CLIMATE ENERGY FINANCE

International Solar PV and BESS Manufacturing Trends

Solar PV's disruption is happening at a speed beyond imagination, turbocharged by BESS firming

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Established in 2022, Climate Energy Finance (CEF) is an Australian based, philanthropically funded think tank. We work pro-bono in the public interest on mobilising capital at the scale needed to accelerate decarbonisation consistent with climate science. Our analyses focus on global financial issues related to the energy transition, and the implications for the Australian economy, with a key focus on the threats and opportunities for Australian investments and exports. Beyond Australia, CEF's geographic focus is the greater Asian region as the priority destination for Australian exports. CEF also examines convergence of technology trends in power, transport, mining and industry in accelerating decarbonisation. CEF is independent, non-partisan, and works with partners in the NGO, finance, business, research, and government sectors. **Contact:** tim@climateenergyfinance.org

We pay our respects to the Traditional Owners of the unceded lands on which we live and work.

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Executive Summary

As investment into variable renewable energy (VRE) continues to hit record highs each new year, solar photovoltaics (PV) continues to experience explosive growth, totally reshaping global energy markets. This disruption is driven by the scale of China's strategic investment into solar PV technology deployment and manufacturing, resulting in significant ongoing cost deflation globally. Solar PV is increasingly undermining the business case for fossil fuel extraction and consumption. A trend that will continue, particularly as carbon prices inevitably are applied to internalise the carbon emissions cost. Solar technology's adaptability across diverse environments and its synergetic deployment in conjunction with battery energy storage (BESS) is dramatically accelerating the transformative role of solar.

Over 2024, solar PV installations surged, with China leading the way. At the same time, emerging markets such as the Middle East and North Africa (MENA) accelerated their deployments to diversify their economies from fossil fuel exposure and decarbonise. Pakistan has experienced an exceptionally rapid expansion due to falling Chinese solar PV costs as consumers seek to access an alternative to volatile and costly grid electricity. These markets highlight the transformative potential and scale of solar PV. Simultaneously, BESS has more recently seen remarkable growth, being deployed faster, at a larger scale and longer duration than ever before. BESS Is unlocking more of solar PV's value and utility.

China is at the centre of these shifts and is the 'gift horse' in this transition, easily criticised but galloping away with extraordinary new industrial value. To stay competitive in this clean technology horse race, policymakers in other jurisdictions must not be distracted by incumbent fossil fuel industry delay tactics, including nuclear or gas generation diversions. Instead, they should focus on collaboration and partnerships with China to jointly deliver on the formidable challenge of solving the global trilemma of the climate crisis, energy security, and equitable access to energy, at speed and scale.

The International Energy Agency (IEA) continues to play a pivotal role in shaping global energy policy through its widely referenced, annually updated flagship reports, including the World Energy Outlook (WEO) and Energy Technology Investments (ETI). CEF notes the IEA consistently underestimates the pace of the global solar PV, BESS and electric vehicle (EV) disruption and the growth in manufacturing capacity. Analysing market trends, manufacturing expansions, and cost trajectories demonstrates the continuing disparity between the IEA's forecasts and actual speed of market developments.

Solar PV is now competitive with new thermal generation across an increasing number of markets globally due to significant reductions in capital expenditure, primarily driven by increasing module efficiencies and technological innovation. Future advancements could halve solar costs again over the coming decade, completely undercutting other generation technologies. In parallel, BESS is experiencing substantial ongoing price deflation, propelled by China's manufacturing scaling-up, commodity price deflation and rapid technology advancement, making hybrid solar-BESS cost competitive and deployable at speed and scale. Manufacturing overcapacity and continued innovation mean the long-term outlook for both technologies will continue to be deflationary.

Underpinning rapid solar PV disruption and price deflation is extraordinary technological acceleration, catalysed by R&D, manufacturing scale, cost reductions of technology, optimisation and large-scale hybrid projects.

CEF expects incremental solar cell efficiency gains to continue to feature over the coming decade as cell efficiencies expand from the current commercialised 25% levels towards 35% as and if long-term perovskite cell stability can be established and commercialised, potentially driving another step change in solar in the coming decade.

Accelerated BESS deployments are making solar competitive with fossil fuels, with hybrid systems are both enhancing project economics and better utilising existing grid capacity, deferring the need for yet more grid capacity. Meanwhile, EVs are emerging as mobile batteries on wheels, reinforcing the synergy between solar, storage, and transport electrification.

China's solar PV and BESS installations shattered all forecasts in 2024. In 2024, China accounted for half of all new solar PV installations and 70% of global BESS deployments. Ongoing policy support, infrastructure investment, and cost reductions propelled installations to record levels. While some forecasters assume a consolidation/pullback, CEF expects another record of installations in both in 2025. Policymakers must look beyond China's conservative targets and current continued thermal generation deployment, focusing instead on China's broader policy direction of progressive electrification of everything, energy security, expanding their global industry leadership and VRE deployment trends to grasp the challenge of catching up to China's almost unbelievable global lead.

Global solar PV and BESS manufacturing is in severe overcapacity, driving record-low prices through intensified competition. China's dominance in both sectors is now unassailable, with its scale, integration, and cost advantages forcing market consolidation and straining manufacturers in the US, and EU. While protectionist policies aim to counter China's lead, policy uncertainty and high costs are delaying Western manufacturing projects. Tariff barriers have provided some protection to domestic US and Indian manufacturers, but at a sustained cost to all energy consumers. Instead of focusing on tariffs, policymakers should hitch their wagons to the Chinese gift horse and explore strategic collaboration to support domestic production and reaching VRE targets.

China isn't just winning the race—it owns the racetrack. Controlling 80-95% of each supply chain, China is maintaining its manufacturing dominance through scale, vertical integration, continued investment, deployment of world-leading technology and strong policy support. Relentless investments saw the solar PV supply chain capacity expanding by 29% in 2024. Overcapacity and intensifying price competition are now driving sustained price deflation, putting pressure on margins. This will inevitably drive industry consolidation and the collapse of weaker competitors unable to weather the prolonged pricing downturn, both in China and globally. In response to growing trade barriers, Chinese companies are continuing to invest in RD&D and targeting new export markets. CEF sees no slowdown in China's solar manufacturing capacity expansion so far in 2025, implying the current record low module prices will, at best, stabilise.

With global manufacturing capacity at 2-3 times current global install rates, CEF does advocate for the global industry to immediately suspend all non-essential capacity expansions for several years.

China's cost advantages, supply chain control and clear government policy direction will sustain its global lead. Harsh as it is, policymakers in other countries will likely pivot towards collaboration with China to remain remotely relevant. Outright competition against the Chinese juggernaut will be ineffective, with Northvolt a stark abject lesson.

Through 2024, China's leading solar PV manufacturers were ramping up production, expanding capacity, and concurrently breaking solar PV efficiency records, underscored by Jinko Solar's massive 56GW per annum (pa) integrated facility in Shanxi and record 33.84% tandem perovskite cell efficiency. As overcapacity erodes margins, even major players are financially strained. Yet Chinese firms continue to operate and even expand in this hyper-competitive environment, driven by a long-term focus on complete market control only achieved by outlasting competitors. Only with significant tariff protection, or sustained policy support and/or joint venture (JV) partnerships can any global competitors remain viable.

China's outbound foreign direct investment (OFDI) in clean technology accelerated in 2024. Chinese companies are securing commanding positions in key regions like MENA and ASEAN through large-scale solar PV and BESS projects, joint ventures, and supply agreements, consequently completely transforming global energy markets at an unprecedented pace. While some nations attempt to counter this influence with tariffs and industrial policy, China's ability to leverage its technology leadership, supply chains, equity and scale, adapting and integrating into emerging markets gives it a powerful advantage.

China's rapid establishment of solar PV and battery manufacturing capacity in strategic locations across ASEAN and MENA from late 2024 signals a clear shift towards decentralising its technology supply chains. This new wave of investment highlights China's targeted strategy of selecting partner countries with favourable regulatory and policy environments and proximity to key markets. Policymakers in other jurisdictions should emulate these countries' approaches and actively engage with China. However, establishing robust governance frameworks that ensure economic benefits are maximised without compromising national sovereignty, democratic principles, safety, or long-term energy security is also vital.

After years of slow deployment, 2024 marked a turning point for India. A record 24.5GW of solar PV was installed, with cumulative deployments now a total of 100GW. India is now on track to meet its 2030 renewable energy target. While domestic solar PV module manufacturing is rapidly expanding, hitting 80GW at the end of 2024, the country remains heavily reliant on Chinese solar wafers and cells, even as its manufacturers are heavily exposed to the growing risk of US trade sanctions, particularly as Indian exports to the US surge. With the return of US protectionism under President Trump, India can reduce external dependencies by doubling down on driving domestic solar installation rates.

The US solar PV and BESS sectors experienced historic growth in 2024 with 49GW of solar PV and 11.9GW of BESS added. Meanwhile, solar PV module manufacturing has surged to 52GW from just 7GW two years earlier. This investment was fuelled by the Inflation Reduction Act (IRA). The US manufacturing 'Mustang' was unleashed to try to catch China. However, the new US administration's decision to freeze clean technology manufacturing funding and impose new tariffs on Chinese imports will likely drive cost inflation for energy consumers and cause capital flight, with firms like KORE Power already cancelling BESS factories. More hospitable jurisdictions are now poised to absorb diverted US investment. The US now risks cementing its trailing position in the energy transition way behind China.

The US will likely exit 2025 with 55-60GW pa of solar module manufacturing capacity (assuming ~10GW of manufacturing proposal cancellations), ironically with more than half of this built in the last 2 years by Chinese firms.

The European Union's (EU) solar PV sector and policymakers face a dilemma in 2025. Last year, the EU made significant progress on solar installations, surpassing the halfway mark toward the REPowerEU 2030 target of 600GW of cumulative solar PV installations. However, the EU's solar manufacturing base is being decimated by China's ongoing aggressive solar module price deflation. EU policymakers are adapting with the recent Clean Industrial Deal, which is expanding financial and regulatory support for EU clean technology manufacturers.

China is building a stable full of world-leading solar PV and BESS projects by pushing the limits of deployment in scale, speed and location. Projects like the 100GW Great Solar Wall in Inner Mongolia and the 4GW Ruoqiang Solar Project showcase its ability to deploy VRE at an unmatched scale and speed. China is also pioneering solar PV in diverse environments with the world's first 1GW open-sea plant in Shandong. Other projects like the 2GW Oasis de Atacama solar PV and 11GWh BESS project in Chile and the 30GW Khavda Renewable Energy Park in India are starting to replicate this ambition.

In the face of China's expanding technology and manufacturing dominance, the US has now entirely left the playing field. This leaves Australia in a challenging position. Australia must 'thread the needle' to safeguard its national interests in this new era of geopolitical upheaval. In 2024, Australia saw a surge of projects in the solar PV pipeline, with solar PV and BESS projects reducing coal generation usage to historic lows. State and federal policies—like the Capacity Investment Scheme (CIS) —are driving this growth. However, a federal Coalition opposition plan for a speculative, taxpayer-funded nuclear fleet risks injecting massive uncertainty aimed to delay and undermine VRE deployments, with inevitable increased energy costs for all consumers.

Australia must focus on proven solar PV and BESS hybrid systems that outperform traditional thermal and nuclear generation in both cost, capital risks and deployment speed. With low-cost energy from solar PV and BESS, Australia can power an expansion of value-added clean technology manufacturing and processing to replace the loss of royalties, corporate tax and employment from the progressive decline of fossil fuel exports. This will also diversify the solar PV supply chain to provide insurance against a global trade crisis. March 2025 saw Rio Tinto, Australia's largest energy user, give this strategy an enormous business endorsement.

Australia should collaborate and partner with China to achieve these aims. Initiatives such as the 'Solar Sunshot' program facilitated by ARENA and SunDrive's joint venture with China's Trina Solar, show that the country can lay the groundwork to start to rebuild a domestic clean technology manufacturing ecosystem. Australia can do this without compromising democratic values and principles with appropriate investment safeguards. Expanding on these initiatives with targeted industrial incentives, realistic local content policies, and further trade agreements is essential to securing Australia's future as a competitive, low-cost, clean energy exporter and innovator.

Key Findings

In CEF's assessment, the continuing deflation in solar PV prices, soaring manufacturing capacity, and a string of record-breaking deployments are setting off a global chain reaction that will dramatically reshape our energy landscape. As solar installations surge toward 1,000GW per year by 2030 and battery systems become ever more cost-competitive, hybrid systems are becoming competitive across global markets. As a result, fossil fuel generation, including fossil gas peaking plants, is quickly becoming obsolete. Moreover, advancements in vehicle-to-grid (V2G) technology are turning electric vehicles (EVs) into 'batteries on wheels'—a massive, untapped resource for firming power and enhancing grid reliability. The convergence of these trends is creating a perfect storm of technological and economic factors that will accelerate the decarbonisation of the global economy right at a critical juncture in the fight against climate change:

- Solar PV is being deployed globally at unprecedented rates, with annual installations hitting almost 600GW (100 times the rate of nuclear deployment). CEF projects installations will surge to a likely conservative 1,000GW pa by 2030. China will drive this expansion, with the country installing over 277GW in 2024 alone — more than 5 times the amount the US deployed.
- Global solar module supply chain manufacturing capacity has expanded enormously over 2024, and continues to grow in 2025, despite the 50% year-on-year (yoy) solar module price reductions seen last year. Global manufacturing capacity will exit 2025 at triple the 2024 solar install rates.
- Polysilicon prices dropped by almost 50% in China (falling to around ~US$5/kg) and 20% globally, which, in turn, has helped lower solar module prices by 37 to 46% yoy, underpinning a global PV disruption. The rapid reduction in component costs driven by oversupply and technological acceleration is expected to halve solar PV capex costs by 2030 to US$400/kW, effectively destroying the business case for coal and fossil gas generation.
- Continuous efficiency improvements in perovskite tandem solar cells (potentially moving from about 25% to 35% efficiency within a decade) will further reduce the cost per watt. Combined with the enormous potential of BESS (both utility-scale and in electric vehicles) to unlock solar PV value, allowing solar PV to dispatch approximately 95% of its power through a 65% smaller grid connection and discharge during nighttime peaks, hybrid systems will likely dominate global deployments by 2030.
- EVs are an underappreciated source of future storage capacity and economic value with up to 2,359GWh of capacity across the fleet by 2050 in Australia. A February 2024 study commissioned by ARENA found that an average EV in New South Wales could earn up to AU$12,000 pa by providing frequency control ancillary services (FCAS) to the grid. A recent report by enX found that with a fast uptake of V2G, there could be AU$2.7bn (US$1.57bn) in wholesale market benefits and AU$2.4bn (US$1.39bn) in distribution network savings by 2040.
- The average lithium-ion battery price has deflated 20% globally in 2024 and has continued in 2025, with major Chinese domestic contracts suggesting another >20% yoy price decline. In China, BESS capacity reached 78GW/184GWh in 2024, with

annual additions of roughly 43.7GW/109.8GWh, reflecting a yoy growth of 103%. A staggering 70% of the world's BESS was deployed in China in 2024. Whilst 93.6% of the total BESS installed globally originated from Chinese companies.

- Of the BESS installed in 2024, over 30% was co-deployed with solar PV, showing a significant trend towards hybridisation. 350GWh of BESS capacity is expected to be deployed in 2025, a more than fivefold expansion of BESS capacity since 2022. Over 1TWh of BESS is in the global project pipeline for 2025-2030.
- On the manufacturing side, global solar PV and BESS production is in severe overcapacity. Chinese manufacturers dominate the market by controlling 80-95% of both supply chains. For example, China's module production capacity stands at almost 1.2TW out of a global total of 1.5TW. Most future capacity is expected to be built in China, and despite likely industry consolidation of lower-tier manufacturers, Chinese companies have announced plans for 163GW of further manufacturing capacity across the supply chain, signalling no price recovery on the horizon and the continuing relentless erosion of the economics of fossil fuel generation.

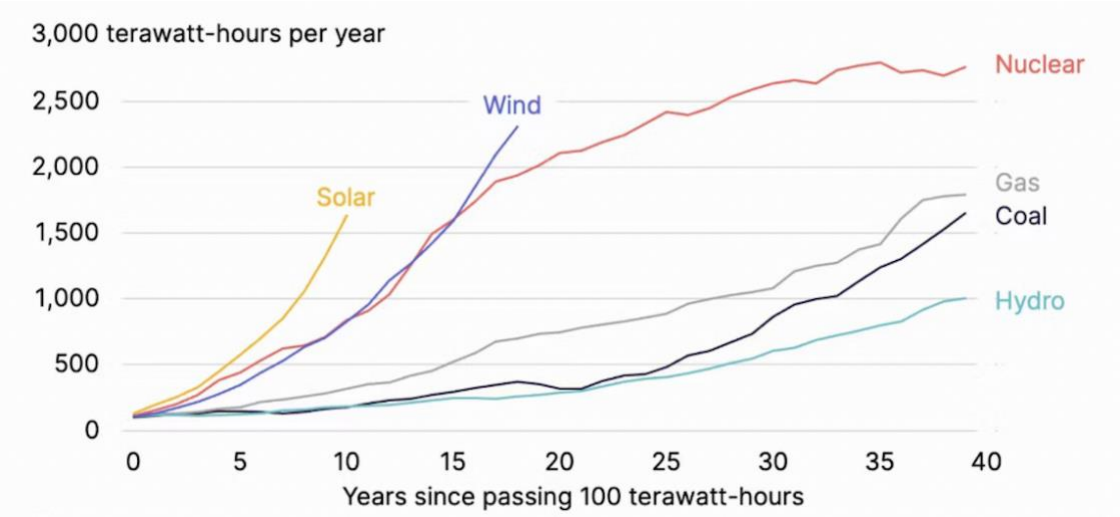
Section 1: The Global Solar PV Disruption

As investment into variable renewable energy (VRE) continues to hit record highs each new year, solar photovoltaics (PV) continues to experience explosive growth, totally reshaping global energy markets. This disruption is driven by the scale of China's strategic investment into solar PV technology deployment and manufacturing, resulting in significant ongoing cost deflation globally. Solar PV is increasingly undermining the business case for fossil fuel extraction and consumption. A trend that will continue, particularly as carbon prices inevitably are applied to internalise the carbon emissions cost. Solar technology's adaptability across diverse environments and its synergetic deployment in conjunction with battery energy storage (BESS) is dramatically accelerating the transformative role of solar.

2024 was a landmark year in the global energy transition, with annual clean technology investment reaching US$2.1 trillion for the first time—more than doubling since 2020.[1] China accounted for 40% of this total, reinforcing its position as the global trailblazer in clean technology development and deployments. Of that US$2.1 trillion, US$748bn was invested in VRE, primarily wind and solar PV. The world needs to see this annual investment double again to the US$4.5 trillion to reach a level the International Energy Agency (IEA) predicts is required to limit global warming to 1.5-2.0°C.[2] This growing investment is turbocharging an unprecedented global energy disruption by solar PV plus BESS.

Solar PV generation continues to grow at a speed of scaling up faster than any other energy generation technology in history — see Figure 1.1. After taking 68 years to install the first terawatt (TW) of solar PV capacity, the world added its second TW in just two years, from 2022 to 2024.[3] At this pace, global solar PV capacity expands tenfold each decade,[4] a trend that conventional forecasters continually underestimate — see section 1.3.

Figure 1.1: Annual Generation After Exceeding 100TWh pa

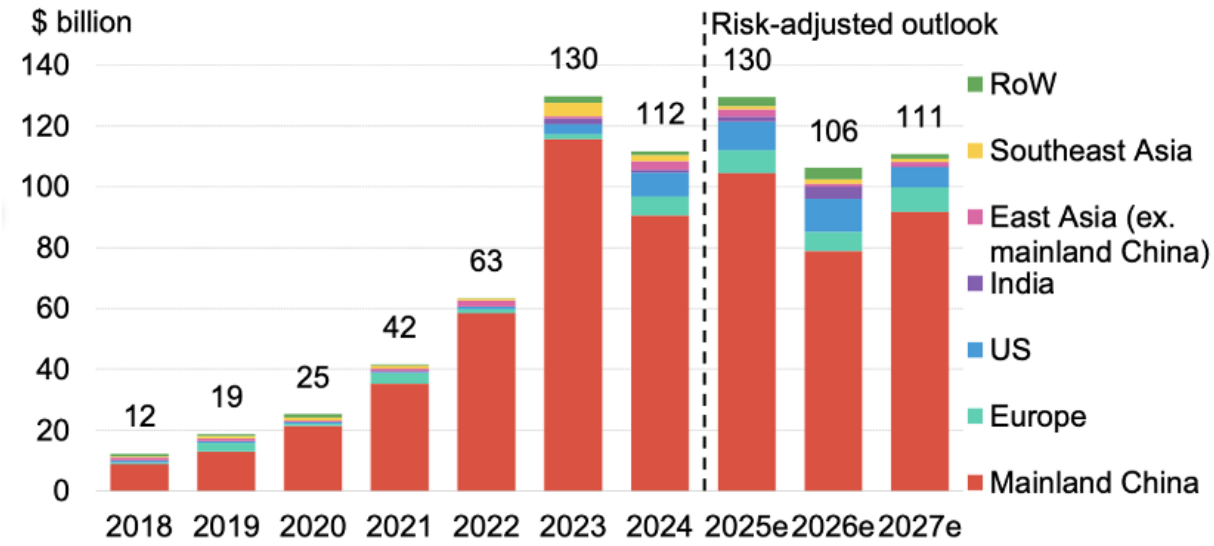


[1] BNEF, Energy Transition Investment Trends, 30 January 2025
[2] IEA, IEA: Clean energy investment must reach $4.5 trillion per year by 2030 to limit warming to 1.5°C, 28 September 2023
[3] Global Solar Council, GSC announces 2 terawatt milestone achieved for solar, 8 November 2024
[4] PV-Magazine, The fastest energy change in history continues, 13 January 2025

Source: Nat Bullard via Ember[5]

At the heart of this disruption is China's growing global clean technology, manufacturing and domestic deployment dominance. China controls 80-95% of solar PV and BESS supply chains. China's cleantech manufacturing investment continues to swamp any other jurisdiction—see Figure 1.2. This investment, supported by two decades of forward-thinking and sustained industrial policy, has driven manufacturing economies of scale, rapid technology advancements, speed of deployment and relentless cost deflation in both solar PV and BESS.

Figure 1.2: Global Clean-Tech Factory Investment by Region



Source: BNEF

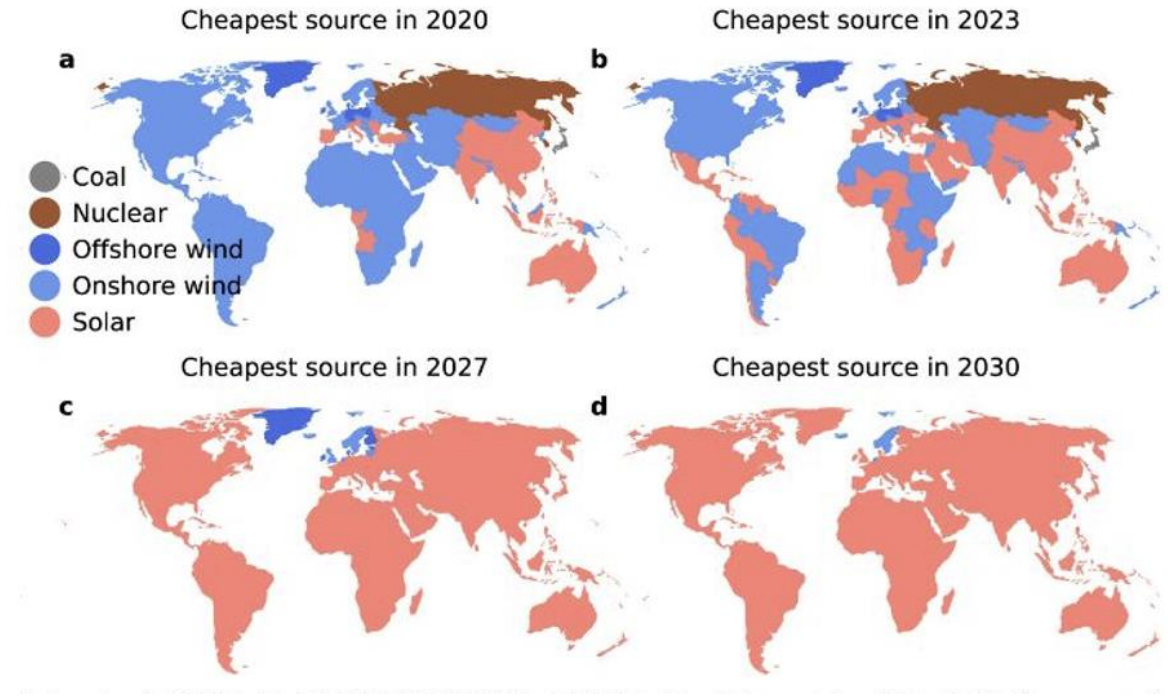
Since 2000, solar module prices have fallen from US$5.10/W[6] to a record low US$0.10/W in 2024, a 64-fold reduction. The world is now crossing price thresholds regularly thought impossible. Similarly, rapid price deflation is happening across battery technologies, with weighted-average lithium-ion battery costs decreasing from US$806/kWh in 2013 to US$115/kWh in 2024, a seven-fold reduction,[7] with significant further reductions seen already in 2025. The improving economics of longer duration batteries have allowed synergistic deployment with solar PV in hybrid systems. By enabling time-shifting of energy production from the daytime, when solar PV generates the most energy, to evening demand peaks, BESS further enhances the already formidable economic value of solar PV and its utilisation — see section 1.3.

