

## SUMMARY

The urgency of the clean energy transition has never been greater, as highlighted by the 2022 IPCC Assessment Report and recent geopolitical developments. These events prompted the European Union to launch the REPowerEU initiative and the EU Solar Energy Strategy, both aimed at achieving a reduction in net emissions by 55% by 2030 and installing an additional 500 GWp of photovoltaic (PV) capacity by the same year. Furthermore, the EU's Net-Zero Industry Act seeks to foster an environment conducive to scaling net-zero industries, with specific targets of achieving 30 GWp of PV manufacturing capacity by 2025 and ensuring that 40% of installed solar PV originates from European manufacturers by 2030.

Photovoltaics have emerged as the fastest-growing renewable energy source, underpinning the global shift towards clean energy. By the end of 2022, global PV capacity had surpassed 1 TWp, with projections indicating a leap to 1.5 TWp by 2023. Within the EU, the installed PV capacity reached 211 GWp in 2022, generating 196 TWh of electricity. Technological advancements have significantly improved PV module efficiency, which has risen from 9% in 1980 to 21.1% in 2022. Silicon-based technologies remain dominant, boasting efficiencies exceeding 24%, while thin-film options, such as Copper Indium Gallium Selenide (CIGS) and Cadmium Telluride (CdTe), are poised to benefit from scaling effects. Emerging technologies, like perovskites and multi-junction silicon-based tandems, offer promising efficiency gains, with potential records of up to 32.65% in specific configurations.

Cost reductions have been pivotal in driving PV adoption. Between 2010 and 2022, the global Levelised Cost of Electricity (LCoE) for utility-scale PV projects plummeted by 88%, from \$0.417/kWh to \$0.045/kWh. In the EU, further cost decreases are anticipated, with a projected 60% reduction by 2050 compared to 2020 levels. These trends are complemented by favorable regulatory frameworks, including feed-in tariffs and renewable energy targets, which have bolstered the competitiveness of PV technologies. However, despite these achievements, public R&D funding for PV in the EU has declined over the years, with a compound decrease of 8% between 2010 and 2019. Although the EU remains a leader in high-value patents, it lags in overall patent numbers and publications compared to China.

From an environmental perspective, PV technologies are becoming increasingly sustainable. The Energy Payback Time (EPBT) of PV systems has seen a 12.8% reduction over 24 years, with systems in Southern Europe achieving an EPBT of just one year. Nonetheless, further improvements are needed to enhance circularity and reduce the environmental footprint of PV manufacturing and deployment.

The global market dynamics present both opportunities and challenges for the EU. While the EU's PV manufacturing value has shown modest growth—rising from €1.47 billion in 2020 to €2.54 billion in 2022—China dominates the industry, producing 84% of the world's PV cells and 78% of PV modules. The cost of manufacturing PV components in China is significantly lower than in Europe, with costs being 35% less in China compared to Europe. To address these disparities, the EU has announced plans to expand domestic manufacturing across the entire PV value chain. However, supply chain risks, particularly the reliance on China for critical materials like PV glass and silver, remain a pressing concern. Efforts to substitute silver with copper and other materials are underway, aiming to mitigate these vulnerabilities.

Employment in the PV sector is another area of rapid growth. Between 2020 and 2022, PV-related jobs in the EU increased by 35%, primarily in deployment activities. Looking ahead to 2027, employment is expected to rise significantly across various segments, including manufacturing, deployment, operation and maintenance, and recycling. However, workforce preparation, including skilling and re-skilling, will be crucial to meet these demands.

The competitiveness of the European PV industry can be understood through a SWOT analysis. The EU's strengths lie in its leadership in polysilicon technology, automated manufacturing processes, and low-carbon PV modules. However, challenges such as high energy and labor costs, lengthy planning procedures, and a negative trade balance with China hinder its progress. Opportunities include leveraging world-class R&D clusters and creating green jobs through large-scale, integrated manufacturing facilities. Threats, on the other hand, stem from the economic availability of critical raw materials and intensified competition from countries like the US and India, which have introduced targeted support schemes for PV manufacturing.

In conclusion, photovoltaics represent a cornerstone of the EU's clean energy ambitions, offering a pathway to achieving the European Green Deal targets. While significant progress has been made, the EU must address its weaknesses and capitalize on emerging opportunities to enhance its global competitiveness. By fostering innovation, scaling domestic manufacturing, and ensuring supply chain resilience, Europe can position itself as a leader in the global PV market while advancing its sustainability goals.

## PAG 9-15

The document provides a comprehensive overview of the status and trends in photovoltaic (PV) technology, offering a detailed analysis of its rapid growth, technological advancements, and innovative applications, while also addressing the challenges and opportunities in the field. It emphasizes the significant role PV plays in the global clean energy transition and the increasing importance of innovative deployment methods to meet ambitious energy targets.

