes with a negative impact of German PV Industry have been Initiated by Chancellor Merkel, who took office in late 2005. Influenced heavily by "old school industry" she abandoned the Nuclear Exit agreement, that the "red-green government" under Chancellor Schröder had signed In June 2000 and started to "improve" the EEG while making it more complicated, such as a cap of 52 GW for PV installations in Germany, that put in danger some € 1Bn in Solar PV investments.

Other EU Member states tried to copy and paste the Idea of the EEG but failed because of legislative insufficient measures and lack of understanding or defaults integrated on purpose.

In France a highly insufficient law with absurd feed-In-tariffs under prime minister de Villepin lead to make France for a short time to the new “Eldorado” of Solar in Europe. The Sarkozy Government stopped this with a completely uncoordinated way of reducing the Feed-in System around 2012 with several legal changes in a very short lapsus of time.

In Spain, the other “Eldorado” of Solar in Europe, similar legislative insufficiency with very high feed-in Tariffs brought the Spanish state and its bad economic situation on the brink of bankruptcy. As a result, the FIT-system was stopped, leading to the immediate decline of Spanish Solar industry with effects on the trust of Investors that continue to have effects.

Looking forward, one can state that PV needs reliable, stable boundary conditions to flourish, based on the cost-advantage of PV electricity plus storage. PV manufacturing in Europe must be re-ignited along the full value chain, and for this process the currently most interesting starting point will be to declare PV manufacturing as an ‘Important Project of Common European Interest ‘(IPCEI). This process is just underway as this report is finished in February 2022.