The rapid cost decline in these synergistic technologies is making other forms of generation increasingly challenged economically. Solar PV has been competitive with new coal-fired power and fossil gas power plants in multiple markets since 2020, particularly with the significant and sustained fossil fuel cost rises of coal and LNG post Putin's invasion of Ukraine. By 2030, solar PV is expected to be the cheapest form of new generation worldwide — see Figure 1.3.

[5] Nat Bullard, Decarbonization: 2021, The Complex, Reagents, January 2025
[6] BNEF, Evolution of solar PV module cost by data source, 1970-2020, July 2020
[7] BNEF, Lithium-Ion Battery Pack Prices See Largest Drop Since 2017, Falling to $115/KWh, 10 December 2024

In 2025, solar PV and BESS hybrids have become competitive with coal generation in India and fossil gas generation in Germany. Wood Mackenzie now forecasts that solar PV with BESS will become cheaper than fossil gas plants across major growth regions like the Asia-Pacific.[8] This will likely mark another significant milestone, further accelerating the transition away from fossil fuel generation. CEF continues to advocate for an Asian carbon border adjustment mechanism (CBAM), to extend the EU CBAM, and provide the much needed explicit cost of carbon emissions industry and finance needs to mobilise at the speed and scale the climate science dictates.

Figure 1.3: Technology with the Lowest LCOE by Year and Region



Source: Njisse et al.[9]

Solar PV's continuous technological advancements have enhanced its versatility—enabling deployment in previously inhospitable environments such as tidal flats, mountains, deserts, dams, and oceans—and making its dominance in the energy transition inevitable. For instance, Jiangsu Province in China has outlined plans for 27GW of floating solar PV by 2030, showcasing the technology's potential.[10] With further technological acceleration, including co-deployment with BESS and continued investment in manufacturing capacity driving cost deflation, the total disruption caused by solar PV is likely to accelerate in 2025 and beyond.

[8] Wood Mackenzie, Asia Pacific Power & Renewables: Five things to watch in 2025, 23 January 2025
[9] Njisse et al., The momentum of the solar energy transition, 17 October 2023
[10] PV-Magazine, China's Jiangsu province launches 27.3 GW offshore solar plan, 2 January 2025

Section 1.1: Global Solar PV and BESS Installations

Over 2024, solar PV installations surged, with China leading the way. At the same time, emerging markets such as the Middle East and North Africa (MENA) accelerated their deployments to diversify their economies from fossil fuel exposure and decarbonise. Pakistan has experienced an exceptionally rapid expansion due to falling Chinese solar PV costs as consumers seek to access an alternative to volatile and costly grid electricity. These markets highlight the transformative potential and scale of solar PV. Simultaneously, BESS has more recently seen remarkable growth, being deployed faster, at a larger scale and longer duration than ever before. BESS Is unlocking more of solar PV's value and utility.

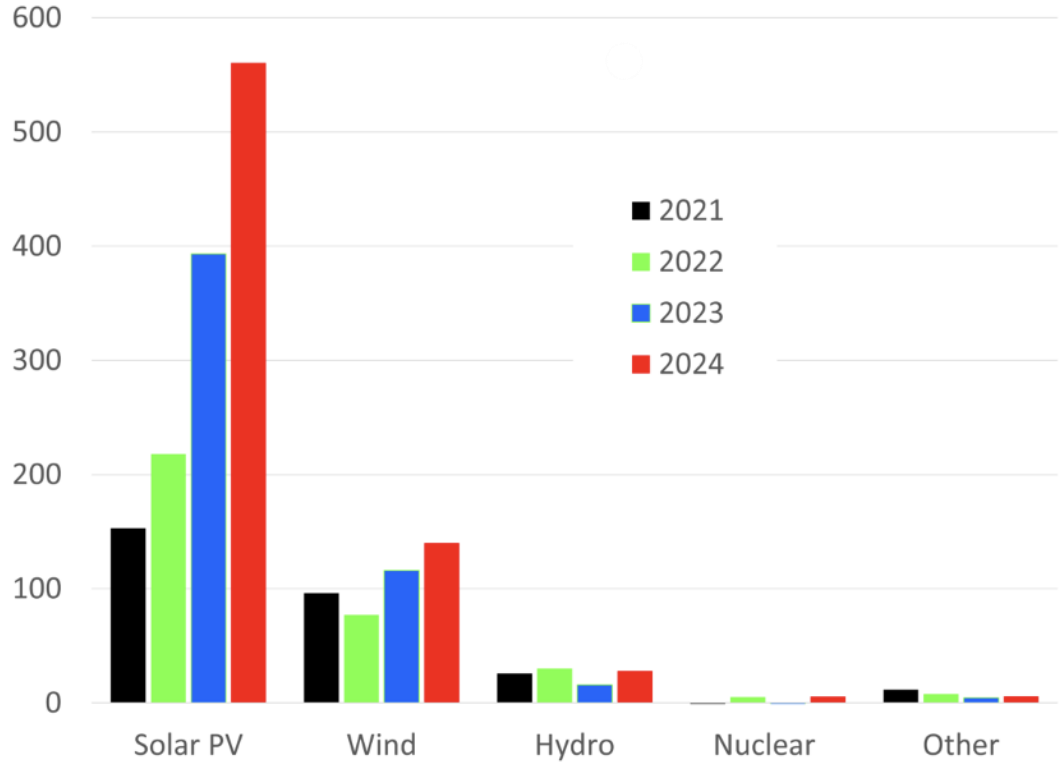
China is at the centre of these shifts and is the 'gift horse' in this transition, easily criticised but galloping away with extraordinary new industrial value. To stay competitive in this clean technology horse race, policymakers in other jurisdictions must not be distracted by incumbent fossil fuel industry delay tactics, including nuclear or gas generation diversions. Instead, they should focus on collaboration and partnerships with China to jointly deliver on the formidable challenge of solving the global trilemma of the climate crisis, energy security, and equitable access to energy, at speed and scale.

Solar PV Deployment is Defying All Expectations

In 2024, solar PV shattered deployment records worldwide. The equivalent of ~1.6GW of solar PV was installed every day in 2024, with a total of 593GW deployed for the year (+22% yoy) — Figure 1.11. To put this in context, this is 100 times the global deployment rate of nuclear energy.[11] The world has now installed over 2TW cumulative of solar PV.

[11] PV-Magazine, The fastest energy change in history continues, 13 January 2025

Figure 1.11: Net Global Non-Fossil Fuel Capacity Additions (GW)



Source: Prof. Ricardo Rüther (UFSC), Prof. Andrew Blakers (ANU), PV-Magazine

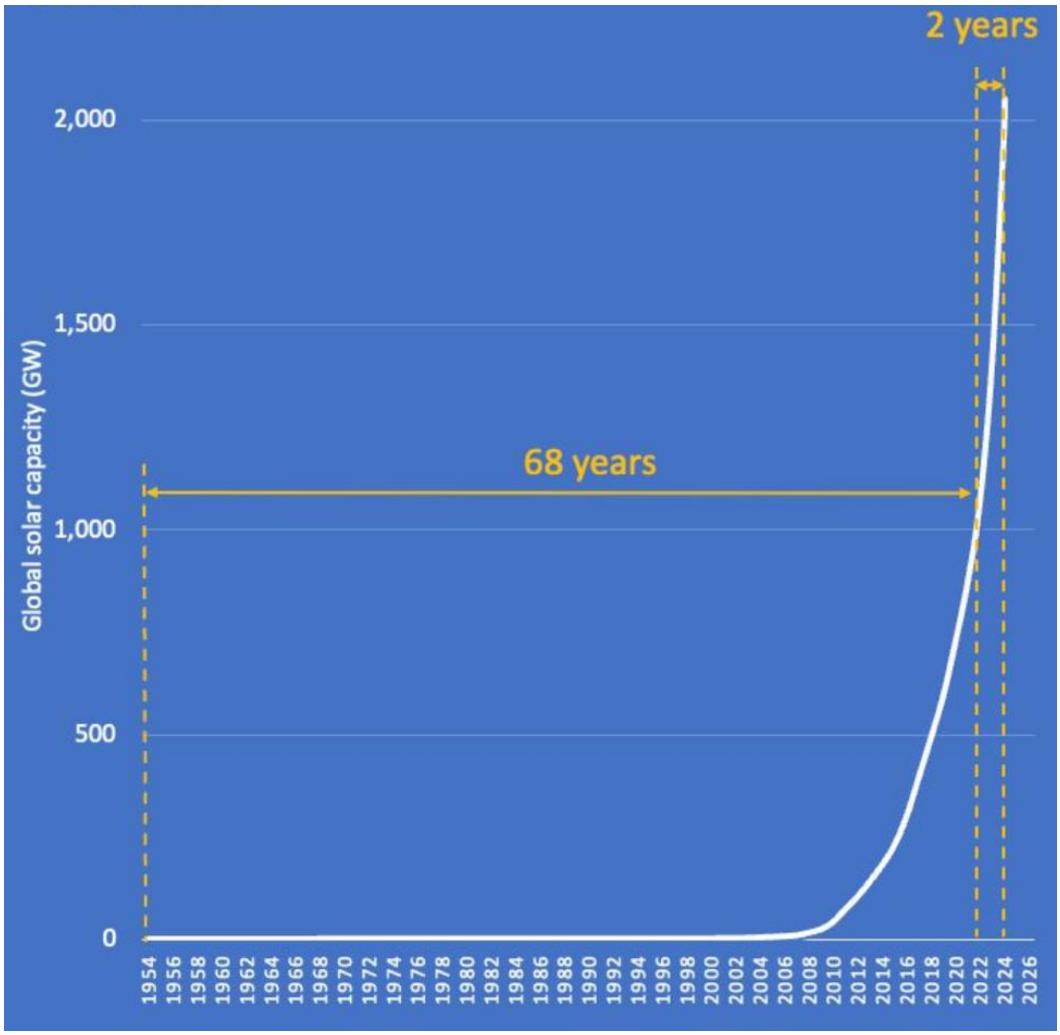
The implications of solar + BESS underpins CEF's estimate of 1,000GW pa of solar PV installations by 2030 as the likely central scenario — see Section 1.2. According to Ember, with the exponential growth of solar PV, the world is on track to meet the global target of tripling total VRE capacity by 2030.

China continues to lead, installing almost half (277GW) of total global solar PV capacity for 2024 — more than five times than the United States (US). The European Union (65.5GW), the US (49GW) and India (24.5GW) were a distant second, third and fourth.[12] China continues to increase solar PV deployment's scale, speed, and versatility— see Section 9. With gargantuan projects like the 100GW Great Solar Wall under construction and GW-scale floating solar PV (FPV) plants being developed (refer Section 9), China undeniably leads this transition. Other markets are also emerging that will underpin accelerating global deployment.

It took the world 68 years to get to a cumulative 1TW of solar installed, and 2 years to get to 2TW – Figure 1.12. CEF expects the world to be installing 1TW annually by 2030.

[12] Ember, Solar power continues to surge in 2024, 19 September 2024

Figure 1.12: Solar PV Installed Capacity Globally



Source: Gavin Mooney, EMBER, Global Solar Council, February 2025

China Photovoltaic Industry Association (CPIA) expects 215-255GW of domestic installs in 2025, a slowdown from China relative to the 277GW in 2024. CEF is more optimistic, and forecasts another year of positive surprise and growth, with a front-loaded year given the likely pull-forward resulting from the NDRC's February 2025 announced plan to replace its feed-in-tariff system with a fully market-driven renewable energy pricing model.[13]

Middle East and North Africa is a Deployment Hot Spot

The MENA region is likely to be the fastest-growing market outside of China. MENA deployed 2.6GW in 2024 (+25% yoy). This growth was primarily driven by Saudi Arabia, Egypt, and the United Arab Emirates (UAE), as these nations leverage their abundant solar resources to diversify their economies and reduce oil and gas dependence.[14] This ambition is highlighted by Masdar's January 2025 announcement of an enormous 5GW solar PV with 19GWh of BESS project in the UAE.[15] Rystad forecasts that total solar PV deployment in the

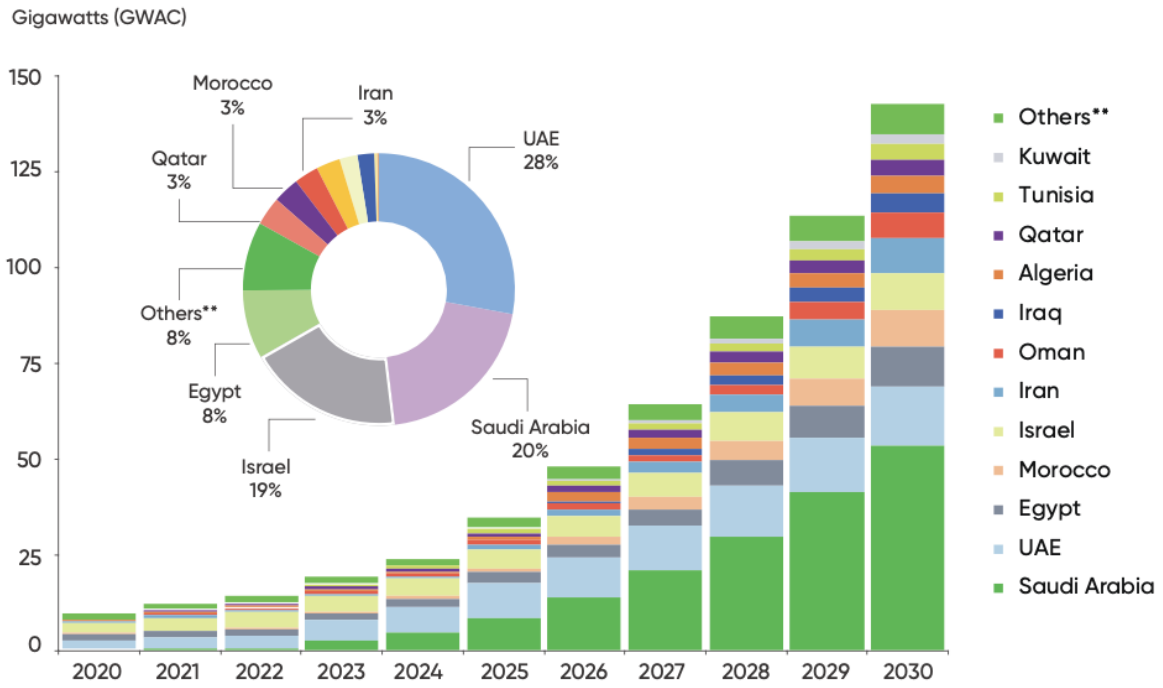
[13] David Fishman, Market Shock: China's 2025 Wind and Solar Additions Set to Drop as Policy Backstops Fade, 10 March 2025

[14] MESIA, Solar Outlook Report 2025, January 2025

[15] FT, Middle East becomes fastest-growing renewables market outside China, 28 January 2025

MENA region will approach 150GW by 2030, underpinned by supportive government policies, low capital costs and targets — see Figure 1.13.

Figure 1.13: Solar PV Installed Capacity by Country, MENA



Source: MESIA via Rystad

The rapid expansion of solar PV in MENA demonstrates that even economies historically reliant on fossil fuels can embrace solar PV as a transformative energy source.

Pakistan has Surprised with Rapid and Unanticipated Solar PV Adoption

Pakistan, too, has seen lightning-speed solar PV deployment. The country has been plagued by electricity price hyperinflation, reduced energy security resulting from increased reliance on imported coal and LNG, and grid instability caused by inconsistent energy policy and extreme fossil fuel price volatility.[16] However, the rapid cost deflation of imported solar PV modules (-60% yoy) has provided energy consumers a viable substitute for unaffordable grid electricity.[17] For example, intermittent grid electricity in Islamabad costs between Rs29-48/kWh (US$0.10-0.17), while solar PV provides electricity for Rs22-30/kWh (US$0.08-0.11).[18] As a result, the country imported almost 17GW of solar PV[19] (+127% yoy) in 2024. Assuming this is all installed, this would be equivalent to 40% of its entire generating capacity.[20] Notably, Chinese solar PV manufacturers have almost entirely supplied this growth.[21]

[16] InfoLink Consulting, Solar Energy in Pakistan: A Growing Market, 5 November 2024
[17] Arab News, Demand for solar power rises in Pakistan as import glut crashes panel prices, 26 April 2024
[18] DW, Pakistan's surprise solar surge shocks experts and grid, 27 November 2024
[19] World Economic Forum, Pakistan is experiencing a solar power boom. Here's what we can learn from it, 25 November 2024
[20] Business Recorder, Installed electricity capacity stands at 42,131MW, 12 June 2024
[21] PV-Magazine, Dealing with Pakistan's solar panel glut, 4 November 2024

The trading relationship between China and Pakistan is also strengthening with the February 2025 signing of a strategic agreement between the Government of Pakistan and Mingyang Smart Energy Group Co., Ltd to develop a 350MW solar PV-wind and BESS hybrid project in Sindh.[22] Pakistan's remarkable example highlights solar PVs disruptive ability to rapidly transform emerging markets while being increasingly driven by market forces. Continued explosive solar deployment expansion should not be discounted as countries see the increasingly destructive, repetitive, socialised cost of ignoring investment solutions aligned with the climate science.

Africa Shows Promise

Africa is a key market where to-date solar penetration has been limited, relative to the massive untapped energy needs. The Global Solar Council estimates that the continent added 2.4GW of solar capacity in 2024. The industry group predicts 42% growth in new installations in 2025,[23] but CEF notes this could easily grow tenfold with stronger Chinese financial and policy support.

BESS is Being Deployed Faster, at Increasingly Larger Scales

CEF considers BESS a key driver of increasing solar PV deployment and utilisation in the coming years — see Section 1.4. In 2024, the BESS market saw unprecedented growth. According to RhoMotion, BESS installations in 2024 surpassed 207GWh, an increase of 53% yoy.[24] Significantly, 30% of global BESS installed was deployed with solar PV, illustrating a significant trend towards hybridisation. BESS is also growing in scale, with 17 projects of over 1GWh becoming operational in 2024, compared to only 4 in 2022.[25] 140 BESS projects planned for installation by the end of 2026 are over 1GWh. Of these, 30 are over 2GWh, with the largest to date being 19GWh. 2025 has also seen significant advances in longer-duration storage as technology improves and capital costs continue to decline.[26] For example, February 2025 saw the New South Wales government award tenders for 2 8-hour duration BESS proposals.[27] An example of this scaling is the 11GWh BESS that started construction in Chile in 2024, in support of 2GW of solar PV, implying a ~5.5-hour storage duration. Developed by Spanish power producer Grenergy Renovables, the project features cutting-edge BESS technology from China's BYD and CATL — see Section 9.

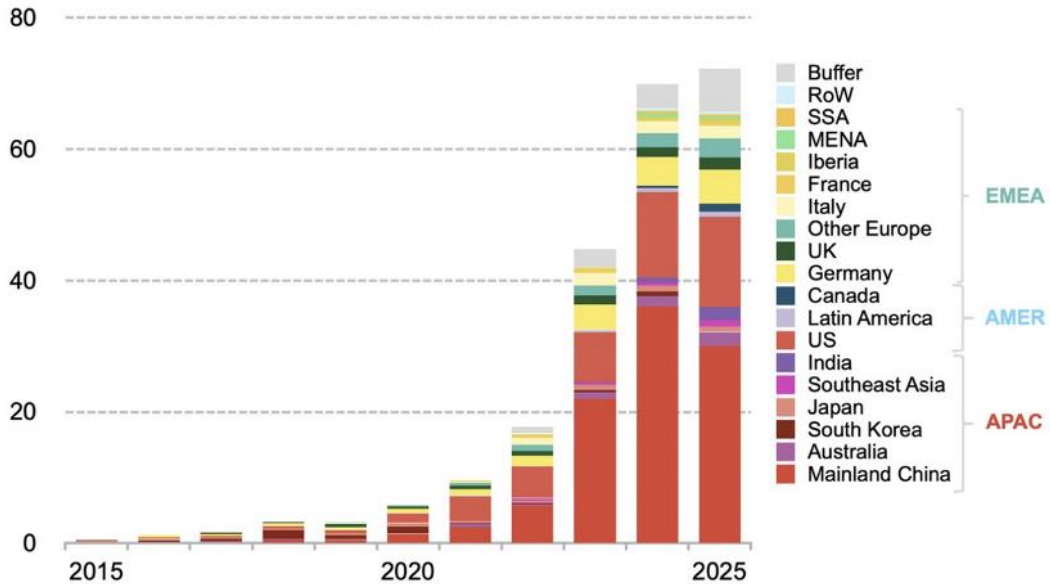
As with solar PV, emerging markets are underpinning a rapid deployment acceleration. The MENA region currently has 9 operational BESS projects with a total storage capacity of about 13GWh. According to Wood Mackenzie, this will grow to 120GWh by 2033 with most (44%) concentrated in Saudi Arabia. The strong momentum in Saudi Arabia was highlighted by the February 2025 deal between the Saudi Electricity Company and China's BYD for 2.5GW/12.5GWh of BESS across five sites in the country.[28] Operational and in-construction BESS now totals 25.5GWh in Saudi Arabia, with the country now vying for the world's third-

[22] China Economic Net, China and Pakistan strengthen renewable energy ties with strategic agreement, 18 February 2025
[23] Bloomberg, Africa's Solar Power Installation Seen Growing Sharply in 2025, 13 March 2025
[24] ESS-News, Global BESS deployments soared 53% in 2024, 14 January 2025
[25] RhoMotion, 2024 – a year in review and what to watch in 2025, 28 January 2025
[26] Energystorage.com, From hours to economics: Why BESS is a contender for long-duration energy storage (LDES), 4 March 2025
[27] RenewEconomy, Prices fall as first pumped hydro and two eight hour battery projects win landmark storage tender, 27 February 2025
[28] RenewEconomy, Saudi Arabia signs world's biggest battery storage deal with China's BYD, 18 February 2025

largest market with Germany. With several agreements between MENA countries, China is the preferred partner of choice for Saudi Arabia to deliver on its ambitions.[29]

China drove the deployment of BESS globally in 2024 (see Figure 1.14) and accounted for 70% of all BESS deployed in January 2025.

Figure 1.14: Global Additions of BESS (GW)



Source: Volta Foundation
Note: This graph represents a 5% yoy growth in 2025, which may yet be very conservative

2025 is set to be another record for BESS, with RhoMotion projecting nearly 350GWh (+~60% yoy) of capacity to be deployed. This would be a more than fivefold expansion of BESS capacity since 2022. Over 1TWh of BESS is in the global project pipeline for 2025-2030. January 2025 showed that this forecast is well within reach with 13.6GWh deployed, a 94% yoy increase.[30] Two projects over 1GWh entered operation – one 2GWh BESS in Saudi Arabia, and a 1.2GWh BESS in Hubei, China.

While the world is experiencing explosive solar PV and BESS growth, China is setting an unmatched pace and scale of deployment and is the key supplier to other emerging markets for their own rapid deployment. The UK, Saudi Arabia and the US are all crowding in rapidly as well. Similarly, Australia is likely to see 100-200% yoy growth in BESS deployments in 2025 and 2026, driven by the 5-minute time intervals and price only nature of our electricity market, with a world leading wholesale price range of -A$1,000 to +A$17,500/MWh. China is the 'gift horse' in this transition, easily criticised but simply galloping away with extraordinary clean industrial value in its saddle bags. Other jurisdictions remain far behind, constrained by higher costs and policy challenges and/or lack of the right market price signals.

