

Photovoltaic Growth Towards the Terawatt Era: Exponential Scaling, bottlenecks, and the Role of AI and Robotics

David Moser*

Becquerel Institute Italia, Via Kufstein 5, 38121 Trento, Italy

e-mail: d.moser@becquerelinstitute.eu

The photovoltaic (PV) industry stands at an inflection point, with global installed capacity exceeding 2 TW and annual deployment rates accelerating beyond 500 GW. This exponential growth trajectory, if sustained, positions solar energy to become the dominant source of electricity generation within the next two decades. However, maintaining this growth rate presents unprecedented challenges across the entire value chain, from polysilicon production and wafer manufacturing to module assembly, installation, and grid integration.

This presentation examines the critical bottlenecks that could constrain the PV industry's path to multi-terawatt scale. Key limitations include: supply chain constraints for critical materials; manufacturing capacity expansion rates; a skilled workforce shortage across R&D, manufacturing, and installation sectors; and grid infrastructure that must evolve to accommodate variable renewable generation at unprecedented scales. Social acceptance and lack of social society involvement represent an additional constraint, as community opposition can significantly delay project timelines and limit suitable deployment areas. Each of these bottlenecks represents not only a technical challenge but also an opportunity for innovation and industrial transformation.

Artificial intelligence and robotics emerge as transformative technologies capable of addressing these constraints across multiple domains. In manufacturing, AI-driven process optimization and predictive quality control are reducing waste and improving cell efficiencies, while advanced robotics enable the automation of increasingly complex production steps required for next-generation technologies such as tandem cells and heterojunction architectures. Machine learning algorithms are accelerating materials discovery and device optimization, compressing development cycles from years to months.

Beyond manufacturing, AI and robotics are revolutionizing downstream activities. Computer vision and robot-based inspection systems enable rapid, accurate assessment of PV installations, while predictive maintenance algorithms optimize O&M strategies and extend system lifetimes. Robotic installation systems address labor constraints and improve installation quality, particularly for utility-scale projects. At the grid level, AI-powered forecasting and dispatch optimization facilitate the integration of variable solar generation into increasingly complex energy systems.

This analysis draws upon ongoing work to quantify the potential impact of AI and robotics adoption on PV deployment rates, system costs, and operational performance. The presentation concludes with strategic recommendations to accelerate the beneficial integration of these technologies throughout the PV value chain, ensuring that solar energy can fulfill its potential as a cornerstone of the global energy transition.