### **Global Growth and Investment in PV Technology**

The global photovoltaic industry has seen a compound annual growth rate (CAGR) of 26% in installations from 2012 to 2022. Investments in PV reached USD 301.5 billion in 2022, accounting for 60% of total renewable energy investments and representing a 47% increase over the previous year. Newly installed PV capacity in 2022 amounted to over 230 GWp, with projections for 2023 exceeding 300 GWp. By the end of 2022, cumulative global PV capacity reached 1,185 GWp, led by China (400 GWp), followed by the European Union (211 GWp) and the United States (142 GWp). The EU remains a leader in per capita PV installation, with an average of 475 Wp/capita, though countries like Australia and the Netherlands surpass it with even higher capacities.

This remarkable growth has been driven by significant cost reductions in PV modules and systems. The price of PV modules has decreased by 25% for every doubling of cumulative production over the last four decades. For instance, in Germany, the cost of a typical PV rooftop system in 2020 was only 7.4% of its cost in 1990, representing a price regression of 92% over 30 years.

### **Advances in PV Module Technologies**

#### **Crystalline Silicon**

Crystalline silicon dominates the market, accounting for 95% of global PV module production, with monocrystalline silicon (mono c-Si) modules now representing nearly the entire market share. Over the last decade, average commercial module efficiency has increased from 15% to over 20%. Notable advancements include:

- Mono c-Si modules with record efficiencies of 24.7% for modules and 26.1% for cells.

- Emerging silicon heterojunction (HJT) technology achieving a record cell efficiency of 26.8%.
- Projections for technologies like Tunnel Oxide Passivated Contact (TOPCon) suggest module efficiencies of 24% by 2033.

These advancements align with the EU's Strategic Research and Innovation Agenda (SRIA), which prioritizes enhancing efficiency, sustainability, and scalability while reducing the levelized cost of electricity (LCoE).

### **Thin-Film Technologies**

Thin-film PV, though only comprising 5% of global production, offers significant potential:

- Cadmium Telluride (CdTe) modules have reached efficiencies of 19.5%.
- Copper Indium Gallium Selenide (CIGS) modules stand at 19.2% efficiency.

However, these technologies face challenges related to the supply of critical materials like indium and tellurium. Scaling production while addressing these supply chain constraints is essential for competing with crystalline silicon modules.

### **Perovskite Technologies**

Perovskites are a rapidly advancing thin-film technology. Since their discovery in 2009, cell efficiencies have improved from 3.8% to 24.35%. The EU leads in perovskite research, with companies like Evolar and Saule Technologies pioneering semi-transparent and flexible modules. Projections indicate that perovskites could match the cost and efficiency of existing commercial technologies within five years, making them a low-cost, high-efficiency option for diverse applications, including building and vehicle integration.

### **Multi-Junction Technologies**

Multi-junction PV, incorporating multiple p-n junctions, achieves the highest efficiencies among all PV technologies. Silicon-based tandem cells with III-V materials have reached efficiencies of 38.8% for cells and 32.65% for modules. By 2030, these technologies are expected to transition from niche to mainstream markets, with anticipated significant market shares by 2026.

### **Innovative Deployment Applications**

To meet the EU's target of over 500 GWp additional PV capacity by 2030, innovative deployment methods are being prioritized:

- **Agrivoltaics:** Combining solar power generation with agriculture could utilize 1% of agricultural land in the EU to produce 944 GWp of capacity, covering 40% of the EU's 2022 electricity consumption.
- **Building-Integrated PV (BIPV):** Replacing conventional building materials with PV modules offers dual functionality. By 2030, BIPV could enable buildings to meet their electricity needs.
- **Floating PV:** Deploying PV modules on water surfaces benefits from cooling effects and reduced land competition. Current capacity in Europe is 0.5 GWp, with global installations at 2 GWp.
- **Infrastructure-Integrated PV:** Incorporating PV into roads, barriers, and landfills could provide up to 401 GWp of capacity in the EU, contributing 11-16% of the region's electricity needs.
- **Vehicle-Integrated PV:** Embedding PV into vehicles can extend electric vehicle range and support auxiliary power needs. However, challenges like shading and safety regulations must be addressed.

## Challenges and Opportunities

### Sustainability and Reliability

Ensuring the reliability and lifetime of emerging technologies like perovskites requires updated testing standards. Research is focused on reducing environmental impacts and integrating circularity into the PV lifecycle.

### Market Dynamics

The EU faces stiff competition from countries like China, which dominates global PV production with significantly lower costs. As of 2022, China produced 33% of global PV electricity, a sharp increase from 1% in 2012. Meanwhile, the EU's share declined from 69% to 15% over the same period.

### Future Directions

To remain competitive, the EU must invest in scaling innovative applications, enhancing research, and addressing regulatory barriers. Integrating low-carbon and sustainable practices into manufacturing will be key to achieving the European Green Deal goals.

## Conclusion

The rapid growth of photovoltaic technology is transforming global energy systems. The EU, while facing challenges from global competitors, has an opportunity to lead through innovation in perovskites, multi-junction technologies, and novel deployment strategies like agrivoltaics and BIPV. By addressing supply chain vulnerabilities and investing in sustainable manufacturing, Europe can position itself as a leader in the clean energy revolution, aligning technological advancements with its climate goals.