[29] Carnegie Endowment, How China Aligned Itself with Saudi Arabia's Vision 2030, 21 January 2025; The Arab Gulf States Institute in Washington, China's Expanding Solar Footprint in the Gulf, 13 September 2024
[30] RhoMotion, BESS Monthly Assessment January 2025, 18 February 2025

Underscoring this, March 2025 saw CATL commission phase 5 of its Fuding Times 120GWh BESS factory, the largest single-site battery factory in the world. The 25GWh factory was constructed, commissioned, and is expected to be fully operational within a single year.[31]

If other countries hope to compete, policymakers must rethink their approach—not just by attempting to diversify supply chains but by recognising that riding this gift horse, meaning collaboration with China, is increasingly unavoidable given their scale and technology leadership. We note the CATL and Stellantis battery factory investment announcement in Spain in December 2024 as a key example of a win-win partnership. Policymakers should also prioritise the deployment of solar PV and BESS over other distracting generation types, including nuclear and fossil gas-fired generation. Any diversion of focus risks slowing deployment and reinforcing China's dominance in the sector.

[31] EnergyTrend, CATL Gigafactory Project Expected to Begin Production in August, 4 March 2025

Section 1.2: Continued IEA Underestimation

The International Energy Agency (IEA) continues to play a pivotal role in shaping global energy policy through its widely referenced, annually updated flagship reports, including the World Energy Outlook (WEO) and Energy Technology Investments (ETI). CEF notes the IEA consistently underestimates the pace of the global solar PV, BESS and electric vehicle (EV) disruption and the growth in manufacturing capacity. Analysing market trends, manufacturing expansions, and cost trajectories demonstrates the continuing disparity between the IEA's forecasts and actual speed of market developments.

In its 2014 WEO, under the most ambitious '450 Scenario,'[32] the IEA projected that total global installed solar PV capacity would reach just 856GW by 2030.[33] In reality, by November 2024, total global installed solar PV capacity had already surged past 2,000GW[34] — more than twice the IEA's forecast, achieved six years early. Even in the 2023 WEO, the Stated Policies Scenario (STEPS) scenario forecasted that the world would reach approximately 500GW of new solar PV installations annually by 2030. [35] In 2024, global solar PV installations were estimated to be 593GW, overachieving the IEA's 2030 projection again six years early. [36]

Based on current trajectories, CEF anticipates that the 2024 WEO STEPS forecast of 600GW of solar PV installs by 2030 will again fall well short of reality.[37] CEF projects that 1,000GW of solar PV installs pa between 2030 and 2035 is both realistic and achievable. This aligns with BNEF's forecast of 11% growth for 2025.[38] In 2023, the world installed 456GW of solar PV capacity[39]; in 2024, 593GW, giving a compound annual growth rate (CAGR) of 30%, well above the 12% CAGR required to achieve 1,000GW by 2030. Others, such as Andrew Birch, estimate higher ongoing CAGR, including up to 25%.[40] CEF may yet be conservative in our forecast.

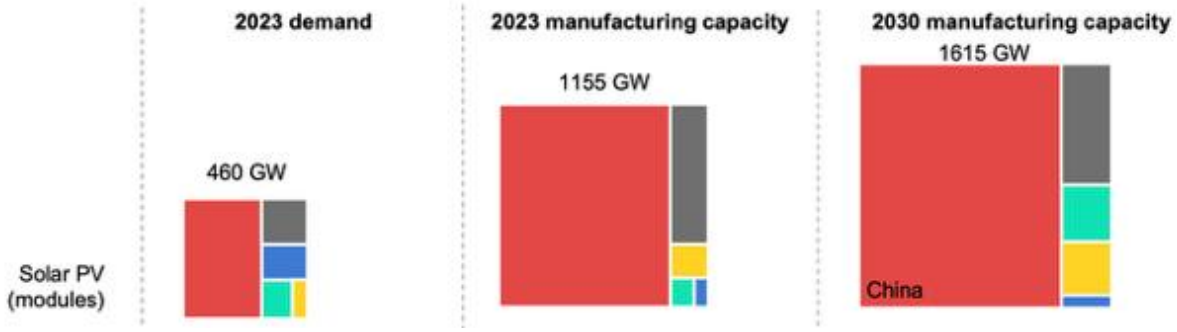
Constrained by a status quo bias,[41] the IEA consistently relies on a linear approach to forecasting rather than the exponential trajectories caused by the convergence of synergistic technologies (solar PV, BESS, and EVs), scaling (see 100GW Great Solar Wall in Section 9), technological improvements, and rapid price deflation. The reliable 20–25% cost reduction rate of solar PV per doubling capacity,[42] augmented with rapid BESS deployment increasing PV utilisation, translates to significant scalability. Added to Solar PVs ability to be deployed in diverse environments, this will ensure solar PV's continued competitive

[32] The 450 Scenario assumes a set of policies bring about a GHG emission trajectory that limits the global temperature rise to 2 °C. Under this scenario, long-term atmospheric CO2 intensity peaks and stabilises at 450 parts per million around mid-century.
[33] International Energy Agency, World Energy Outlook 2014, October 2014
[34] Reuters, Exclusive: Global solar capacity hits 2 TW on path to climate goal, data shows, 7 November 2024
[35] International Energy Agency, World Energy Outlook 2023, October 2023
[36] PV Magazine, The fastest energy change in history continues, 13 January 2024
[37] International Energy Agency, World Energy Outlook 2024, October 2024
[3838] BNEF, BNEF: Five Energy Transition Lessons for 2025, 9 January 2025
[39] International Energy Agency, Trends in PV Applications 2024, October 2024
[40] RenewEconomy, It's the S-Curve, stupid: New model predicts half of world's energy will come from solar by 2035, 15 January 2025
[41]K Mohn, The Gravity of Status Quo: A Review of IEA's World Energy Outlook, February 2021
[42] VDMA, International Technology Roadmap for Photovoltaics, May 2024

advantage and dominance. Global solar PV manufacturing capacity projections indicate that supply will not constrain scaling deployment.

The IEA itself projected that by 2030, the world would have 1,615GW of annual solar PV manufacturing capacity, with most developed in China — Figure 1.21. At a 60-70% capacity utilisation rate, this would exceed the 1,000GW demand estimate. Even with the consolidation of lower-tier manufacturers that Wood Mackenzie is forecasting in 2025, significant overcapacity, continued manufacturing expansions, and the ability of leading Chinese solar manufacturers to continue operating at loss-making levels[43] in an oversupplied market would ensure the ongoing availability of affordable panels for capacity growth.

Figure 1.21: Global Manufacturing Capacity Forecast



Legend: China (Red), EU (Blue), US (Turquoise), India (Yellow), Rest of World (Grey)

Source: IEA[44]

Demand is also plentiful and driven by supportive policies such as record-low tariff government solar PV reverse auctions[45], hybrid power purchase agreements in India[46], higher VRE targets, streamlined permitting, mandates, and market reform under the EU Solar Energy Strategy[47] and Affordable Energy Action Plan[48] in the EU. Additionally, China's continuous policy support, including a new energy law and proposed massive clean tech-heavy stimulus,[49] combined with rapidly improving technology cost affordability, energy security ambitions and yoy GDP growth of >4.5%,[50] will drive ongoing demand. China continues to install solar PV at extraordinary rates (over 277GW in 2024[51] — see Section 2),

[43] PV-Tech, Tsunami of Chinese solar company insolvencies in 2025 revealed in latest PV Tech Bankability Report, 31 October 2024; PV-Tech, LONGi's Q1-3 2024 shipments reach 51GW, financial losses continue, 11 November 2024
[44] International Energy Agency, Energy Technology Perspectives 2024, October 2024
[45] VRE Global, Vision 2030: The way forward for clean energy transition in India, 9 December 2024
[46] PV Magazine India, India expected to hit 132 GW of installed solar capacity by March 2026, 19 November 2024
[47] European Commission, EU Solar Energy Strategy, 18 May 2022
[48] Reuters, What is in the EU's Affordable Energy Action Plan?, 27 February 2025
[49] Carbon Brief, China Briefing 9 January 2025: 2025 government priorities; China's first energy law; What to watch in year ahead, 9 January 2025; CNBC, China likely to cut inflation outlook to two-decade low, lay out stimulus plans at 'Two Sessions' meet, 26 February 2025
[50] Trading Economics, China GDP Annual Growth Rate, January 2025
[51] Taiyang News, China Installed 25 GW New Solar PV Capacity In November 2024, 23 December 2024

emerging markets like the Middle East and North Africa (MENA) are rapidly transitioning,[52] and the Global South,[53] in particular, has seen a 23% CAGR over the last 5 years[54] — exemplified by the explosive growth seen in Pakistan[55] and India. Combined with the EU's and China's ambitions for decarbonisation, these forces will ensure demand remains robust, even while the US erects significant trade barriers, regresses on energy policy and plateaus solar PV installations at ~40GW pa for the next five years.[56]

[52] Rystad Energy, Power surge: Solar PV to help meet soaring Middle East power demand, reduce reliance on fossil fuels, May 2024; China Daily, CEEC inks mega Saudi solar project, 8 August 2024; Financial Times, China's ties with Saudi Arabia buoyed by green tech, 4 December 2024

[53] Eco-Business, Why China's clean energy need not fear US tariffs, 9 January 2025

[54] Financial Times, 'It's boom time': Renewable growth is faster in the global south than in rich countries, 16 October 2024

[55] Vox, A surprise solar boom reveals a fatal flaw in our climate change projections, 1 December 2024

[56] SEIA, Solar Market Insight Report, 4 December 2024

Section 1.3: Global Solar PV and BESS Prices

Solar PV is now competitive with new thermal generation across an increasing number of markets globally due to significant reductions in capital expenditure, primarily driven by increasing module efficiencies and technological innovation. Future advancements could halve solar costs again over the coming decade, completely undercutting other generation technologies. In parallel, BESS is experiencing substantial ongoing price deflation, propelled by China's manufacturing scaling-up, commodity price deflation and rapid technology advancement, making hybrid solar-BESS cost competitive and deployable at speed and scale. Manufacturing overcapacity and continued innovation mean the long-term outlook for both technologies will continue to be deflationary.

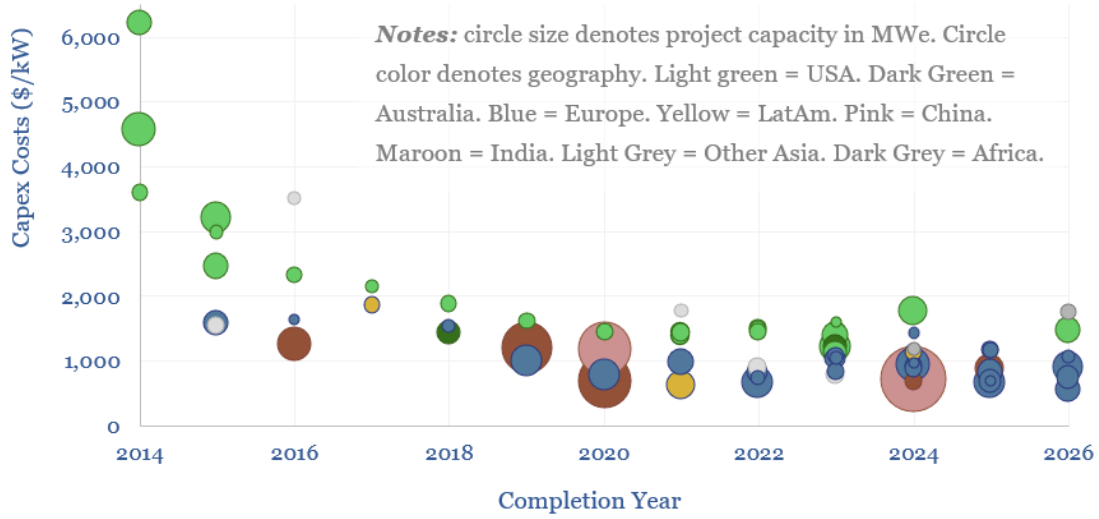
Solar PV Projects are Cost-Competitive with Thermal Generation

The global average capital expenditure (capex) of solar PV projects has seen dramatic reductions over the past decade. Falling from US$3,000/kW in 2014–16 to approximately US$1,000/kW in 2024–26—a two-thirds decrease.[57] Improving solar module and cell efficiencies has driven ~60% of this cost deflation — see Section 1.4.

While solar PV costs continue to decline globally, the US remains an outlier with significantly higher costs (>US$1,200/kW) due to tariffs exceeding 50% on imported solar PV modules. However, outside the US, Asia is achieving even lower costs, with some recent projects estimated to be US$500–700/kW, including India and Australia — see Figure 1.31.

This compares to the estimated capex of coal-fired power plants of US$1,700/kW in Asian countries like Indonesia.[58] Wood Mackenzie estimates solar now has a levelised cost of electricity (LCOE) competitive with gas generation in most Asia-Pacific markets.[59]

Figure 1.31: Capex Range of Solar PV Projects Per Region 2014-26



Source: Thunder Said Energy

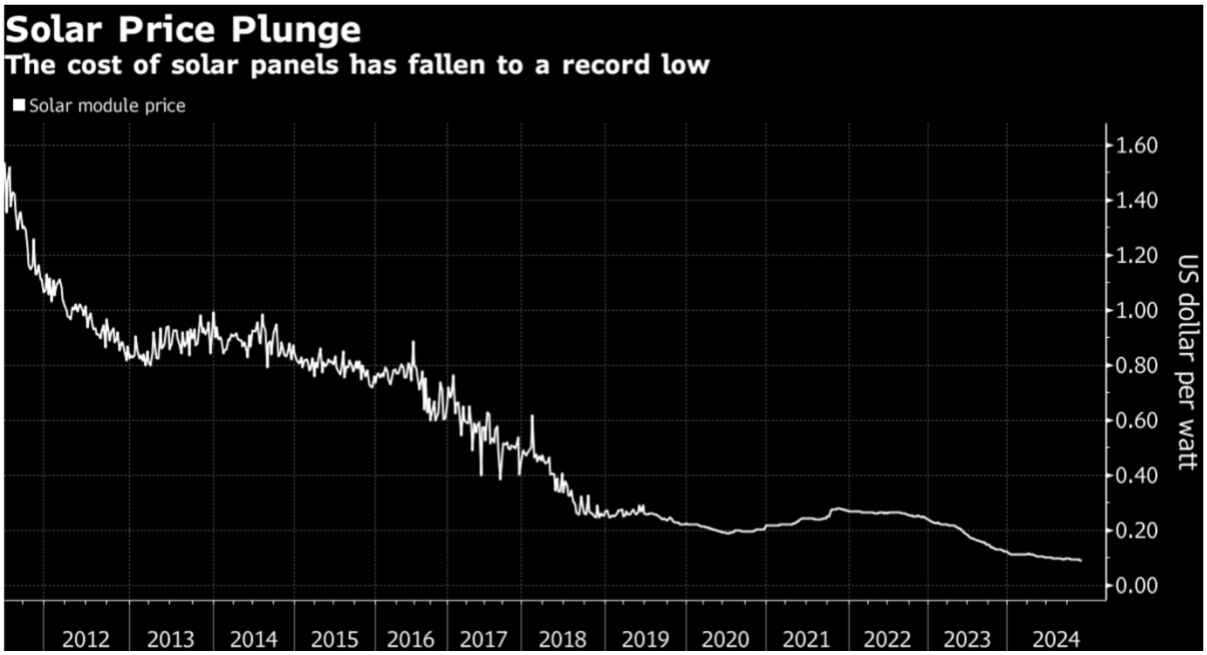
[57] Thunder Said Energy, Solar power: the economics?, January 2025
[58] Chojkiewicz et a., Indonesia Can Cost-effectively Supplant Captive Coal-fired Power Plants with Solar Energy, March 2024
[59] Wood Mackenzie, Asia Pacific Power & Renewables: Five things to watch in 2025,

Looking forward, Thunder Said Energy forecasts that advancements in solar PV technology could halve costs over the next decade, bringing capex below US$400/kW and disrupting the business case for both new coal and fossil gas peaking generation worldwide. When combined with BESS, this could further extend to pumped hydro storage.

Solar PV Module Prices Continue to Plummet

Solar PV module prices remain a critical driver of declining solar PV capex. Over the last decade, they have been rapidly deflating — see Figure 1.32. While near-term adjustments—such as supply rebalancing in China — might temporarily influence prices, the broader trend of price deflation will continue, driven by overcapacity, economies of scale and rapid technology acceleration. January 2025 reports from the OPIS Benchmark found China produced Tunnel Oxide Passivated Contact (TOPCon) modules (regarded as a successor to Passive Emitter and Rear Contact cell technology) in the US$0.080–0.092/W range, a 37-46% drop yoy from the US$0.147/W achieved in October 2023.[60] Comparatively, the EU average price was €0.098/W and the US was significantly higher at US$0.284/W due to higher production costs and tariffs.

Figure 1.32: Cost of Solar Modules



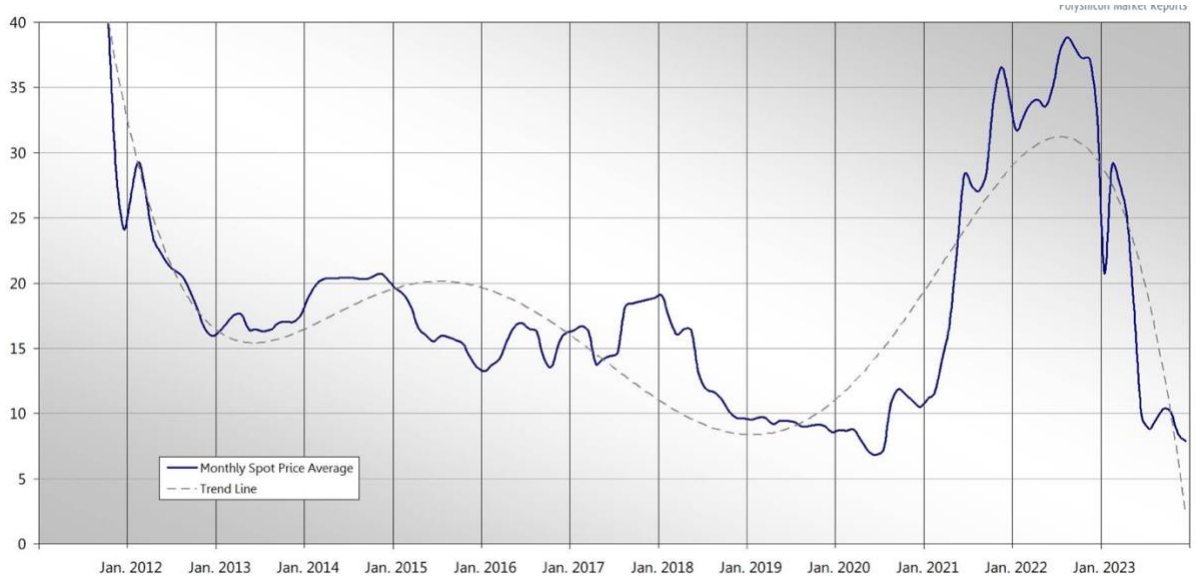
Source: Bloomberg[61]

Solar PV Deflation Driven by Polysilicon Oversupply

The collapse in polysilicon prices over 2024 contributed to the significant deflation in solar PV costs in the year. Polysilicon is the essential raw material used to make wafers and, therefore, modules. Over the past few years, polysilicon has experienced dramatic price fluctuations. After reaching record highs in 2022 (up to US$40/kg[62]), global polysilicon prices collapsed by almost 20% over 2024 to ~US$20/kg. In China, it was far more dramatic, with an almost 50% drop to ~US$5/kg — see Figure 1.33.

[60] PV Magazine, Global solar module prices mixed on varying demand expectations, 17 January 2025
[61] Bloomberg, China's Solar Industry Looks to OPEC for Guide to Survival, 9 December 2024
[62] Bernreuter Research, Current Level, Chart, Forecast & History of the Polysilicon Price, 5 February 2025

Figure 1.33: Monthly Polysilicon Prices in China (US$/kg)

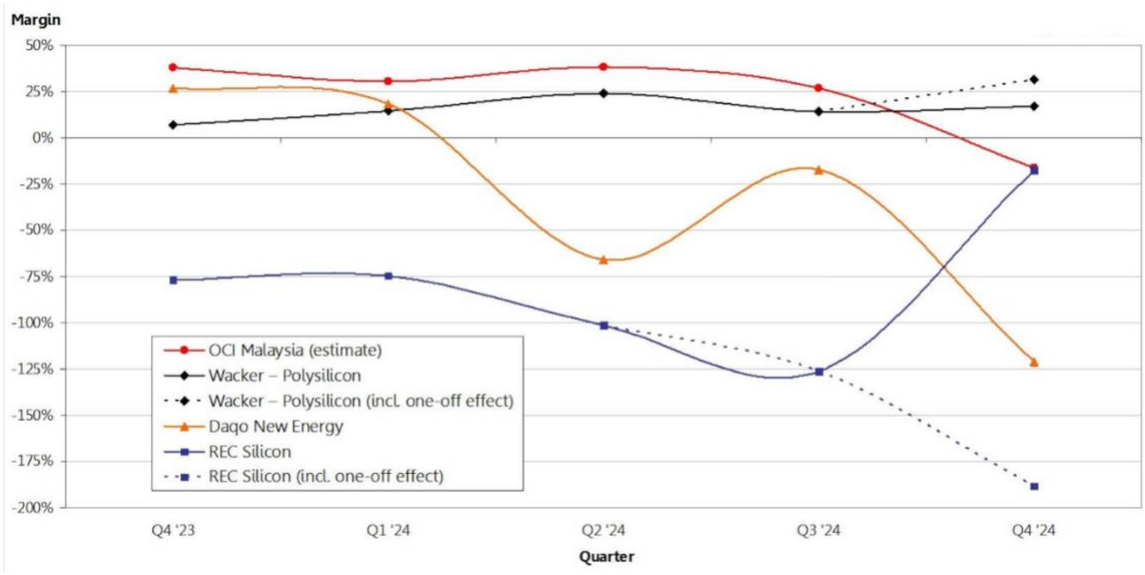


Source: Bernreuter Research

The deflation in benchmark polysilicon prices has been driven by massive capacity expansions, which has subsequently led to significant margin compression and reduced profitability for producers, particularly in China given its dominance in global polysilicon production capacity (80%).

The world's largest polysilicon manufacturers have experienced a collective collapse in gross profit margins (earnings before interest, tax, depreciation and amortisation (EBITDA)) between 4QCY2023 and 4QCY2024 – Figure 1.34. REC Silicon suffered major production problems and ceased production at its Moses Lake, Washington facility, while Daqo took significant one-off capital write-downs.[63]

Figure 1.34: Polysilicon EBITDA Margins for OCI, Wacker, Daqo & REC Silicon (%)



Source: Bernreuter Research

[63] Bernreuter Research, Wacker copes with polysilicon headwinds better than its peers, 19 March 2025

Manufacturing overcapacity has led to increased inventory stockpiling through 2024, with estimates of up to 300,000Mt[64] — enough for several months of module production.

However, in December 2024, self-discipline agreements among Chinese polysilicon producers reduced production to a reported 101,500Mt, a ~25% decline from November averages.[65] By February 2025, these measures, combined with increasing domestic and overseas demand for solar PV modules, caused a slight uptick in prices, which have now stabilised along the polysilicon industry chain.[66] In the longer term, CEF expects technological acceleration and economies of scale to continue to put medium to longer-term downward pressure on module prices.

BESS Costs Also Drop

The global BESS market has also witnessed a dramatic collapse in lithium-ion BESS prices over the last decade, creating a disruptive opportunity for VRE deployment. According to Bloomberg New Energy Finance (BNEF), the weighted-average price of lithium-ion BESS fell to a record low of US$115/kWh in 2024—a 20% yoy reduction from 2023 and the most significant drop since 2017 — see Figure 1.35.[67]

BESS prices were lowest in China, averaging US$94/kWh, although a recent BESS tender by the Power Construction Corporation of China attracted bids between US$61–82/kWh.[68] This sharp decline has profound implications for scaling VRE projects, particularly hybrid systems, which are now cost-competitive with thermal generation in jurisdictions like India – see Section 6. According to BNEF, the rapid scaling of Chinese BESS gigafactories, including Tesla's newly commissioned Shanghai BESS gigafactory,[69] is leading to significant market overcapacity (more than 2.5 times annual demand). This, combined with the 2023/24 decline in battery material input costs, a slowdown in EV sales in Europe and the US, plus a shift to lower-cost lithium-iron-phosphate (LFP) cells are all factors driving this deflation.

In the long term, Goldman Sachs is forecasting BESS prices to drop further to US$64/kWh by 2030,[70] whilst Recurrent is projecting as low as US$45/kWh, driven by innovation in battery density and assuming the collapse in mineral input prices is ongoing.[71]

While challenges like tariff barriers increasing prices in the world's second-largest BESS market—the US[72]—and rising demand for batteries for global EVs and BESS grid deployment may temporarily stabilise prices, the long-term trajectory remains deflationary. BNEF projects that BESS prices will decline in 2025 by US$3/kWh.[73]

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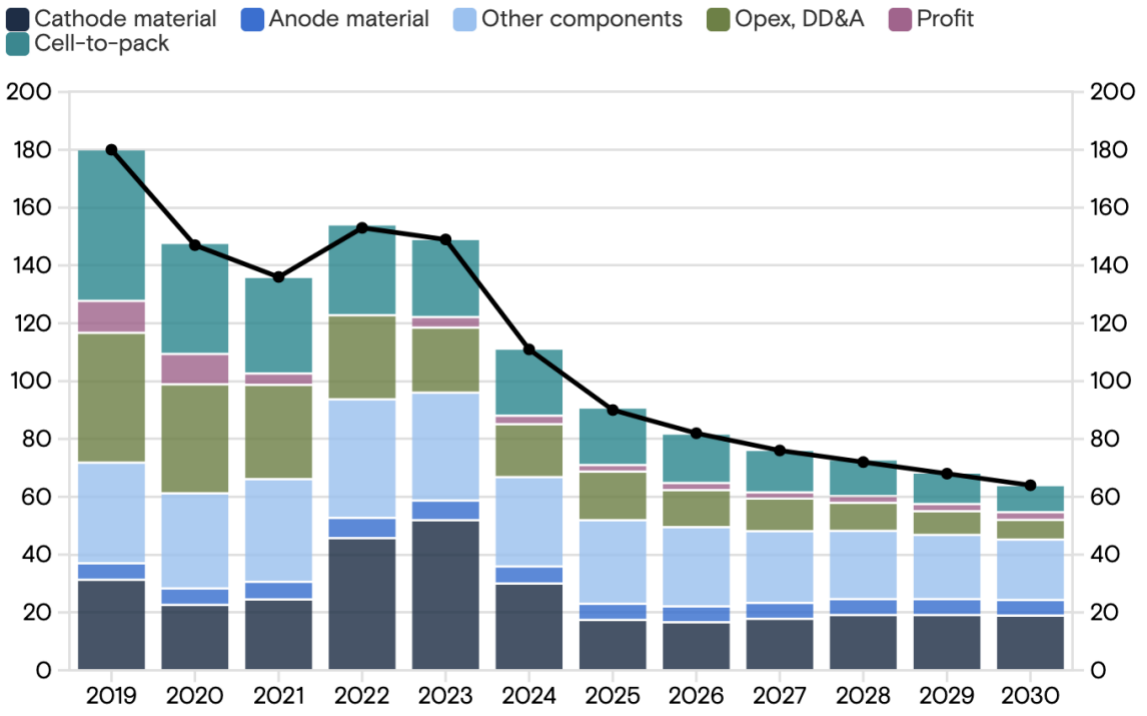
[64] PV Magazine, Polysilicon prices decline amid rising inventories, weak demand, 15 November 2024
[65] TrendForce Corp, Impact Analysis of Silicon Production Cuts and Futures Listing 1. Polysilicon Production Cuts and Supply-Demand Balance, 7 January 2025
[66] PV-Magazine, Polysilicon market holds steady, awaiting policy-driven shift, 21 February 2025
[67] BNEF, Lithium-Ion Battery Pack Prices See Largest Drop Since 2017, Falling to $115 per Kilowatt-Hour:, 10 December 2024
[68] RenewEconomy, "Mind blowing:" Battery cell prices plunge in China's biggest energy storage auction, 17 December 2024
[69] ESS-News, Tesla starts production at Shanghai Megapack factory, 2 January 2025
[70] Goldman Sachs, Electric vehicle battery prices are expected to fall almost 50% by 2026, 7 October 2024
[71] Recurrent, Used Electric Car Prices & Market Report — Q1 2025, 28 January 2025
[72] ESS-News, Cutthroat competition: the race to the top of the BESS supply chain, 14 January 2025
[73] BNEF, Lithium-Ion Battery Pack Prices See Largest Drop Since 2017, Falling to $115 per Kilowatt-Hour: BloombergNEF, 10 December 2024

Figure 1.35: BESS Price Estimates



Source: Goldman Sachs

BNEF believes this drop will be catalysed by continued R&D investment in advanced manufacturing, technologies like solid state cells,[74] and manufacturing scaling. As of February 2025, the commercialization of new cell technologies and advanced manufacturing is already underway, with China's Gotion High Tech unveiling a next-generation BESS featuring a 7MWh 20-foot container, a 40% greater energy capacity and a 40% smaller footprint than the standard 5MWh system.[75]

The global solar PV and BESS markets continue to experience significant and consistent price deflation. While short-term price fluctuations may occur, the long-term trajectory remains firmly deflationary. This deflation is making VRE increasingly disruptive to fossil fuels, a trend CEF sees only accelerating.

[74]CATL, Pursuing sustainable growth through a value-centered approach: Dr. Robin Zeng, 27 May 2024; EnergyTrend, 20 companies' solid-state battery mass production "timetable", 16 July 2024
[75] PV-Magazine, Gotion launches 7 MWh BESS container, 650 Ah cell, 27 February 2025

Section 1.4: Solar Technology Acceleration

Underpinning rapid solar PV disruption and price deflation is extraordinary technological acceleration. catalysed by R&D, manufacturing scale, cost reductions of technology, and large-scale hybrid projects. In particular, high-efficiency tandem perovskite cells and accelerated BESS deployment are making solar competitive with fossil fuels, while hybrid systems are enhancing grid stability and project economics. Meanwhile, EVs are emerging as mobile batteries on wheels, reinforcing the synergy between solar, storage, and transport electrification.

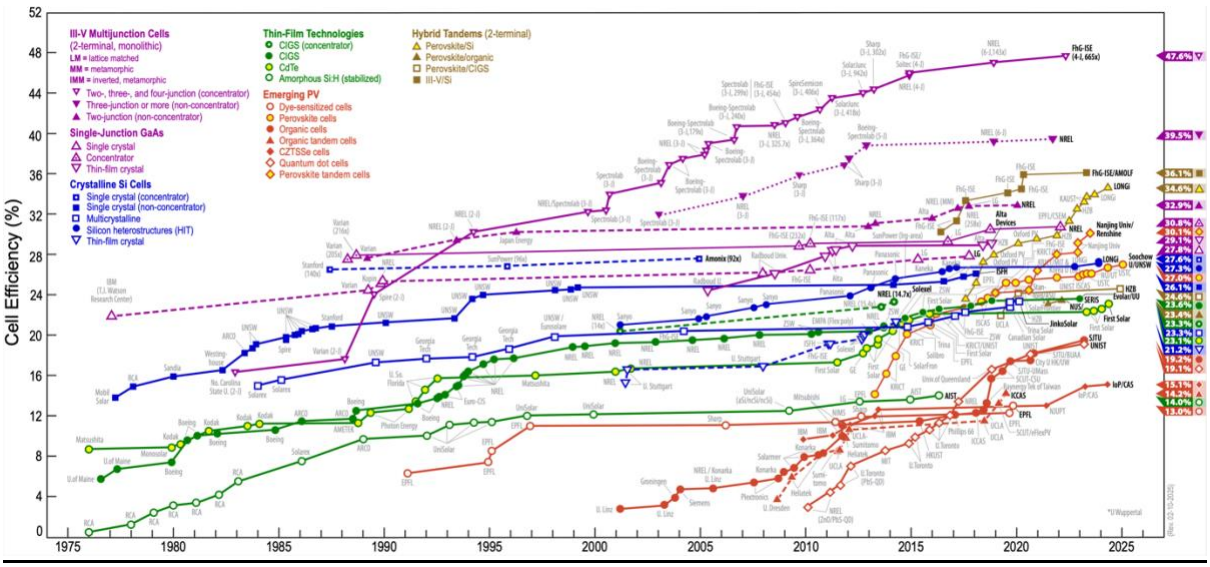
CEF expects incremental solar cell efficiency gains to continue to feature over the coming decade as cell efficiencies expand from the current commercialised 25% levels towards 35% as and if long-term perovskite cell stability can be established and commercialised, potentially driving another step change in solar in the coming decade.

In 2025, continued R&D investment and pairing with synergistic technologies like BESS and EVs will push solar PV's efficiency, utilisation, and economics to new heights. Because of this, consistently wrong historic projections by the likes of IEA and Wood Mackenzie that solar PV's global install rate will stall and plateau are likely to be proven way too conservative, again and again, in CEF's view.

Record-Breaking Cell Efficiencies and Tandem Technologies

Over the last five decades, cell efficiency has continued its dramatic upward trajectory across all technology types (see Figure 1.41), reliably improving 0.3% to 0.5% annually.

Figure 1.41: Best Research-Cell Efficiency (%), Jan 1970-Jan 2025



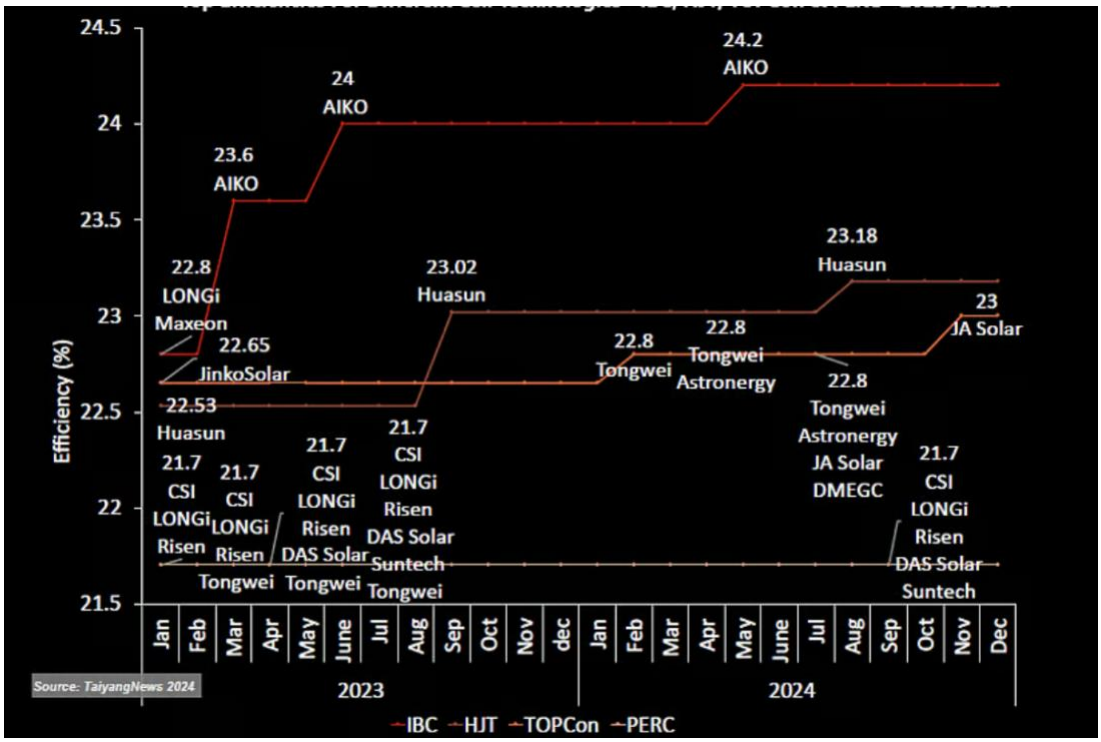
Source: NREL, Interactive Best Research-Cell Efficiency Chart, March 2025

In 2025, this upward improvement is becoming more acute, with manufacturers striving to create a breakthrough in the development of higher-performing products to differentiate themselves in a globally oversupplied market (Section 3) with historically low module prices (see Section 1.3).

In 2023, the leading commercial Passive Emitter and Rear Contact (PERC) cell efficiency was 21.70%, 22.80% for Tunnel Oxide Passivated Contact (TOPCon) and 22.53% for

Heterojunction (HJT). By the end of 2024, PERC efficiency had remained at 21.70%, whilst TOPCon hit 23% and HJT 23.18%, a 0.2 and 0.65 percentage point gain respectively — see Figure 1.42.

Figure 1.42: Top Efficiency of Each Cell Technology, 2023-24



Source: Taiyang News[76]

Current solar cell technologies are reaching the maximum level of efficiency around 27% (translating to ~25% for solar modules). The use of bifacial module technologies can significantly enhance module efficiencies.

There remains a major focus on the dramatic gains possible from tandem solar cells with RD&D investments in still yet-to-be-commercialised perovskite cells proceeding at extraordinary speed. A key advantage of perovskite cells is their compatibility with tandem structures, where are stacked with crystalline silicon or other solar materials to achieve higher conversion efficiencies (>30%) previously thought to be impossible to achieve.[77] Cost deflation follows these efficiency gains. Just five kilograms of perovskite can match the performance of an entire ton of PV silicon while requiring around 90% less energy per kilogram to produce.[78] Perovskite cells also promise straightforward manufacturing, lightweight design, and flexibility.

Countries, manufacturers and researchers are moving quickly to dominate this new cell technology. In 2024, China's LONGi set a record with a 34.6% cell efficiency for a two-terminal tandem perovskite solar cell prototype,[79] surpassing the previous record of 33.70% set by Saudi Arabia's King Abdullah University of Science and Technology (KAUST) in May

[76] Taiyang News, Top Efficiency Of Each Cell Technology, 6 January 2025
[77] Mitsui & Co, China Moves to GW-Scale Mass Production of Perovskite Solar Cells, July 2024
[78] Thunder Said Energy, Perovskite solar: beyond silicon?, 6 February 2025
[79] LONGI, 34.6%! Record-breaker LONGi Once Again Sets a New World Efficiency for Silicon-perovskite Tandem Solar Cells, 18 June 2024

2023.[80] There is plenty of space for continued improvement, with the Fraunhofer Institute for Solar Energy Systems (Fraunhofer ISE) estimating that perovskite tandem solar cells could achieve up to 39.50% conversion efficiency,[81] LONGi claiming it could 43%,[82] while some researchers estimate the theoretical limit could be as high as 45%.[83] To date, a key challenge in making commercial perovskite cells has been the technology's limited durability. However, on 17 March 2025, A research team at Japan's Nagoya University, in collaboration with Denso Corp announced it had succeeded in introducing new design and chemical elements to perovskite cell design to enhance flexibility and durability.[84]

Commercialising perovskite cells would be a significantly disruptive development, allowing further price deflation and increased solar deployment potential. A race is now on to produce these cells at scale. In December 2024, Japan's Sekisui Chemical announced plans to develop a 100MW pa thin-film perovskite cell manufacturing facility[85] and was awarded Rmb217bn (US$1.4bn) in support to achieve mass production by the Government of Japan.[86] However, these plans were dwarfed by the commissioning of UtmoLight's GW-scale perovskite factory in Wuxi [87] and construction beginning on Keneng New Energy's GW-scale perovskite factory in Zhejiang in February 2025.[88]

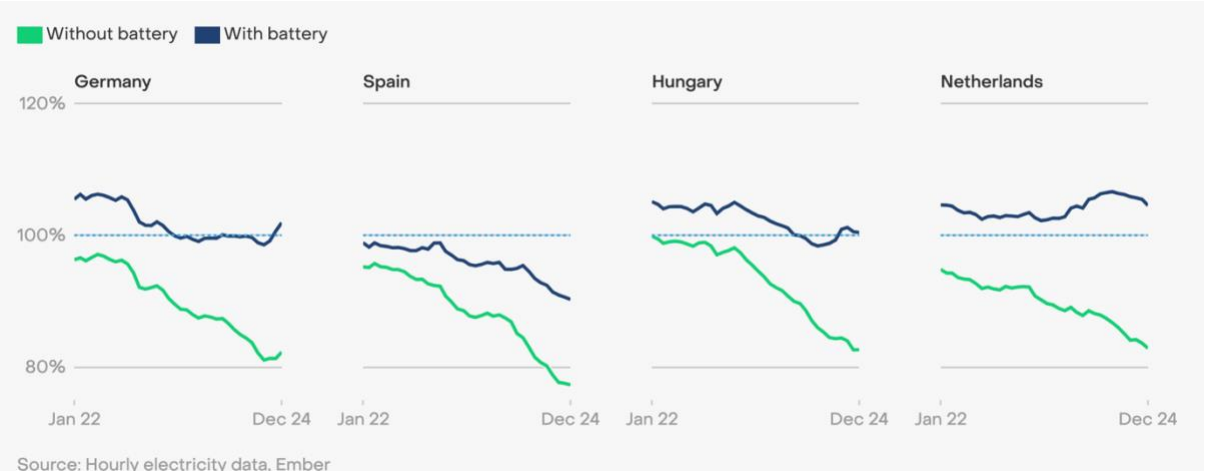
CEF also notes the ongoing technology development and innovation in solar and battery applications to extend market reach. March 2025 saw the launch of Growatt's 8kWh apartment inverter-integrated battery system.[89]

Grid Integration of BESS

The solar PV sector is witnessing a significant shift towards hybridisation through the co-location with BESS – Figure 1.43.

[80] PV-Magazine, KAUST claims 33.7% efficiency for perovskite/silicon tandem solar cell, 30 May 2023
[81] PV-Magazine, Perovskite-silicon tandem solar cells have practical efficiency potential of 39.5%, 30 Nov 2023
[82] PV Tech, JinkoSolar unveils TOPCon perovskite tandem solar cell with 33.24% conversion efficiency, 3 June 2024
[83] Ho-Baillie et al., Recent progress and future prospects of perovskite tandem solar cells, 15 October 2021
[84] PV-Magazine, Scientists unveil durable perovskite PV modules with carbon nanotube electrode, 17 March 2025
[85] PV Tech, Japan's Sekisui Chemical to build 100MW perovskite solar cell factory, 6 January 2025
[86] FT, Japan's $1.5bn bet on ultra-thin solar cells in challenge to China, 16 February 2025
[87] PV-Magazine, Chinese PV Industry Brief: UtmoLight starts perovskite module production, 7 February 2025
[88] Taiyang News, China Solar PV News Snippets: Jinko ESS On BNEF's Tier 1 List Again , 18 February 2025
[89] ESS-news.com, Growatt releases all-in-one 8 kWh balcony storage system,11 March 2025

Figure 1.43: EU Price Captured by a Typical Solar + BESS Hybrid Asset Relative to the Average Price of Electricity



Source: Ember[90]

Solar PV plants in jurisdictions with high VRE penetration frequently encounter wide intraday price spreads (including negative prices), temporary grid congestion at times of peak solar production and subsequent grid curtailment. However, integrating BESS allows solar PV plants to store surplus energy in negative price periods and export it when prices increase, e.g. during the evening peak. This also allows solar PV to effectively compete with thermal generation, such as coal and fossil gas plants by enhancing utilisation, capturing better prices for operators and improving project economics whilst reducing fossil fuel use.[91]

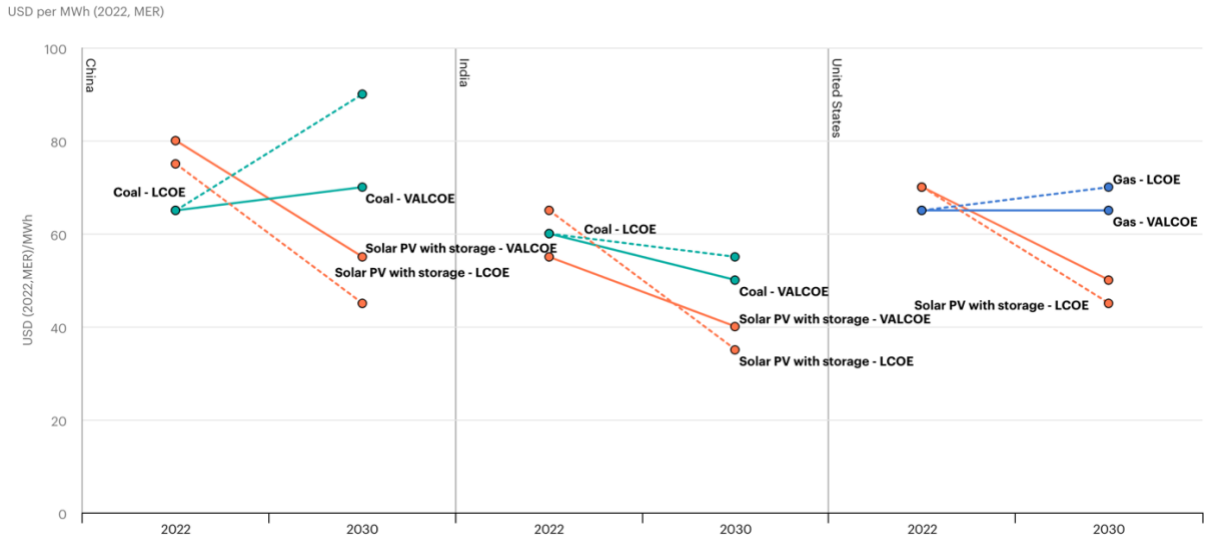
Gridcog's modelling of a hypothetical 300MW solar PV plant in South Australia found that including 300MW of BESS with a 2-hour discharge increased exported energy by 33% and project revenue by 170%. Even under a scenario where the grid is congested and capacity is halved, energy exports were 20% greater with BESS.[92] Similarly, Thunder Said Energy found that BESS co-deployment can allow a solar PV installation to dispatch approximately 95% of its power through a 65% smaller grid connection.[93]

The cost advantages are becoming increasingly evident globally. A recent study on generation costs in Germany found that pairing grid-scale BESS with utility-scale solar PV had a lower levelised cost of electricity (LCOE) than new coal or fossil gas power plants in Germany.[94] Solar PV plus BESS hybrid projects are also now cost-competitive with new coal generation in India — see Section 6.

The IEA has forecasted that dramatic reductions in LCOE will also make solar PV and BESS competitive with thermal generation in China and the US — see Figure 1.44.

[90] Ember, European Electricity Review 2025, 23 January 2025
[91] Ember, EU battery storage is ready for its moment in the sun, 23 January 2025
[92] Gridcog, Why BESS is more: Solar Development in a Grid Capacity Constrained World, 20 January 2025
[93] Thunder Said Energy, Solar plus batteries: the case for co-deployment?, 24 October 2024
[94] Fraunhofer ISE, Photovoltaic Plants with Battery Cheaper than Conventional Power Plants, 6 August 2024

Figure 1.44: LCOE and Value-Adjusted LCOE for Solar PV + BESS, Coal and Fossil Gas in Selected Regions in the Stated Policies Scenario



Source: IEA[95]

Projects like the US$6bn 5GW solar PV with 19GWh BESS hybrid giga-project in the United Arab Emirates (UAE) are signalling that this is where the market sees the value now.[96]

Tenders like the March 2025 Philippines Department of Energy (DOE) auction scheme for renewable power paired with storage aiming for 9GW of capacity[97] are becoming increasingly common across the global, including the Global South.

The hybrid approach creates a virtuous cycle: higher VRE penetration drives demand for BESS, enabling more aggressive utilisation of solar PV plants even in congested grid conditions. By decoupling energy generation from temporary intra-day grid limitations, the synergy between PV and BESS increases annual exports and unlocks significant value for developers and investors. This as well as providing an excellent opportunity to improve grid asset utilisations, and hence permanently lower the cost of delivered energy for all customers.

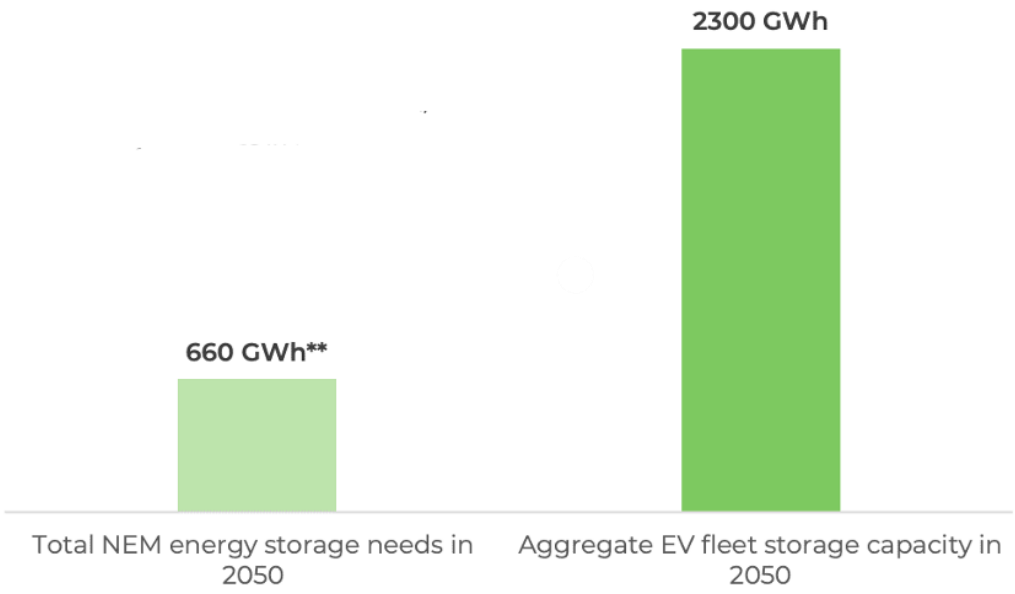
EVs are Batteries on Wheels

The rapid electrification of transport presents another significant synergy with solar PV. EVs will reduce imported oil use by increasing low emissions, lower cost domestic electricity demand. EVs will also be a significant and valuable source of demand flexibility and supply. With vehicle-to-grid (V2G) technology, EVs can effectively function as batteries on wheels.

By 2050, according to the Australian Renewable Energy Agency (ARENA), the usable storage capacity in Australia's EV fleet could be over three times the total projected NEM storage capacity needed by 2050 —Figure 1.45.

[95] IEA, Batteries and Secure Energy Transitions, April 2024
[96] Reuters, Philippines, UAE's Masdar agree $15 bln renewable energy project, 16 January 2025; Forbes, Masdar's Solar-Plus-Battery Project Will Redefine Reliable Energy, 9 February 2025
[97] PV Tech, Philippines opens tender for 9.4GW of renewable energy and storage, 13 March 2025

Figure 1.45: Storage Capacity of EVs Compared to NEM Needs



Source: ARENA[98]

The opportunity is considerable. For example, the total EV fleet battery capacity in Australia is expected to surpass all other forms of storage in the NEM (National Electricity Market) by early 2030s, including the 350GWh Snowy 2.0.[99]

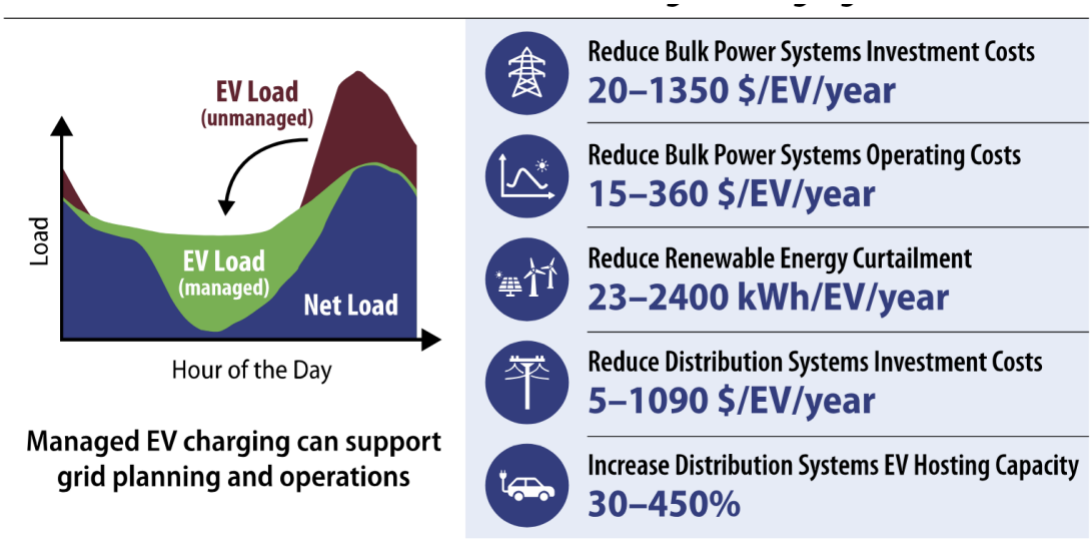
In the US, NREL forecasts that EVs will increase capacity by 90GW/540GWh by 2030.[100] Coordinated charging can help these EVs absorb excess solar PV generation, mitigating price volatility and reducing curtailment risks —see Figure 1.46.

[98] ARENA, Bidirectional charging hailed as next big thing in Australia as ARENA lays out V2G roadmap, 12 February 2025

[99] enX, V2X.au Summary Report – Opportunities and Challenges for Bidirectional Charging in Australia, 30 June 2023

[100] NREL, Integrating Electric Vehicles into the Grid, 3 December 2024

Figure 1.46: Value of EV Managed Charging



Source: Anwar et al.[101]

V2G also offers broader grid benefits, such as reducing costly and difficult transmission upgrades,[102] improving grid reliability by supporting supply-demand balance[103] and providing emergency backup. For example, in Australia, enX estimates that with a fast uptake of V2G, there could be AU$2.7bn (US$1.57bn) in wholesale market benefits and AU$2.4bn (US$1.39bn) in distribution network savings by 2040.[104]

For consumers, V2G also offers a chance to earn income from providing grid services. A February 2024 study commissioned by ARENA found that an average EV in New South Wales could earn up to AU$12,000 pa by providing frequency control ancillary services (FCAS) to the grid.[105]

Sensing the opportunity, in June 2024, CATL signed a strategic cooperation agreement with NETA Auto and others to develop a V2G demonstration project in Zhejiang Province, Eastern China.[106] This project was supported by a directive issued by China's National Development and Reform Commission (NDRC) in January 2024 promoting V2G projects.[107] In September 2024, the NDRC also issued a notice inviting cities with high and uneven electricity demand to apply for designation as pilot V2G reform sites.[108] Similarly, October 2024 saw Nissan co-invest with Ford, BMW, and Honda in ChargeScape, which is developing a software platform

[101] Anwar et al. Assessing the value of electric vehicle managed charging: a review of methodologies and results, 7 Jan 2022
[102] IEA, Global EV Outlook 2023, 26 April 2023
[103] China Briefing, Unlocking China's V2G Potential: Opportunities and Challenges in the Evolving Market, 10 October 2024
[104] enX, V2G Electricity Market Modelling Report, 12 February 2025
[105] Energeia, Insights from the Realising Electric Vehicle-to-Grid Services Project – Final Report, 20 February 2024
[106] CATL, CATL joins hands with partners to promote V2G Ecosystem, 14 June 2024
[107]China Briefing, Unlocking China's V2G Potential: Opportunities and Challenges in the Evolving Market, 10 October 2024
[108]NDRC, Notice on Promoting Large-Scale Application Pilots for Vehicle-to-Grid (V2G) Interaction, September 2024

to manage V2G charging.[109] In January 2025, Hyundai and Kia also invested in WeaveGrid, another software company aiming to capitalise on the V2G opportunity.[110] While on 13 March 2025, General Motors announced it was offering eligible customers the opportunity to enrol in their 'Vehicle to Everything' pilot in partnership with California's Pacific Gas & Electric. Participants will receive up to US$4,500 off bidirectional home charging equipment.[111]

Further EV adoption acceleration is likely with the March 2025 BYD announcement from BYD of new ultra-fast charging capacities for its EVs, with the staggering new ability to add 400km range in just 5 minutes. Once the new charging infrastructure is rolled out, this entirely overcomes any range anxiety issues, aside from cost, this has been the major barrier to many consumers' adoption of EVs. This announcement also shows the phenomenal speed of technology developments underway in batteries, concurrently disrupting both the transport and energy sectors.[112]

As solar PV generation expands, the demand for BESS (including EVs) grows in tandem, further enhancing the financial and operational feasibility of solar PV plants. This powerful, self-reinforcing cycle will drive the energy transition in the coming decades, increasingly challenging the utilisation—and ultimately, the viability—of costly fossil gas peaker plants for grid firming and other generation sources like nuclear. Policymakers should not be sidetracked by nuclear energy and gas-fired generation, which only promote investment and regulatory uncertainty, drain public finances, distract the public and lock in high-cost energy. Instead, they must focus on preparing electricity grids for the disruptive transformation led by solar PV, BESS, and EVs.

[109] The Verge, Nissan buys into Ford, BMW, and Honda's home EV charging business, 8 October 2024
[110] Electrek, Hyundai and Kia invest in WeaveGrid to power smarter EV charging, 29 January 2025
[111] MSN, GM EV Owners Eligible For $4,500 Off 'Vehicle-to-Everything' Pilot, 15 March 2025
[112] Australian Financial Review, BYD shares soar to record high after breakthrough, as Tesla falters, 19 March 2025

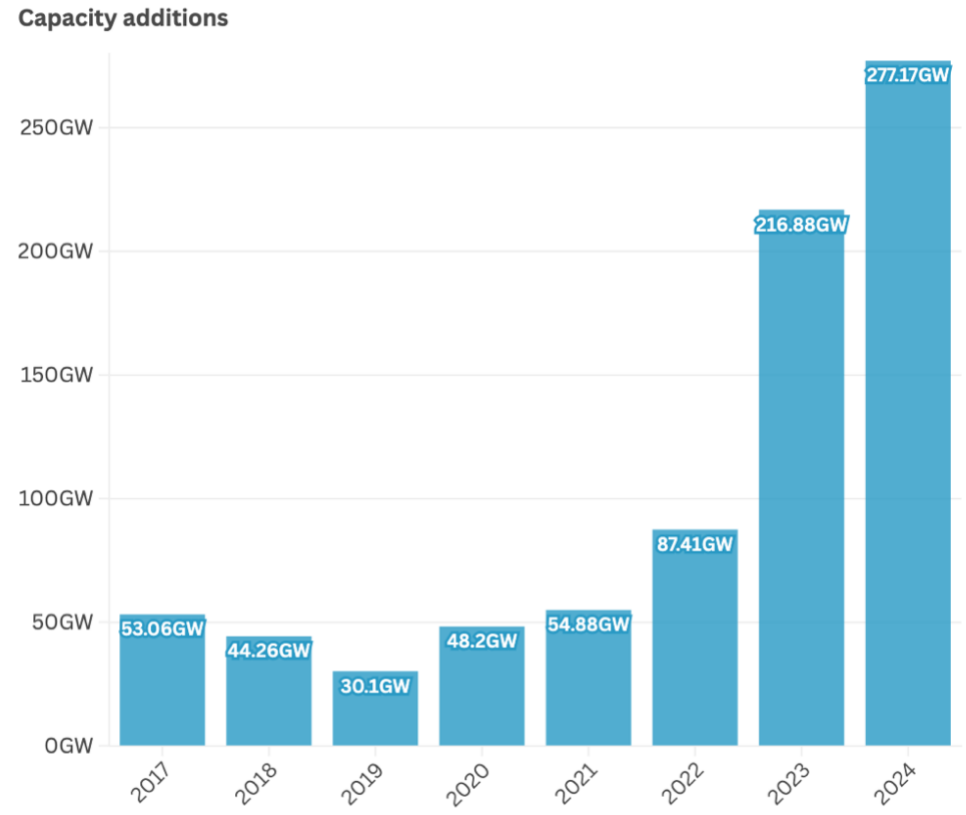
Section 2: China's Solar PV and BESS Installations

China's solar PV and BESS installations shattered all forecasts in 2024. In 2024, China accounted for half of all new solar PV installations and 70% of global BESS deployments. Ongoing policy support, infrastructure investment, and cost reductions propelled installations to record levels. While some forecasters assume a consolidation/pullback, CEF expects another record of installations in both in 2025. Policymakers must look beyond China's conservative targets and current continued thermal generation deployment, focusing instead on China's broader policy direction of progressive electrification of everything, energy security, expanding their global industry leadership and VRE deployment trends to grasp the challenge of catching up to China's almost unbelievable global lead.

China's Solar PV Installations Continue to Beat Forecasts

By the close of 2024, China's cumulative installed solar PV capacity hit 887GW, more than six times the amount deployed capacity in the US.[113] Over 277GW of new solar PV generation capacity was added during the year, a 45.5% yoy increase in China's installed base and three times China's installations of 2022 — see Figure 6.1.[114]

Figure 6.1: China's New Solar PV Installations



Source: PV-Tech via National Energy Administration

[113] Reuters, China to roll back clean power subsidies after boom, 9 February 2025
[114] PV Magazine Australia, China hits 277.17 GW of new PV installations in 2024, 22 January 2025

China alone installed just under half of all global solar PV. This surge in deployment surpassed the expectations of the IEA, Wood Mackenzie, S&P, Rystad Energy[115] and Chinese industry associations, which variously predicted between 190-260GW for the year.[116]

China still deployed 54.1GW of thermal generation to keep up with a massive 6.8% yoy electricity consumption growth,[117] but it was only 13% of total CY2024 capacity installations — see Figure 6.2.

Figure 6.2: New Capacity Installed in China (2024)

		Jan-Dec 24	% Share of total new adds	% yoy change	Dec-24	% Share of new adds
Thermal Power	GW	54.1	13%	-7%	10.2	9%
Hydropower	GW	14.4	3%	79%	3.9	3%
Nuclear Power	GW	3.9	1%	184%	2.8	2%
Wind Power	GW	79.3	18%	5%	28.5	25%
Solar Power	GW	277.2	65%	28%	68.3	61%
Total capacity added	**GW**	**429.0**	**100%**	**21%**	**113.6**	**100%**
Renewable Energy adds	GW	370.9	86%	25%	100.7	89%
Zero Emissions Capacity Adds	GW	374.8	87%	26%	103.4	91%
Total new spent on power grid investment	US$bn	84.7		15%		

Source: NBS, CEF estimates[118]

In December 2024, the NDRC and the National Energy Administration (NEA) also introduced the 'Implementation Plan for Optimizing Power System Adjustment Capabilities (2025–2027),' which outlined a goal to add over 200GW of renewable capacity annually through 2027. The plan also sets a national VRE utilisation target of over 90%. In comparison, the utilisation rate for solar PV was >97% in 2024.[119] It is clear that the Chinese Government remains conservative in its target setting.

While setting achievable targets, the Chinese Government continues to support solar PV expansion and utilisation with policies like the recently introduced National Energy Law,[120] the 'New Renewable Energy Plan,'[121] and VRE market reform.[122] The Government has further reinforced its VRE commitment through its 10 official priorities for 2025 as part of its commitment to accelerating its energy system transformation and meeting the 'dual carbon' goals.[123] To keep up with the rapid growth of VRE generation through 2025, China's

[115] Rystad Energy, China's wind, solar, and coal energy statistics, August 2024
[116] PV Tech, China hits another record high with 277.17 GW of new PV in 2024, 22 January 2025
[117] Yicai Global, China's Electricity Use Outpaced GDP Growth Again in 2024, 22 January 2022
[118] CEF, China hit new record of solar and wind power capacity additions in 2024, 18 February 2025
[119] National Energy Administration (China), China's renewable energy progress in 2024, 20 December 2024
[120] Carbon Brief, China Briefing: 9 January 2025 – Priorities and energy law, 9 January 2025
[121] China Briefing, China's New Renewable Energy Plan: Key Insights for Businesses, 26 November 2024
[122] PV-Magazine, China to switch from FITs to market-oriented renewables pricing, 12 February 2025
[123] National Development and Reform Commission (China), 2025 energy policy update, 15 December 2024

State Grid Corporation (SGC) also plans to invest a record Rmb650bn (US$89bn) in upgrading the nation's network infrastructure.[124] This is an increase of 6.8% over 2024.

China's policies and investment are already driving scale and speed in deployment beyond anything comprehensible in the West. For example, in June 2024, the China Green Development Group's 3.5GW Midong solar PV project near Urumqi in Xinjiang was commissioned. The capacity marked it as the world's largest operational solar farm at the time, and it was constructed in only 9 months.[125] This record was immediately surpassed in December by commissioning the 4GW Ruoqiang solar project in the Taklamakan Desert.[126] March 2025 saw China Huadian commence construction on the 19GW Rmb80bn/US$11bn Qaidam Golmud East Desert Base Power Project, including HVDC grid connectivity.[127] By 2030, the 100GW Great Solar Wall in the Kubuqi Desert is also anticipated to be completed — see Section 9. China is installing solar at such an extraordinary speed and scale that, despite the China Photovoltaic Industry Association (CPIA) conservatively forecasting 215-255 GW of installations, CEF expects 2025 to set another record for deployment.[128]

China's BESS Installations Gather Pace

2024 was an astonishing year for BESS in China - Figure 6.3. China's cumulative installed capacity reached 78GW/184GWh in 2024, marking a 127% yoy increase, surpassing PHS for the first time. By end 2024, the installed BESS capacity had already doubled the Chinese Government's 2025 40GW target, exceeding this milestone a year ahead of schedule.[129]

Figure 6.3: China's Cumulative Installed BESS Capacity

Source: China Energy Storage Alliance[130]

[124] Bloomberg, China State Grid plans record $89 billion spend amid green surge, 15 January 2025.
[125] Enerdata, China completes 35 GW PV project in Xinjiang, begins new 46 GW project, 5 June 2024
[126] PVTime, 40 GW: China operates largest PV plant in desert, 23 December 2024
[127] TaiyangNews, Construction begins on China's largest desert, Gobi, and waste area renewable energy transmission base, 5 March 2025
[128] PV-Tech, China's new PV installations forecast to reach up to 255GW in 2025, 27 February 2025
[129] Reuters, China struggling to make use of boom in energy storage, calls for even more, 5 July 2024
[130] Xinhua News, China's energy developments in January 2025, 16 January 2025

Yearly BESS additions totalled 43.7GW/109.8GWh, representing yoy growth of 103% and 136%, respectively and accounting for 70% of global BESS additions. BESS discharge durations also grew from 2.1 hours on average to 2.3 hours.[131] Much of this growth has been driven by improving BESS economics, maximising VRE utilisation, and provincial government policies requiring VRE projects to include BESS.[132]

This rapid deployment is likely to continue, underpinned by large projects like the China Three Gorges Renewables' Corporations Integrated Energy Project in Inner Mongolia. This project features 5GWh of BESS coupled with solar PV, wind and thermal generation and is planned to be completed by 2027.[133] There are also massive BESS tenders, such as PowerChina's 16GWh tender for delivery in 2025-26[134] and CGN New Energy's recent 10GWh BESS tender. This had a world record low bid of US$63/kWh[135] benchmarked against a global average of US$115/kWh in CY2024.[136] The Chinese Government is also supporting continued BESS deployment. On 27 February 2025, the NEA released the "Guiding Opinions on Energy Work in 2025," emphasising the development of new market mechanisms for BESS deployment and advancing research and innovation in batteries.[137]

According to the China Energy Storage Alliance, 2025 installations are expected to be between 40.8-51.9GW. CESA projects a cumulative 240GW (22% CAGR) will be deployed by 2030, while RhoMotion is anticipating ~222GW by 2033.[138]

2025 has also seen significant advances in longer duration storage as technology improves and capital costs continue to decline.[139] February 2025 saw NSW award tenders for 2 8-hour duration BESS proposals, underpinning the importance of public support for grid reliability values.[140]

With staggering solar PV and BESS installation rates in 2024, completely surpassing expectations and far outpacing other regions, China is setting the standard for speed and scale of deployment. Policymakers in other jurisdictions should look beyond the government's conservative headline targets, continued thermal capacity additions, or short-term fluctuations of VRE utilisation, focusing instead on China's clear, broader policy direction and actual VRE deployment trends. By this measure, China's solar PV and BESS installations will likely continue to grow rapidly, further cementing the Chinese gift horse's considerable lead in the global energy transition.

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[131] ESS News, China's new energy storage capacity surges to 74 GW, 168 GWh in 2024, up 130% YoY, 23 January 2025
[132] Rhomotion, China's transition from mandatory energy storage to BESS leasing solutions, 15 August 2024
[133] Reuters, China Three Gorges Renewables plans $11bn new energy project in Inner Mongolia, 28 June 2024
[134] RenewEconomy, Mind-blowing: Battery cell prices plunge in China's biggest energy storage auction, 17 December 2024
[135] PV Magazine, China's CGN New Energy announces winning bidders in 10 GWh BESS tender, 16 January 2025
[136] BloombergNEF, Lithium-ion battery pack prices see largest drop since 2017, falling to $115 per kilowatt-hour, 10 December 2024
[137] Xinhua Finance, China's new energy storage companies won 20 overseas orders at the beginning of the year, and the policy-driven shift to market-oriented development, 3 March 2025
[138] Benchmark Minerals, Chinese battery energy storage market to triple by 2033, 21 February 2025
[139] Energystorage.com, From hours to economics: Why BESS is a contender for long-duration energy storage (LDES), 4 March 2025
[140] RenewEconomy, Prices fall as first pumped hydro and two eight hour battery projects win landmark storage tender, 27 February 2025

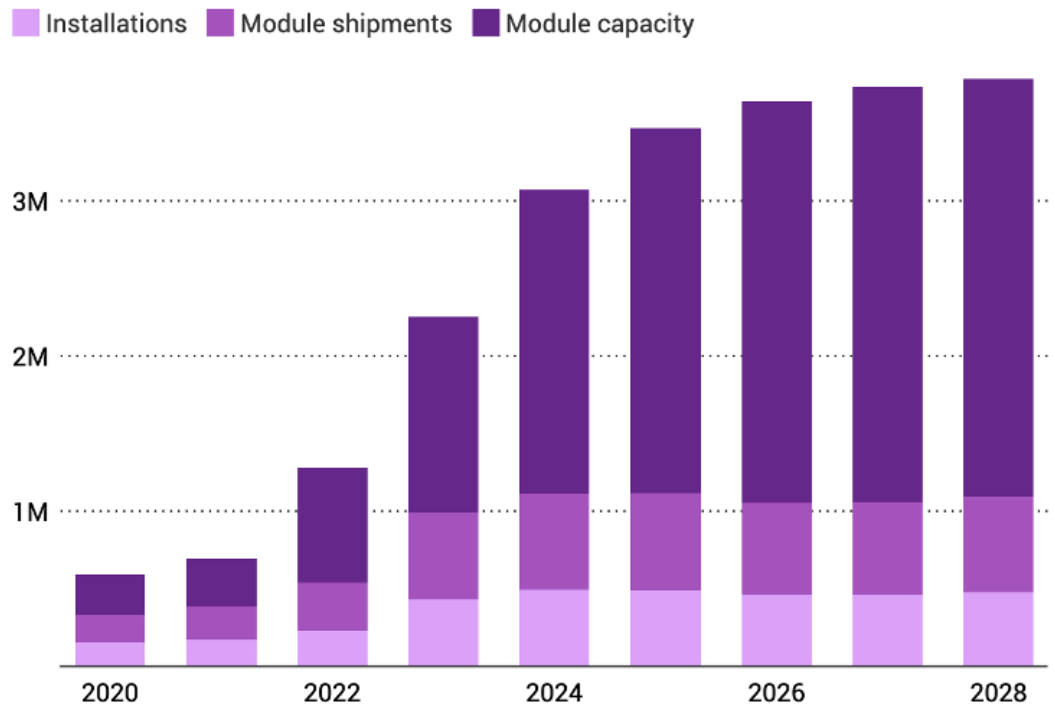
Section 3: Global Solar PV and BESS Manufacturing Capacity

Global solar PV and BESS manufacturing is in severe overcapacity, driving record-low prices through intensified competition. China's dominance in both sectors is now unassailable, with its scale, integration, and cost advantages forcing market consolidation and straining manufacturers in the US, and EU. While protectionist policies aim to counter China's lead, policy uncertainty and high costs are delaying Western manufacturing projects. Tariff barriers have provided some protection to domestic US and Indian manufacturers, but at a sustained cost to all energy consumers. Instead of focusing on tariffs, policymakers should hitch their wagons to the Chinese gift horse and explore strategic collaboration to support domestic production and reaching VRE targets.

Global Solar PV Manufacturing Faces Oversupply and High Market Concentration

In 2025, the global solar PV manufacturing sector is grappling with structural overcapacity throughout the supply chain, as seen with modules — see Figure 3.1. The rapid expansion of Chinese manufacturing leading to significant overcapacity has driven solar PV prices to record lows (-60-80% yoy in every solar PV supply segment[141]). This has intensified price competition for manufacturers in China and other international markets. Chinese Tier-1 manufacturers such as LONGi, Trina, and JinkoSolar have been able to weather profitability challenges due to economies of scale, however many smaller firms—especially in the US, and the EU—are struggling to compete.

Figure 3.1: Global Solar PV Supply-Demand Reconciliation (MW)



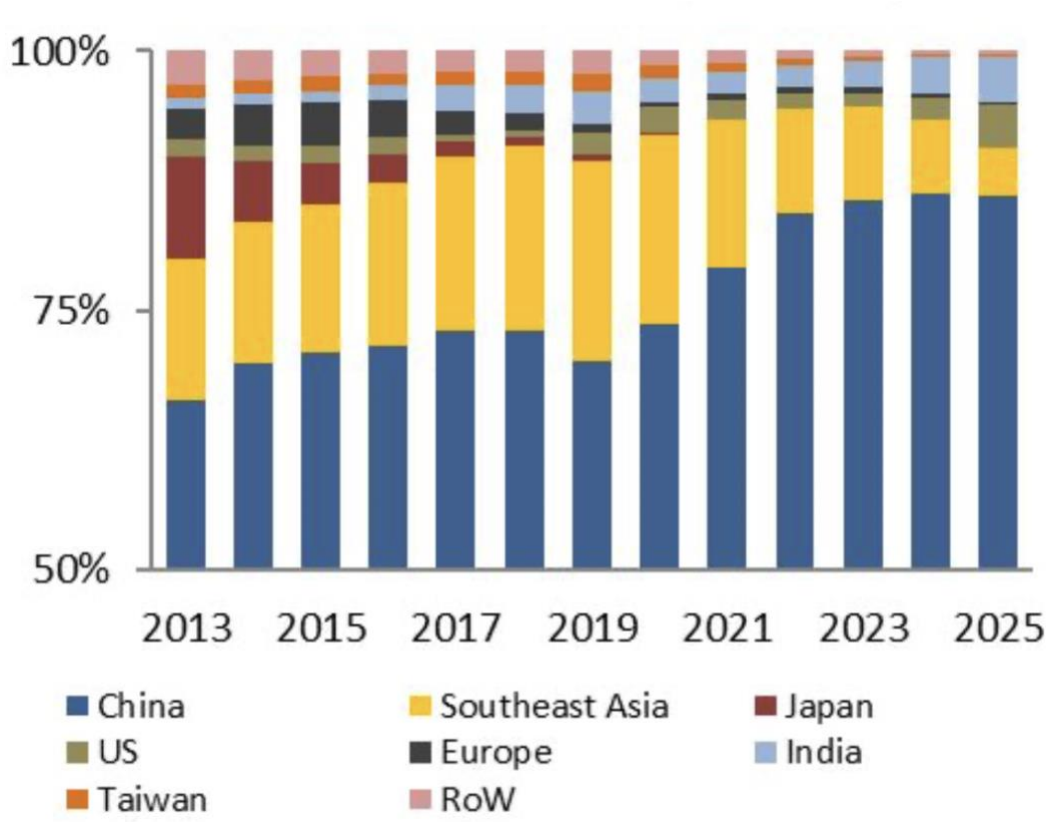
Source: SCMP using BNEF data

[141] SCMP, Storm brewing in China's solar-panel sector threatens to spiral out of control, 11 January 2025

Chinese manufacturers currently control 80-95% of the total solar PV supply chain, and their market share is increasing. China's solar PV module capacity far exceeded global demand in 2024, surpassing our projections for total global installations (1,000GW) even in 2030.[142] Chinese manufacturers are continuing to expand manufacturing even despite overcapacity. This will likely lead to continued cost deflation and market consolidation of lower-tier suppliers.

The rise and rise of China's dominance of solar module manufacturing over the last decade is understated in Figure 3.2, given China owns much of the capacity in ASEAN and the US.

Figure 3.2: Global Solar Module Production (c-Si & TF)



Source: Finlay Colville, PV-Tech, 18 March 2025
Note: the y-axis starts at 50% to allow non-China module production to be seen more clearly.

China's dominance is prompting tariff and non-tariff responses, particularly in the US and EU, where governments are introducing measures to protect domestic manufacturers from China's low-cost manufacturing advantage — see Figure 3.3. In 2024, US industrial policies like the Inflation Reduction Act 2022 catalysed significant operational and planned manufacturing — see Section 7. The EU, however, has lost its solar PV manufacturing capacities to intense import competition from China.[143] The recent collapse of Northvolt, once hailed as Europe's flagship home-grown battery manufacturer[144] and others[145] has raised serious concerns about the future of batteries 'made in Europe'. Despite the EU's

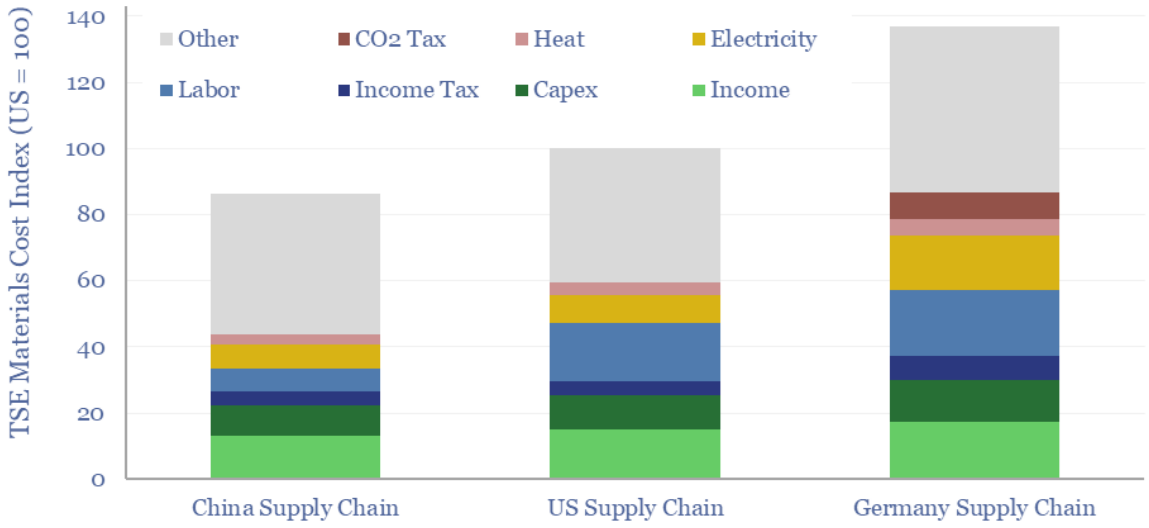
[142] China Energy News, The world is still unable to get rid of its dependence on coal. Coal demand rebounds in Asian countries, 13 February 2025
[143] European Commission, The Future of European Competitiveness, September 2024
[144] Taiyang News, European Solar Wafer Maker NorSun Filing For Bankruptcy, 18 December 2024
[145] Taiyang News, Manufacturer Cuts Down Staff Work Time, 14 January 2025

ambition to maintain and develop clean tech manufacturing capacity, the Draghi Report on the future of European competitiveness pointed to multiple signs of a trend in the opposite direction, with EU companies announcing production cuts, shutdowns and partial or full relocation.[146]

Both the US and EU now face significant challenges in addressing this issue with considerable cost disadvantages, even with supportive industry policy and tariffs. Cost disparity in the US will likely worsen with the new US administration withdrawing clean technology policy support under the IRA and increasing tariffs. As a result, manufacturing projects are already being delayed or abandoned. However, the EU shows signs of an effective policy adjustment with new policy support and possible local content rules.[147] Countries like Spain, Portugal and Hungary are also actively courting Chinese investment through policy incentives and government support.

India, supported by focused and consistent industrial policy settings, also continues to pursue domestic manufacturing with the goal of energy security — see Section 6. India's industry is currently buoyed by US demand for its modules. Yet, the new US administration and higher trade barriers may force a strategic policy adjustment by the Government of India, and Indian manufacturers to focus on domestic consumption of locally made clean technology products.

Figure 3.3: Material and Manufacturing Costs by Region (2024)



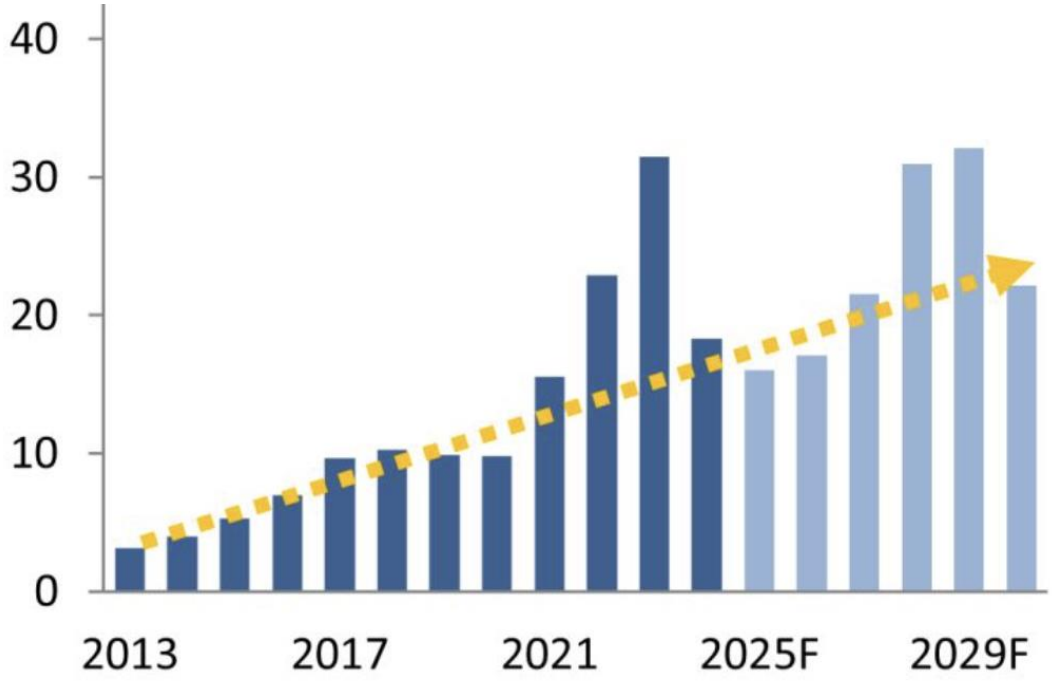
Source: Thunder Said Energy[148]

The solar PV industry is now in a period of consolidation and geopolitical realignment, resulting in reduced margins and altered global supply chain investment. CEF expects rising market exit rates and consolidation, particularly for manufacturers operating in high-cost jurisdictions like the EU and US. CEF also sees further shifting of Chinese investment to hospitable jurisdictions outside of the US, India, and the EU, including expanding manufacturing capacity in MENA, Southeast Asia, and the Global South — see Section 5.

[146] European Commission, The Future of European Competitiveness, September 2024
[147] European Parliament, Implementing the EU's Net-Zero Industry Act, February 2025
[148] Thunder Said Energy, Material and manufacturing costs by region: China vs US vs Europe?, January 2025

Whilst the huge capex over-build in solar of 2023 has subsided into 2024/25, it remains expansionary, as new projects continue to be completed, and regular maintenance capex is undertaken to keep 'older' lines built 3-5 years ago current. Figure 3.4 shows the March 2025 capex forecasts of Finlay Colville, Head of Research at PV-Tech. The continued technology enhancements being led by Chinese solar leaders are pushing the boundaries towards braking through the historic ceiling of 27% cell efficiency barriers – refer Section 1.4.

Figure 3.4: Global Solar PV Manufacturing Capex (c-Si Ingot to Module and TF (US$bn))

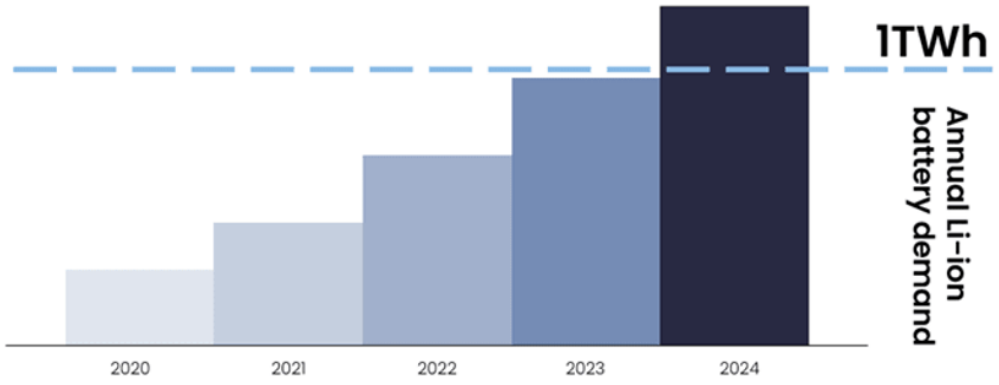


Source: Finlay Colville, Head of Research at PV-Tech, 19 March 2025

China is also Driving Global BESS Manufacturing

In 2024, the global BESS manufacturing sector experienced a boom. BESS shipments reached 202GWh in the first three quarters of 2024, marking a 42.8% yoy increase. Manufacturing capacity exceeded 1.5TWh in 2024,[149] while total demand was ~1TWh (a 27% yoy increase), continuing structural oversupply in the sector — see Figure 3.5.

Figure 3.5: Global Lithium-Ion Battery Demand



Source: RhoMotion[150]

Like the solar PV market, the rapid expansion of Chinese gigafactories has driven down BESS prices. According to Thunder Said Energy, most cost analyses of BESS suggest that 2024 lithium-ion BESS prices should be US$110-130/kWh, yet the pricing on Chinese BESS has been US$50-80/kWh.[151] PV-Tech has estimated that average BESS system prices in China decreased by 40% over 2024 alone.[152] This significant cost deflation has intensified competition for other manufacturers worldwide.

Leading Chinese BESS manufacturers are leveraging huge economies of scale, vertical integration, and R&D to maintain their market dominance. Chinese companies control market share up and down the supply chain — see Figure 3.6. For example, CATL and EVE Energy jointly hold nearly 55% of the lithium-ion BESS manufacturing market.[153] As a consequence, over 85% of BESS installations globally rely on Chinese batteries[154] — up from 59% in 2015.[155] This shows no sign of changing; China's CATL, for example, recently constructed the world's largest single-cell lithium-ion battery gigafactory (25GWh) in just over 4 months.[156]

This is a speed of deployment and scale simply incomprehensible in the West. This gigafactory is just one of five in the same precinct in Fuding City, amounting to 110GW pa of production capacity. This is more than all the US' operational, announced and under-construction capacity and in only one site.

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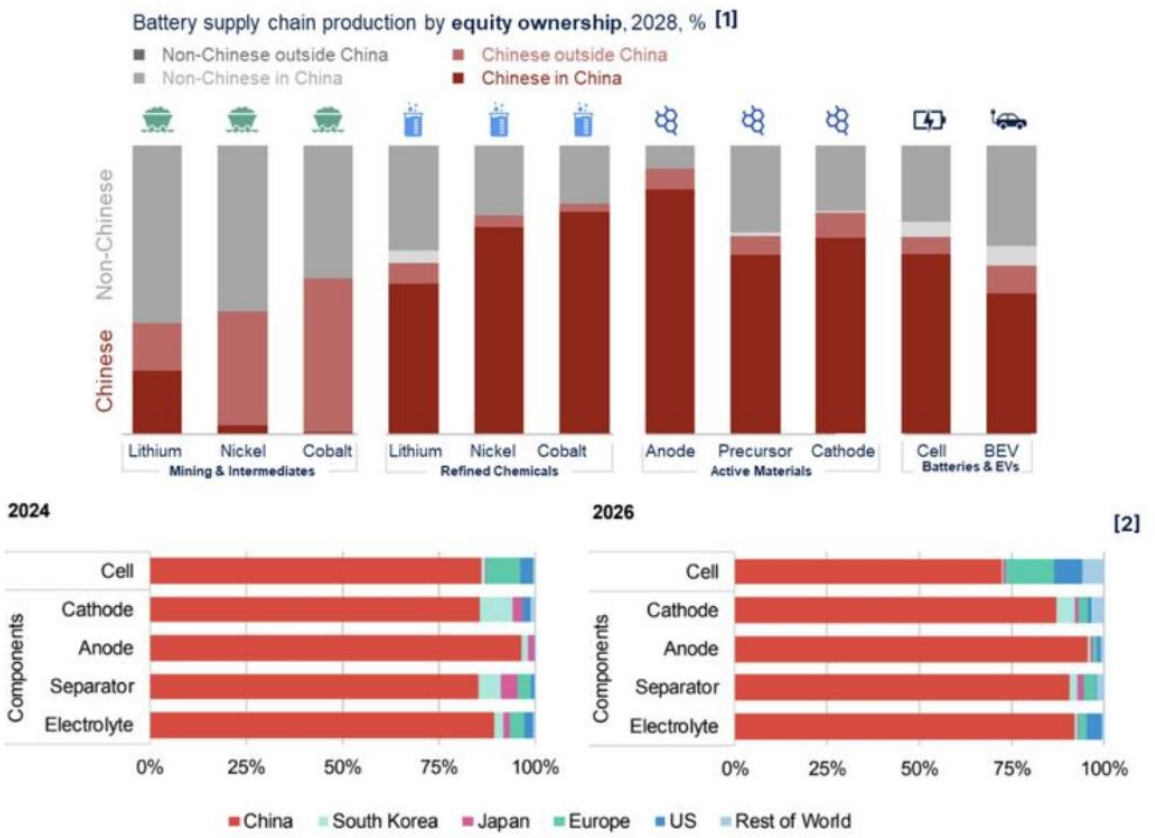
[149] Volta Foundation, Battery Report 2024, January 2024
[150] RhoMotion, The year of the terawatt hour, who deployed the most batteries in 2024?, 10 February 2025
[151] Thunder Said Energy, LFP batteries: cathode glow? 26 September 2024
[152] PV-Tech, PV Tech Power Volume 41, 17 December 2024
[153] ESS-News, InfoLink reports BESS cell shipments of 202.3 GWh in first 3Q of 2024 - Energy Storage, 28 November 2024
[154] ESS-News, Cutthroat competition: the race to the top of the BESS supply chain, 14 January 2024
[155] Benchmark Minerals, How the world reached 1 TWh of battery production, 4 February 2025
[156] EnergyTrend, CATL Gigafactory Project Expected to Begin Production in August, 4 March 2025

Figure 3.6: Battery Supply Chain Production by Equity Ownership



Source: Volta Foundation

Manufacturers in the EU and US are now delaying or cancelling BESS manufacturing projects due to high costs, changing policy support, unrelenting pressure from Chinese competitors and weaker-than-expected EV demand growth. China's dominance in the BESS supply chain has triggered protectionist policy responses, particularly from the US and the EU.

In the US, despite the Inflation Reduction Act boosting planned projects, the new US administration's recent 10% tariff increase on Chinese goods plus freezing clean technology funding have created investment uncertainty, threatening to slow future sector growth — see Section 7. As US trade barriers increase, this is simply pushing Chinese manufacturers to look to other regions to locate manufacturing facilities — see Section 5.

Similarly, in the EU, manufacturers are struggling to remain competitive, leading to numerous stalled or cancelled BESS manufacturing projects — see Section 8. The EU has responded by releasing plans for significantly expanded industrial policy support and is also now contemplating mandatory local content requirements for Chinese companies manufacturing in the EU.

Using the lessons of the US, EU, and India, policymakers in other jurisdictions should focus on hitching their wagons to the Chinese gift horse, collaborating rather than relying on protectionist policies that risk slowing their own transitions and raising prices for consumers. While tariffs and trade restrictions may aim to support domestic industries, they are simply ineffective with China's widening lead.

Section 4: China's Solar PV Manufacturing Capacity

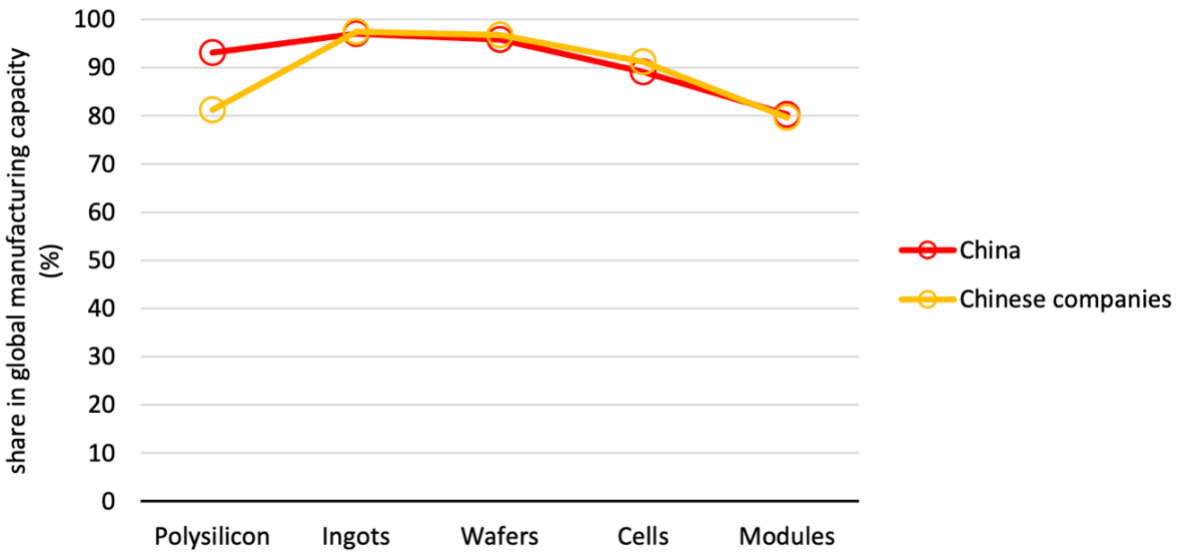
China isn't just winning the race—it owns the racetrack. Controlling 80-95% of each supply chain, China is maintaining its manufacturing dominance through scale, vertical integration, continued investment, deployment of world-leading technology and strong policy support. Relentless investments saw the solar PV supply chain capacity expanding by 29% in 2024. Overcapacity and intensifying price competition are now driving sustained price deflation, putting pressure on margins. This will inevitably drive industry consolidation and the collapse of weaker competitors unable to weather the prolonged pricing downturn, both in China and globally. In response to growing trade barriers, Chinese companies are continuing to invest in RD&D and targeting new export markets. CEF sees no slowdown in China's solar manufacturing capacity expansion so far in 2025, implying the current record low module prices will, at best, stabilise.

With global manufacturing capacity at 2-3 times current global install rates, CEF does advocate for the global industry to immediately suspend all non-essential capacity expansions for several years.

China's cost advantages, supply chain control and clear government policy direction will sustain its global lead. Harsh as it is, policymakers in other countries will likely pivot towards collaboration with China to remain remotely relevant. Outright competition against the Chinese juggernaut will be ineffective, with Northvolt a stark abject lesson.

China controls 80-95% of the world's polysilicon, wafers, cells, and modules production capacity — Figure 4.1. In modules, for example, China has almost 1.2TW of the total 1.5TW production capacity globally.[157]

Figure 4.1: Shares of China (location) and Chinese Firms' Manufacturing Capacity (2024)



Source: REI via BNEF, September 2024

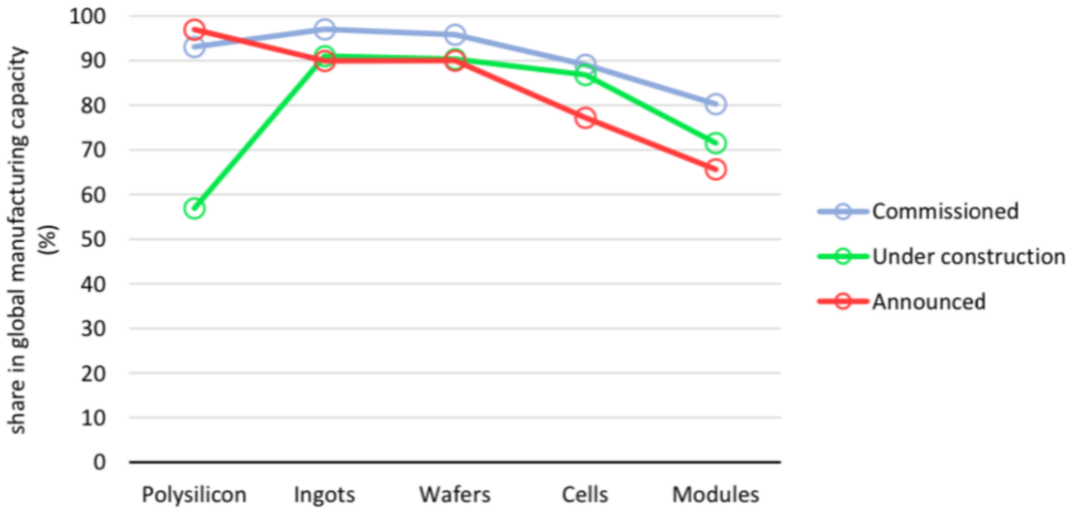
Chinese companies' unparalleled production scale, vertical integration, innovation, ongoing investment in RD&D and consistent policy support underpins its unrelenting dominance, and CEF sees zero sign this will change. For example, just five Chinese factories have 36% of

[157] PV-Magazine, 'Solar module prices will soon go back to over $0.12/W', 27 February 2025

the world's ingot production capacity.[158] China's Trina Solar alone has a staggering 347GW of vertical production capacity across five solar PV components (culminating in 100GW pa of solar module capacity). China's value chain expansion shows no sign of stopping, with most solar firms expanding horizontally into BESS manufacturing, and downstream into solar and BESS EPC and generation ownership as well.

Capacity across China's solar PV value chain grew by an average of 29% in 2024.[159] Much of this capacity is concentrated in regions like Inner Mongolia, which is home to LONGi's under-construction 100GW Ordos facility. Also, provinces like Yunnan, Zhejiang, Jiangsu, and emerging Shandong, which is home to Trina Solar's operational 10GW Huai'an module facility[160] and a 50GW wafer facility currently under construction. China's dominance in solar PV manufacturing is set to continue, with the majority of planned global capacity located domestically — see Figure 4.2.

Figure 4.2: Share of China (location) in Solar PV Manufacturing Capacity by Project Status (Sep 2024)



Source: REI using BNEF data

Chinese Companies Maintain the Lead in Solar PV Shipping Volumes

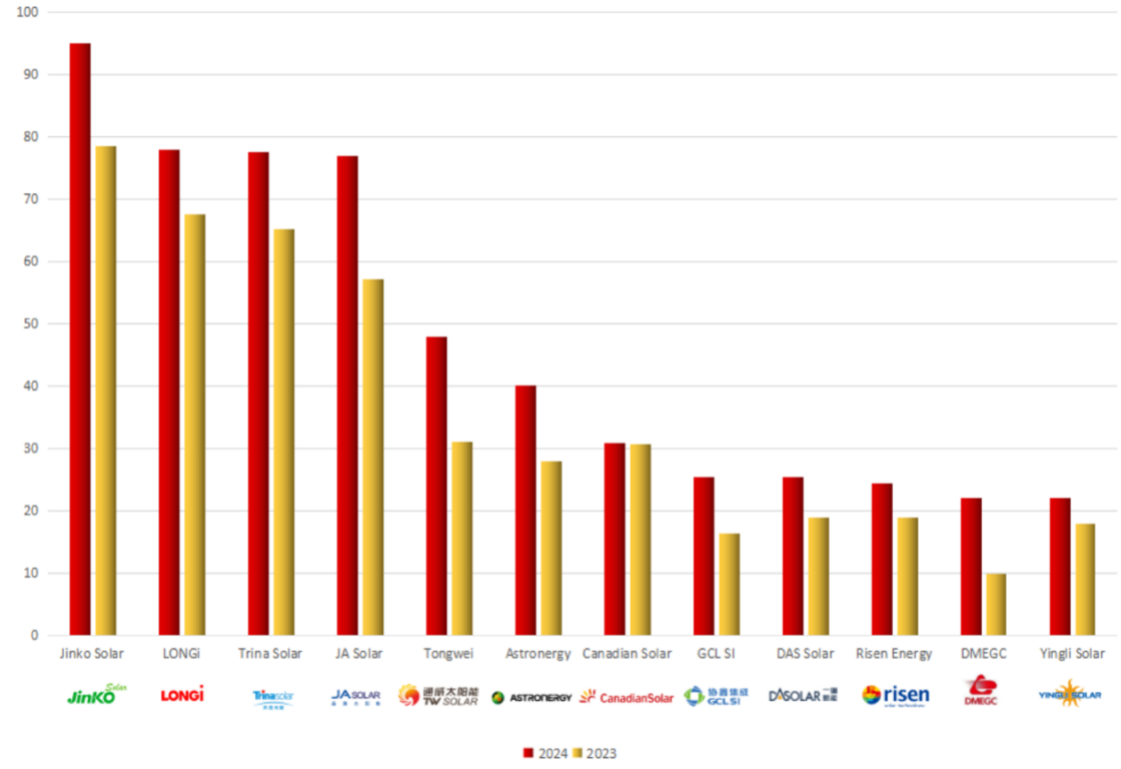
In 2024, Chinese solar PV module manufacturers recorded astonishing shipment volumes, exceeding 680 GW for the year. [161] For the second consecutive year, Chinese companies dominated the top 10 module producers by shipment volume. They also increased their total volume shipped from 2023 (+22% yoy) – see Figure 4.3. These suppliers shipped more than 500GW in 2024,[162] with 235GW exported (+13% yoy).[163] The industry expects ~600GW to be shipped in 2025.[164] For a company to even enter the top 10 and be competitive with Chinese firms, annual module shipment volumes must be >25GW —a significant and almost

[158] REI, Progress in Diversifying the Global Solar PV Supply Chain, December 2024
[159] F Haugwitz, China Solar PV Upstream Industry development btw. Jan-Oct 2024, December 2024
[160] Taiyang News, China PV News Snippets, 4 April 2023
[161] Solar Quarter, China's Solar Module Shipments Hit 680 GW In 2024, Raising Concerns Over Growing Warehouse Stockpiles, 13 March 2025
[162] PV-Tech, The top 10 PV module suppliers in 2024, 10 January 2025
[163] PV Magazine, China exports 235.9 GW of solar panels in 2024, 7 February 2025
[164] Taiyang News, Top 10 Solar Module Manufacturers Ship 502 GW In 2024, 20 February 2025

insurmountable hurdle for nascent manufacturers even in the biggest non-Chinese solar installation markets of the EU, US, and India.

Chinese solar PV continues to be the most imported product worldwide. 97% of the EU's modules come from China,[165] with 94.4GW imported over 2024.[166]

Figure 4.3: Global Module Shipment of Chinese Suppliers (GW)



Source: PVTime[167]

This is despite the EU's protective tariffs and domestic industrial policy support, clearly demonstrating an unassailable cost advantage for the Chinese. UBS finds Chinese products are at least 50% cheaper than EU alternatives,[168] decimating the business case for EU solar PV manufacturers even with ongoing government subsidies and tariffs.

Asian countries, like Pakistan, which imported 16.9GW in 2024 (+127% yoy), are becoming growth export markets for China. Asian countries briefly overtook the EU in 2023 and 2024 in solar PV imports.[169] Chinese firms are also expanding into emerging markets in the Middle East (28.8GW, + 99% yoy), and Africa (11.4GW, +43% yoy) to compensate for restricted access to US and Indian markets, where trade barriers protect domestic solar PV industries.

Imposing trade barriers on China has done little to diminish its dominance in the solar PV sector. Instead, it has the global benefit of accelerating Chinese expansion into the Global South, where most of the world's new energy demand growth is occurring. 47% of China's

[165] European Commission, International trade in products related to green energy, October 2024
[166] PV-Magazine, European solar market 2024-2025: balancing growth, challenges and opportunities, 10 January 2025; PV- Magazine, China exports 235.9 GW of solar panels in 2024, 7 February 2025
[167] PVTime, Global Module Shipments of 20 Chinese Solar Module Manufacturers in 2024, 31 January 2025
[168] SCMP, Storm brewing in China's solar-panel sector threatens to spiral out of control, 11 January 2025
[169] Ember, China's Solar PV Export Explorer, January 2025

solar PV, wind and EV exports went to the Global South in 2024, only 4% went to the US.[170] The Global South has driven a 70% increase in China's exports in clean technology segments over 2020-2024. CEF's analysis shows China's outbound Foreign Direct Investment (FDI) in clean technology sectors has accelerated materially since the start of 2023.[171]

The Chinese Solar PV Manufacturing Sector Faces a Correction in 2025

While China's dominance in the solar PV manufacturing market is unmatched, it has challenges. The industry has been grappling with significant overcapacity despite phenomenal growth in domestic solar installations and in export volumes. This has created intense price wars that have impacted solar PV manufacturers' revenues and dramatically eroded sector profitability.

Between January and October 2024, polysilicon, wafer, cell and module prices in China dropped by more than 35%, 45% and 25% respectively.[172] In 2024, 39 of the nation's 121 listed solar PV producers reported losses. In late 2024, to reduce pressure on the sector, the Chinese Government introduced revised manufacturing guidelines to curb speculative capacity expansions, accelerate innovation and improve product quality.

The guidelines included stricter efficiency standards (i.e., N-type cells must exceed 26% efficiency), increased project capital requirements, and more stringent energy consumption standards for factories.[173] These measures favour established players like Tongwei and JA Solar while pushing smaller producers to exit. Producers also entered a voluntary OPEC-style agreement to reduce the production of components across the supply chain. At the same time, the China Photovoltaic Industry Association issued standardised price guidance for manufacturers, attempting to prevent a race to the bottom on module prices.

Combined with increasing solar PV demand, these interventions have stabilised prices after two years of rapid deflation.[174] CEF views a slight uptick in 1QCY2025 to be a temporary reprieve, given the industry's manufacturing overcapacity continues to get worse as factories entering development 1-2 years ago are still being commissioned throughout 2025.

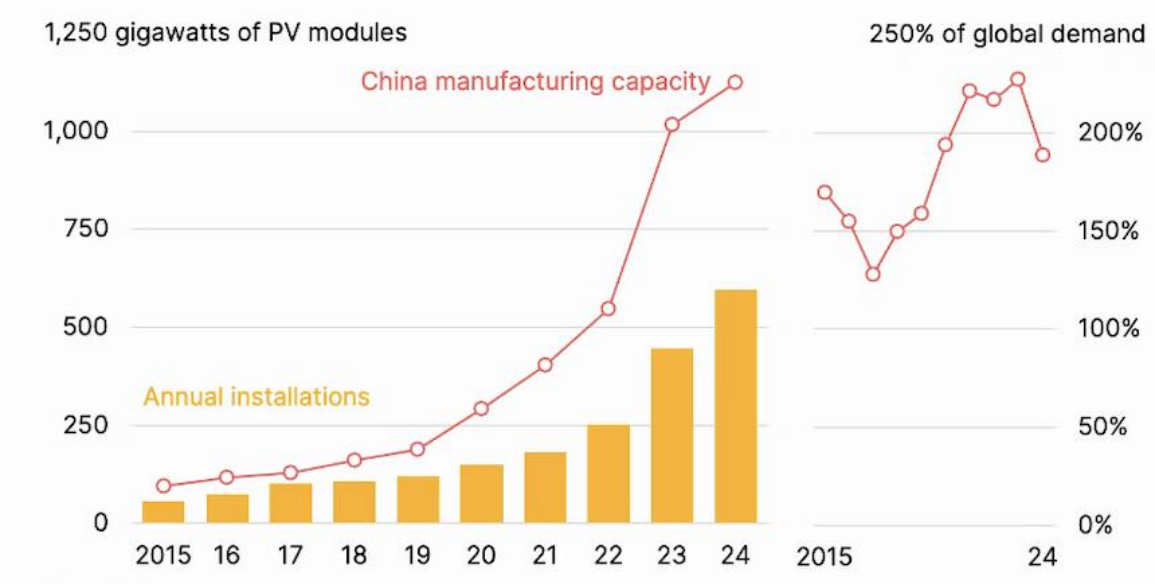
According to Polaris, at the start of 2025, 20 new manufacturing projects were announced, signed, or broke ground. A further 163GW of new solar PV component manufacturing capacity is planned.[175] Policymakers in other jurisdictions should understand that the Chinese focus is far from maximising profit; it is centred on aggressively growing total market growth whilst continuing to increase market share over the long term and achieving this by manufacturing the latest solar PV technology and supporting local employment in the provinces.

Consequently, Chinese manufacturers are willing to endure short-term price fluctuations while still aggressively pursuing expansion. CEF concludes that the current rebound in module prices will be temporary, as ongoing overcapacity is expected to exert continued downward pressure on prices in the long term. As Wood Mackenzie recently forecast,[176]

[170] Dialogue Earth, Why China's clean energy need not fear US tariffs, 9 January 2025
[171] CEF, Green capital tsunami: China's >$100 billion outbound cleantech investment since 2023 turbocharges global energy transition, October 2024
[172] PV-Tech, Solar and Daqo New Energy announce polysilicon production cuts, 31 December 204
[173]Wood Mackenzie, The impact of China's 2024 solar PV manufacturing guidelines, 13 December 2024
[174] PV-Magazine, Solar module downward price trend has been reversed, 24 February 2025
[175] PVTime, 163GW! 20+ PV-related Projects Launched in China in January 2025, 25 February 2025
[176] PV-Magazine, 'Solar module prices will soon go back to over $0.12/W', 27 February 2025

these sustained pressures will likely accelerate consolidation among smaller and financially weaker Tier 2 and 3 manufacturers that cannot withstand prolonged price volatility and operational challenges.[177] Given the sector's substantial surplus capacity, global solar PV supply will remain well ahead of continued strong global demand growth, and balance will remain elusive through 2026 — see Figure 4.4. The key global positive of this is that global solar PV installation growth will continue to surprise on the upside, stimulated by both the fact solar PV is now the lowest cost source of new energy capacity and the massive value enhancement that solar plus BESS now offers.

Figure 4.4: China's Solar PV Module Manufacturing Capacity



Source: Nat Bullard using BNEF data[178]

Another consequence of fierce competition and oversupply has been a sharper focus on innovation and technology enhancements as manufacturers seek to differentiate their products. LONGi, for example, has said it plans to "strategically contract" and focus on R&D, including back contact cells, while Trina Solar and Canadian Solar are prioritising N-type cells and advancements in PERC technology – refer to Section 1.4.[179]

China Also Controls Global BESS manufacturing

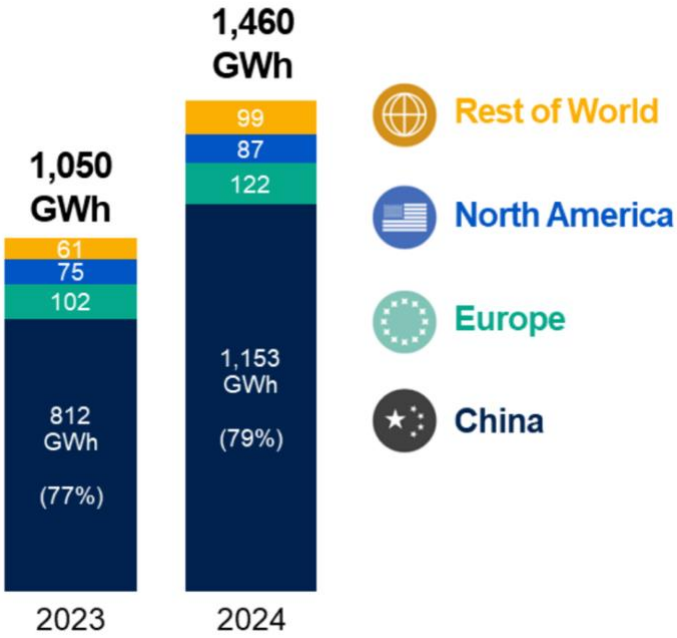
China's dominance in the global clean technology supply chain extends beyond solar PV to BESS manufacturing. At the end of 2024, China had almost 80% of the world's 1.5TWh lithium-ion Phosphate BESS manufacturing capacity — see Figure 4.5. In 2024, Chinese companies accounted for 93.5% of total global BESS shipments.[180]

Despite the 40% yoy decline in battery prices in 2024, CATL reported its CY2024 net profit was +15% yoy to Rmb50bn (US$7.0bn), on revenues -10% (volumes up dramatically, mostly offsetting price deflation).[181]

[177] PV-Tech, Tsunami of Chinese solar company insolvencies in 2025 revealed in latest PV Tech Bankability Report, 31 October 2024
[178] Nat Bullard, Decarbonization: 2021, The Complex, Reagents, January 2025
[179] SCMP, China's Trina Solar sets world record for solar conversion technology, 6 January 2025
[180] Xinhua News, China's energy developments in January 2025, 16 January 2025
[181] Reuters, China's CATL sees slowest profit growth in six years, 15 March 2025

Most of the EU and the US's BESS is currently imported from China, noting this will progressively decrease with increased tariff barriers and China's response of localising manufacturing. China is leveraging its control over the growing global manufacturing base, vertical integration of supply all the way to the mining and refining sectors, plus massive R&D investment, automation and robotics, low capital and operational costs to create considerable cost advantages over other jurisdictions — see Figure 4.6. Chinese firms like CATL and BYD are uncatchable world leaders.

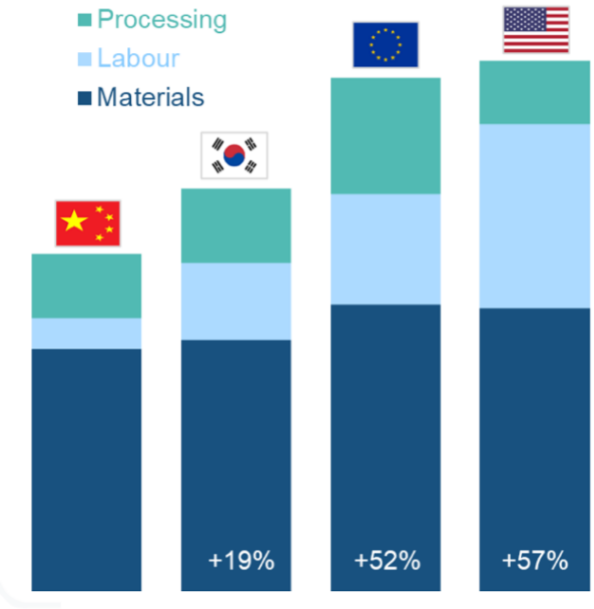
Figure 4.5: Global Lithium-Ion Phosphate Manufacturing Capacity



Source: Volta Foundation[182]

[182] Volta Foundation, Battery Report 2024, January 2024

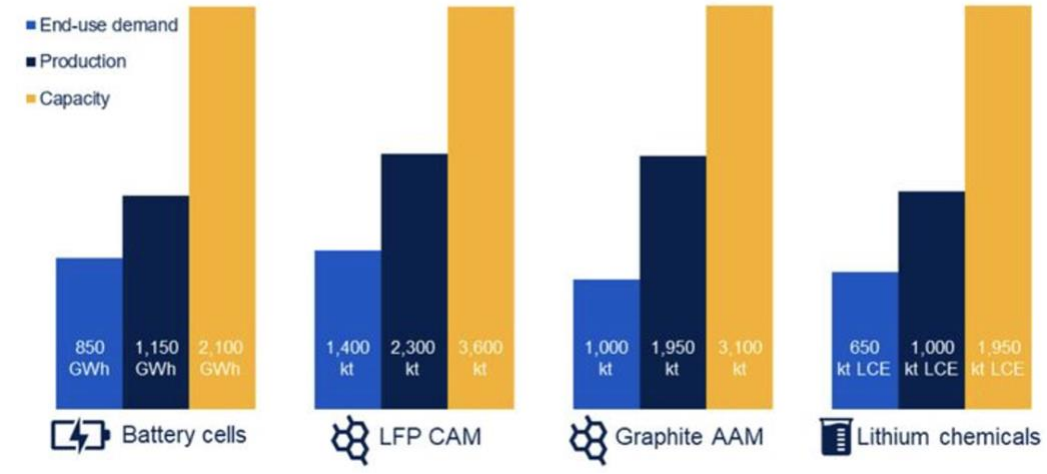
Figure 4.6: Average Battery Cell Production Costs US$/kWh (2024)



Source: Volta Foundation

In 2024, significant overcapacity and continued critical mineral and lithium commodity price deflation combined to drive down prices across the BESS value chain — see Figure 4.7. For example, over 2024, lithium prices plummeted by over 22% yoy,[183] contributing to a substantial decline in lithium-ion BESS costs. The global weighted-average BESS price dropped to US$115/kWh, with bids as low as US$61–82/kWh for some tenders in China.

Figure 4.17: Demand, Production Capacity Across BESS Sectors (2024)



Source: Volta Foundation

In June 2024, China's Ministry of Industry and Information Technology finalised revised guidelines for the country's BESS industry in response to overcapacity. These new guidelines set higher standards for energy intensity, power density, cycle life, and other battery specifications.[184] The industry is also responding to oversupply by cancelling planned

[183] Investing News Network, Lithium Market 2024 Year-End Review, 31 December 2024
[184] Financial Times, Chinese battery industry faces consolidation wave, 7 August 2024

expansions and aggressively advancing next-generation technologies. These include solid-state and high-capacity LFP batteries, which promise greater energy efficiency and lower costs.

According to the Volta Foundation, even with cancellations, current and planned Chinese BESS production capacity totals 5,782GWh. Combined with an enormous and growing solar PV manufacturing base, it is unlikely that any other jurisdiction will dislodge China from its leading position. RhoMotion forecasts China's BESS deployments will triple between 2024 and 2033,[185] a forecast CEF would suggest is likely to prove very conservative.

Policymakers should recognise that absent sustained and substantial public financial support of the scale and ambition of former President Joe Biden's Inflation Reduction Act, tariffs are ineffective in containing Chinese companies' relentless expansion. Erecting further trade barriers with China would only trigger cost inflation for their own VRE initiatives, slow rollout, and increase consumer electricity costs. China's manufacturing scale and technology lead are also so considerable that directly competing profitably is unlikely. This reality should prompt a pivot to collaboration and joint ventures rather than direct competition. Stellantis' battery manufacturing joint venture with CATL in Spain in December 2024[186] is a clear example of a more effective win-win investment outcome.

[185] Benchmark Minerals, Chinese battery energy storage market to triple by 2033, 21 February 2025

[186] Stellantis and CATL to Invest Up to €4.1 Billion in Joint Venture for Large-Scale LFP Battery Plant in Spain, 10 December 2024

Section 4.1: Chinese Solar PV Manufacturing Company Examples

Through 2024, China's leading solar PV manufacturers were ramping up production, expanding capacity, and concurrently breaking solar PV efficiency records, underscored by Jinko Solar's massive 56GW per annum (pa) integrated facility in Shanxi and record 33.84% tandem perovskite cell efficiency. As overcapacity erodes margins, even major players are financially strained. Yet Chinese firms continue to operate and even expand in this hyper-competitive environment, driven by a long-term focus on complete market control only achieved by outlasting competitors. Only with significant tariff protection, or sustained policy support and/or joint venture (JV) partnerships can any global competitors remain viable.

JinkoSolar 晶科能源

JinkoSolar Holding Co., Ltd continues to lead the global solar PV market, shipping more than 90GW of modules in 2024.[187] N-type technology accounts for 90% of its shipments. JinkoSolar and JA Solar have been selected to supply 2.6GW of high-efficiency N-type modules for the UAE's Masdar giga-scale solar PV + BESS hybrid project.[188]

JinkoSolar estimates that its 2024 production capacity will total 120GW for wafers, 95GW for cells, and 130GW for modules, with an average module efficiency of 26.2%.[189] To differentiate itself, JinkoSolar continues to invest heavily in R&D. In January 2025, JinkoSolar achieved an N-type TOPCon-based perovskite tandem solar cell conversion efficiency of 33.84%, surpassing its previous May 2024 record of 33.24%.[190] JinkoSolar holds over 2,800 issued patents, including 462 for N-type TOPCon technology.[191]

In October 2024, the company announced plans to raise up to US$4.5bn in global depository receipts (GDRs) to support its US 1GW module factory, and the expansion of its major solar PV manufacturing project at the Xiaoxiao River Industrial Park in Shanxi — which commenced construction in March 2024.[192]

JinkoSolar's four-phase, 56GW vertically integrated facility in Shanxi consolidates all critical production processes—including silicon pull rod fabrication, wafer production, solar cell manufacturing, and N-type module assembly—within a single site. This move reflects JinkoSolar's broader strategy to optimise logistics, enhance production efficiency, and lead in N-type module technology.

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[187] PVTime, China's domination is unequivocal, driven by unparalleled production scale, vertical integration, robust R&D investment, and a policy environment that supports aggressive expansion, 31 January 2025
[188] EnergyTrend, JinkoSolar's Perovskite Tandem Solar Cell Based on N-Type TOPCon Sets New Record with Conversion Efficiency of 33.84%, 22 January 2025
[189] JinkoSolar, JinkoSolar Announces Third Quarter 2024 Financial Results, 30 October 2024
[190] PR Newswire, JinkoSolar's Perovskite Tandem Solar Cell Based on N-Type TOPCon Sets New Record with Conversion Efficiency of 33.84%, 22 January 2025
[191] JinkoSolar, JinkoSolar Files Patent Infringement Lawsuit Against VSUN and Others, 12 July 2024
[192] PV Magazine, Chinese PV Industry Brief: JinkoSolar Breaks Ground on 56 GW PV Panel Factory in Shanxi, 29 March 2024; EnergyTrend, JinkoSolar Expands N-Type Solar Cell Production Capacity with New Facilities, 21 October 2024

February 2025 saw JinkoSolar announce its enormous 20GW wafer plus 20GW cell facility in Sichuan is nearing completion, with operations beginning in March 2025 and full production by June 2025.[193]

March 2025 saw JinkoSolar release its preliminary unaudited financial results for FY2024. The company reported a 22% yoy decline in revenue, totalling Rmb92.62bn (US$12.8bn).[194] Additionally, net profit saw a sharp decrease of 99%, falling to Rmb90m (US$12.5m). The company acknowledged these financial setbacks were primarily due to a decline in PV product prices.

LONGi Green Energy Technology 隆基绿能科技

LONGi Green Energy Technology Co., Ltd is an industry giant. Its reported module shipments totalled 51.2GW over the first three quarters of 2024, a 17.7% yoy increase.[195] Over the past five years, LONGi has significantly increased its R&D investment to try to protect itself from industry overcapacity.[196]

In 2024, LONGi achieved a breakthrough with its HPBC2.0 technology, recording a cell efficiency of 26.6% and a module conversion efficiency of 24.43%. It also achieved a record for two-terminal tandem perovskite solar cells, hitting a power conversion efficiency of 34.6%.[197]

LONGi's expansion plans are ambitious. On 8 January 2025, the environmental impact assessment of LONGi's Rmb1.2bn (US$170m) 5GW module factory in Yulin was approved. By the end of 2025, the company aims to build 70GW of BESS production capacity[198] and the first phase of a 16GW cell manufacturing facility, co-developed with Yingfa Ruineng.[199] By the end of 2027, LONGi aims to expand its annual production capacity to 200GW for wafers, 100GW for cells and 150GW for modules[200] — up from 170GW, 80GW, and 120GW for each in 2023.[201]

Despite positive momentum, LONGi has forecast a net loss for 2024 between Rmb8.2-8.8bn (US$1.1-1.2bn), marking its first annual loss since 2013.[202] The loss is primarily attributed to a low percentage of BC 2.0 product production, declining prices and gross margins for its PERC and TOPCon products, limited capacity utilisation, increased asset impairment provisions, and losses from its silicon investments.

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[193] PVTime, 40GW! Solar Cell Factory to Start Operations in Sichuan, China, 19 February 2025
[194] Taiyang News, China Solar PV News Snippets: Top PV Rank For Trina In Sustainable Fitch Ratings & More, 6 March 2025
[195] LONGi, LONGi reports Q3 2024 financial performance with revenue of CNY 58.593 billion and 51.23 GW in module shipments, 11 November 2024
[196] PV-Tech, LONGi Ships 51GW Modules in 9M 2024, Financial Losses Continue,11 November 2024
[197] PV Magazine, LONGi Achieves 34.6% Efficiency for Two-Terminal Tandem Perovskite Solar Cell Prototype, 12 September 2024
[198] PV Magazine, LONGi Introduces 665 W HPBC Photovoltaic Modules, 11 October 2024
[199] PV Time, 16GW HPBC Solar Cell Factory Signed by LONGi and Yingfa in Sichuan, China, 6 November 2024
[200] LONGi, Half-year Report 2024: LONGi achieved revenues of €5.03 billion - Return to growth expected by 2025 with new HPBC 2.0 back contact series for DG market, 18 September 2024
[201] LONGi, LONGi Releases 2023 Annual Report: Advancing BC (Back-Contact) Technology and Facing New Industrial Cycle, 30 April 2024
[202] PV-Magazine, Chinese PV Industry Brief: Longi issues net loss warning for 2024, 17 January 2025

Tongwei 通威

Tongwei Co., Ltd is a fully vertically integrated global solar PV manufacturing leader. Its production capacity includes 850,000tpa of polysilicon, 20GW of ingots and wafers, 126GW of cells, and 85GW pa of modules.[203] By 2026, Tongwei plans to increase its cell capacity to 130- 150GW. In 2024, the company reported shipping 45-47GW of modules, a ~50% yoy increase. In Q4 alone, the company shipped 15-17GW modules.

Tongwei has invested significantly in R&D, with US$569m allocated in 2024 (X% of revenue). In June 2024, the company opened their Global Innovation and R&D Centre in Chengdu, China. The facility covers an area of 270,000 square meters, with 108,000 square meters dedicated to R&D workshops.[204] Tongwei's new 25GW N-type cell factory in Shuangliu has commenced production. The company's N-type cell capacity is expected to exceed 100GW by the end of 2025.[205]

In August 2024, Tongwei announced its intention to acquire a controlling stake in Runergy for Rmb5bn (US$698m). This move was expected to strengthen Tongwei's presence in the US market, as Runergy is constructing a 5GW solar module plant in Huntsville, Alabama.[206] Runergy operates a total production capacity of 57GW of cells and 13GW of modules. However, February 2025 saw Tongwei withdraw from the planned acquisition, likely anticipating far more favourable terms as ongoing oversupply continues to increase financial pressure on the industry.[207]

On 9 January 2025, Zhongwei New Energy, a wholly owned subsidiary of Tongwei, received approval for a 20GW silicon wafer manufacturing project.[208] The first phase, located in Sichuan, involves an investment of ~Rmb700m (USD$97m). Construction is expected to finish by September 2025.

However, Tongwei was still subject to the intense pressures felt across the industry and has forecasted a net loss of up to ~Rmb7.5bn (US$1bn)[209] and attributed this to the challenging market environment throughout 2024.

Other Solar PV Companies

TCL Zhonghuan - Huansheng New Energy 华盛新能源

In August 2024, Huansheng New Energy Co., Ltd a subsidiary of TCL Zhonghuan, completed the first phase of its 10GW module factory in Inner Mongolia.[210]

On 10 January 2025, Aiko Solar began producing n-type modules at its new facility in Jinan, which has a planned total capacity of 30GW for cells and modules by 2029.[211]

[203]Taiyang News, Tongwei Solar PV Cell R&D & Module Updates,31 January 2024
[204] Tongwei, Tongwei Expands Solar Manufacturing with New Capacity Additions, 2 January 2024
[205] EnergyTrend, Tongwei Announces New Solar Capacity and Expansions, 8 November 2024
[206] Reuters, Chinese Solar Firm Tongwei Plans to Take Controlling Stake in Runergy for $698 Million, 14 August 2024.
[207] PV-Magazine, Tongwei drops plan to acquire Runergy, 24 February 2025
[208] PVTime, 163GW! 20+ PV-related Projects Launched in China in January 2025, 25 February 2025
[209] PV-Magazine, Chinese PV Industry Brief: JinkoSolar, TBEA report lower profits, 21 January 2025
[210] EnergyTrend, The First Phase of TCL Zhonghuan 10GW Module Project in Inner Mongolia Was Put Into Production, 22 January 2022
[211]PV Magazine, Chinese PV Industry Brief: Aiko Solar starts making back contact PV panels, 10 January 2025

Grand Sunergy

Grand Sunergy Tech Co., Ltd installed the first equipment for its 5GW HJT module project in Shandong on 17 January 2025. The project will be developed in three phases. The company will[212] invest Rmb30bn (US$4.09bn) in its solar PV manufacturing by the end of 2025, targeting average cell efficiencies above 25%.

DMEGC Solar

On 29 January 2025, DMEGC launched the second phase of its cell plant in Sichuan province, adding 6GW of TOPCon cell capacity. This milestone is part of the company's broader goal of 20GW pa cell production capacity, with the first two phases contributing a combined 12GW. The total investment for these stages is ~Rmb3.55bn (US$487m).[213]

SPIC New Energy

On 19 February 2025, SPIC New Energy Science & Technology Co., Ltd began construction on a 10GW HJT cell and module project in Jiangxi. The facility, developed in two phases, represents a total investment of Rmb8bn (US$1.1bn). Production is expected to commence in October 2025.[214]

Although last financial year was extremely challenging for these manufacturers, they are continuing to push ahead with significant expansion plans, invest in R&D and explore diversifying into emerging markets. This seems irrational. However, policymakers in other jurisdictions should understand that short term earnings fluctuations are not a determinant of continued company operation or ambitions. In many ways the core of the Chinese mindset is as long as they can outlast their competitors, they will enjoy the future market alone. The only way for competitors to remain viable in this cutthroat global marketplace, driven by the Chinese, is either significant tariffs and barriers or substantial policy support combined with strategic partnerships with Chinese market leaders. CEF recommends the latter.

A summary of new Chinese solar manufacturing facilities just in January 2025[215] suggests no sign of any slowdown in capacity expansions even from Chinese firms outside the top 10 majors, despite the growing oversupply and record low pricing across the whole module supply chain.

[212] PV Tech, Grand Sunergy: First equipment delivered to Laizhou 5GW HJT project, 19 January 2025
[213] Taiyang News, China Solar PV News Snippets: DMEGC Commissions 12 GW Sichuan Solar Cell Fab & More, 29 January 2025
[214] Taiyang News, China Solar PV News Snippets: Jinko ESS On BNEF's Tier 1 List Again & More, 18 February 2025
[215] PVTime, 163GW! 20+ PV-related Projects Launched in China in January 2025, 25 February 2025

Section 5: China Outbound Foreign Direct Investment

China's outbound foreign direct investment (OFDI) in clean technology accelerated in 2024. Chinese companies are securing commanding positions in key regions like MENA and ASEAN through large-scale solar PV and BESS projects, joint ventures, and supply agreements, consequently completely transforming global energy markets at an unprecedented pace. While some nations attempt to counter this influence with tariffs and industrial policy, China's ability to leverage its technology leadership, supply chains, equity and scale, adapting and integrating into emerging markets gives it a powerful advantage.

China's overseas foreign direct investment reflects a government goal of expanding global influence. By fostering cooperation and creating goodwill, each successful clean technology project bolsters China's image as a development partner. This potentially translates to support for Chinese priorities, access to resources and support in international forums. Chinese companies are using investments in other jurisdictions to circumvent protectionist trade barriers while tapping into growing markets. China's government and its companies are achieving these objectives through strategic partnerships with foreign investors and governments, concentrating on completely dominating clean technology globally.

Much of the world's attention has been focused on China's Belt and Road Initiative—which supported the installation of 8GW of solar PV in 2024. However, the BRI represents only a part of China's OFDI.[216] CEF estimates that since 2023, Chinese companies have invested over US$140bn in clean technology projects outside China.[217] This sum is a portion of a thundering capital stampede of Chinese OFDI, with total ODFI increasing over 11% yoy in CY2024.[218] In 2024, the clean technology OFDI pattern was characterised by larger deals and deeper market integration, multi-GW projects, Chinese firms as the preferred product suppliers and builders, long-term PPAs, forming consortia that blend Chinese capital with local partners, such as state utilities, developers, and investment funds.

China is Investing Heavily in Offshore Solar PV and BESS Generation Projects

In terms of energy generation, China is moving at pace to supply, build or develop projects across the world. In November 2024, in the UK, China's Sungrow signed a supply contract with Fidra Energy for a 1.45GW/2.9GWh BESS in South Yorkshire and another 500MW/1,000MWh BESS in Nottinghamshire. [219] In Australia in November 2024, China's Jinko Solar proposed a 600MW solar PV plus 400MW/800MWh BESS project in Queensland.[220] While in the EU, December 2024 saw Northleaf Capital and Qualitas Energy sell their 494MW Spanish solar PV plant to China Three Gorges for US$449m.[221] In Latin America, in December 2024, Power China signed an EPC contract for the 530MW 'Sajalices Photovoltaic Project' in Panama.[222] Similarly, China's BYD and CATL are the suppliers for the

[216] PV-Magazine, China installed 8 GW of solar in 'Belt and Road' countries in 2024, 27 January 2025
[217] CEF, Green capital tsunami: China's >$100 billion outbound cleantech investment since 2023 turbocharges global energy transition, October 2024
[218] China Briefing, China Outbound Direct Invest (ODI) Tracker: 2024-25, 5 February 2025
[219] PV-Magazine, Developers Fidra and Innova secure planning consent for two UK BESS, totalling over 5GWh, 9 October 2024
[220] RenewEconomy, China solar giant Jinko seeks federal approval for massive PV and battery project in Queensland, 27 November 2024
[221] China Three Gorges, China's CTG Said to Ink Deal for Northleaf's Spanish Solar Plant, 30 December 2024
[222] PowerChina, POWERCHINA to develop solar power in Panama, 25 December 2024

massive BESS being installed in Chile as part of the Oasis de Atacama solar PV plus storage project — see Section 9.

In 2024, the most important trend CEF observed was the Chinese focus on strategic partnerships and massive multiphase projects in Southeast Asia, MENA, and the Global South more broadly. Government renewable energy targets, utility auctions, incentive programs, and long-term PPAs have attracted Chinese companies to these regions.

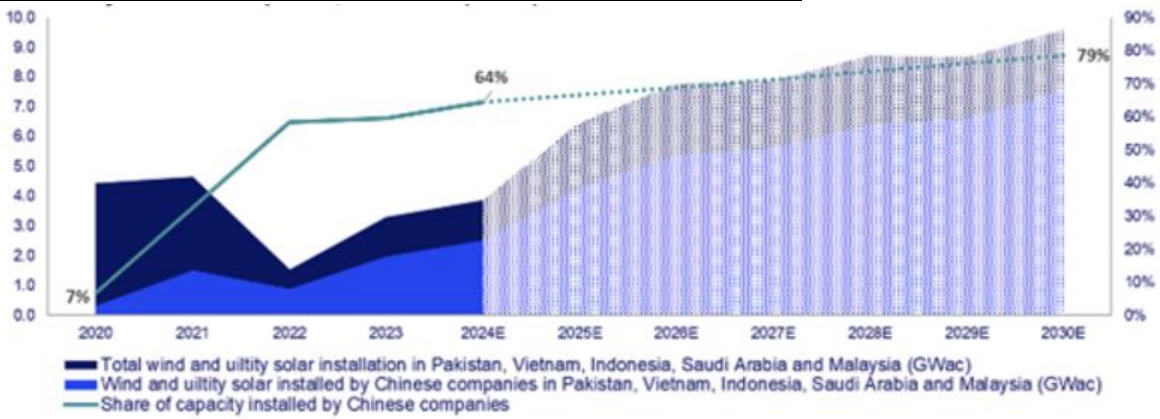
This trend is exemplified by EPC contractor PowerChina partnering with the Philippines' Meralco in December 2024, to build the Terra Solar Philippines' 3,500MW solar PV plus 4,500MWh BESS 'MTerra' project.[223] China's Huawei will provide batteries for the project.[224] The project is underpinned by a 20-year PPA.[225] In February 2025, two other solar PV projects in the Philippines, with a combined capacity of 750MW, had significant announcements, and both involved Chinese companies.[226]

In Cambodia, in late 25 February 2025, China's Shanxi Institute, a subsidiary of China Energy Engineering Corporation, won a US$233m EPC contract to develop the 250MW 'Prey Veng Solar Farm' in Cambodia,[227] targeting March 2026 for commissioning. The project will contribute to Cambodia reaching its target of 1GW of solar PV capacity by 2030.

In MENA, in December 2024, the UAE's Masdar and China's Silk Road Fund signed an MoU to invest up to US$2.8bn in VRE projects jointly.[228] China is now involved in 50% of all projects currently in progress in the UAE.[229] To achieve Saudi Arabia's 50% VRE by 2030 target, February 2025 also saw China's BYD sign a deal with the Saudi Electricity Company to supply, install and operate 12.5GWh of BESS across five sites.[230] In December 2024, in Egypt, Trina Solar and Energy China ZPTC signed a contract with AMEA Power to supply 300MWh of BESS to the 'Abydos Solar Power Plant.'[231] To illustrate the growing enmeshment of Chinese companies in these regions, Wood Mackenzie is projecting that Chinese companies will build almost 80% of new wind and solar PV capacity in Pakistan, Indonesia, Vietnam, Saudi Arabia and Malaysia by 2030 — see Figure 5.1.

[223] PowerChina, POWERCHINA signs contract for Southeast Asia's largest photovoltaic project, 2 December 2024
[224] PV Tech, Huawei to provide 4.5GWh BESS for Philippines Terra Solar project, 10 December 2024
[225] AsianPower, MGen's $4b Terra Solar plant to aid Philippine RE transition, October 2024
[226] PV Tech, CHINA ROUND-UP: CEEC active in Cambodia and the Philippines, CECEP subsidiary starts construction at 650MWp project, 21 February 2025
[227]Thailand Construction, Chinese firm Shanxi Institute wins bid for $230M solar project in Prey Veng, Cambodia, 25 February 2025
[228] NS Energy, Masdar and China's SRF to co-invest up to $2.8bn in renewable energy projects, 25 November 2024
[229] SCMP, Chinese firms forge ties with UAE as Gulf nation acts as 'superconnector' in global trade, 17 December 2024
[230] PV-Magazine, BYD to supply 12.5 GWh of battery storage in Saudi Arabia, 17 February 2025; ESS-News, Saudi Electricity Company awards 12.5 GWh battery storage contracts to China's BYD, 13 January 2025
[231] ESS-News, AMEA Power picks Trinasolar to supply BESS for Africa's largest single-site solar PV plant, 24 December 2024

Figure 5.1: Wind and Solar Newbuild Capacity in Pakistan, Indonesia, Saudi Arabia, Malaysia and Capacity Installed by Chinese Companies (GWac)



Source: Wood Mackenzie[232]

China is Establishing Manufacturing Footholds in Key Emerging Markets

Chinese companies are also moving far beyond developing VRE projects and exporting solar PV and BESS to building entire value chains abroad. By investing in overseas projects, Chinese companies see an opportunity to diversify their revenues and supply chains. For example, Chinese companies simply dominate planned EU BESS manufacturing, making up 65% of the project pipeline through to 2030. This is underscored by the Stellantis-CATL joint venture in Spain (see Section 9) and the February 2025 announcement of CALB's first overseas battery factory worth $US2.1bn in Portugal, with construction planned to commence in 2027.[233] Both countries have been actively fostering a supportive policy environment for these investments.

Chinese manufacturers not only dominate the EU's imported solar PV market but are also expanding their manufacturing presence within the region. In October 2024, Trina Solar was awarded financial support through the European Commission's Innovation Fund for its planned 1.5GW pa module factory in Spain.[234] The European Commission's Innovation Fund is capitalised by the EU Emissions Trading Scheme, which internalises the negative externalities of carbon emissions from emitters, including coal and methane gas-based electricity generators in the EU, to subsidise the commercialisation of low-emission energy and industrial technologies, including renewable energy generation and storage manufacturing.

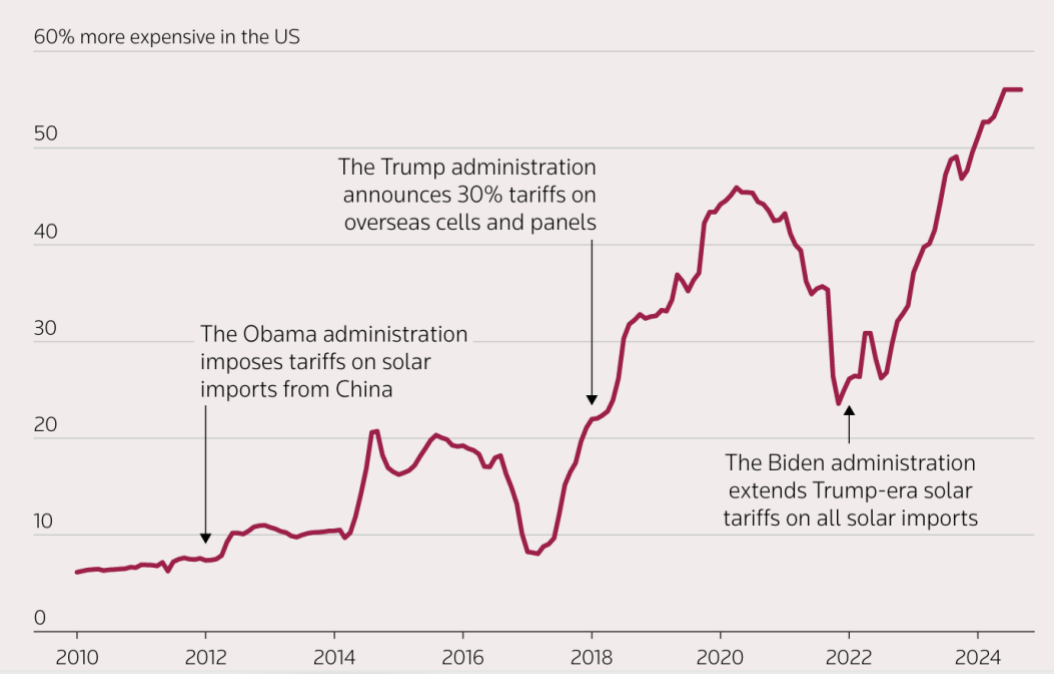
In November 2024, DAS Solar announced they would invest US$115m into building a 3GW pa module factory in France, to be operational in 2026.[235] With EU solar PV and BESS manufacturing projects being delayed or cancelled due to pressure from low-cost Chinese suppliers, EU policymakers are being forced to rethink their industrial strategy.

[232] Wood Mackenzie, Record year for Chinese overseas power projects: 24 GW installed in Belt & Road countries, 27 January 2025
[233] CNEVPOST, CALB breaks ground on battery plant in Portugal as Chinese battery maker begins deploying capacity overseas, 25 February 2025
[234] PV Tech, European Commission invests in 3GW of solar PV manufacturing from Trina Solar and FuturaSun, 28 October 2024
[235] PV-Magazine, Solar to build 3 GW solar module factory in France, 19 November 2024

Chinese companies have been attracted to the US market by IRA incentives.[236] In February 2024, Invenergy, in a joint venture with China's LONGi, commenced operations at their 5GW pa solar module factory in Ohio.[237] October 2024, also saw Runergy commission their 2GW pa module factory in Alabama.[238] Chinese companies had planned to develop more than 20GW of solar PV component manufacturing capacity in the country by the end of 2025.[239]

Yet, the new US Administration's retrograde policy changes, including increasing trade barriers on China, are risking all of this. Tariffs can protect domestic manufacturers but at the cost of increasing costs for domestic consumers — see Figure 5.2. Combined with the Administration pausing incentives under the IRA and freezing DoE loans, Chinese companies are increasingly cautious about further direct investment in the US Market and have moved into SEA and other markets to skirt these barriers.

Figure 5.2: Price Difference for Mono-module Solar Panels Sold in the U.S. vs. in China



Source: Reuters[240]

By expanding into SEA, Chinese companies can supply Western energy consumers by circumventing trade barriers while also securing a foothold in countries with rapidly growing energy demand. To date, much of China's solar PV manufacturing investment in SEA has been in Vietnam, Thailand, Cambodia, and Malaysia. However, in late 2024, the US imposed significant antidumping/countervailing duties on panels (up to +271%) exported from these countries.[241]

These new duties have exerted considerable financial pressure on Chinese manufacturers and prompted production cuts and idling factories in countries like Vietnam.[242] In Malaysia,

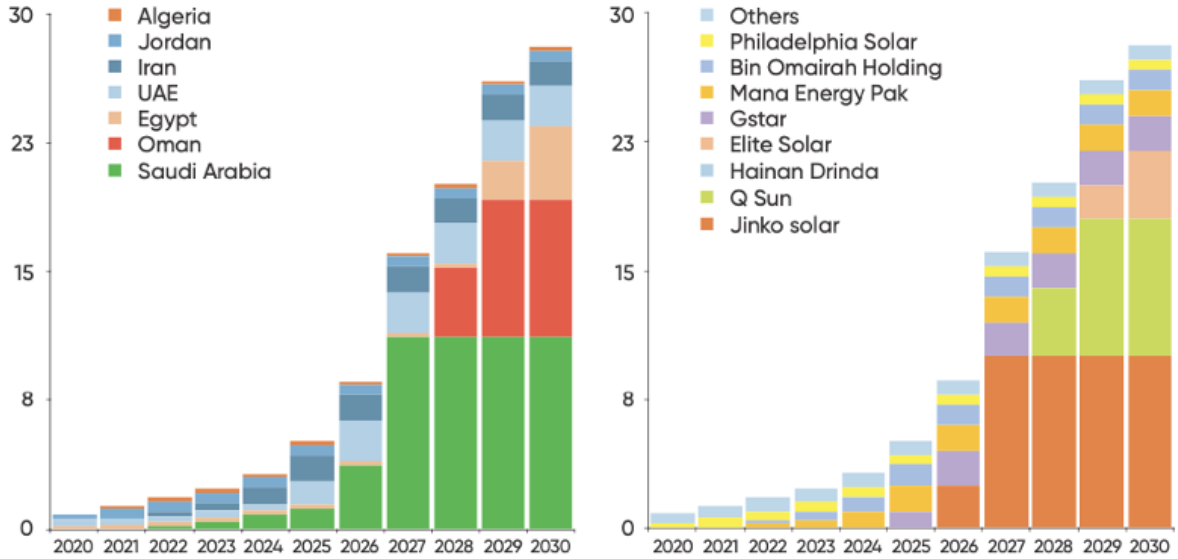
[236] Asia Financial, China Solar Firms Are Taking Over US And No One Can Stop Them, 17 July 2024
[237] SAN, US renewable energy subsidies benefit a Chinese solar company in Ohio, 30 October 2024
[238] PV Tech, Runergy commissions 2GW Alabama module production plant, 4 October 2024
[239] Reuters, Chinese solar firms go where US tariffs don't reach, 5 November 2024
[240] Reuters, US solar tariffs can't keep up with Chinese firms, 4 November 2024
[241] PV-Magazine, US sets antidumping duties for Southeast Asian solar cells, 2 December 2024
[242] Reuters, Chinese solar firms go where US tariffs don't reach, 5 November 2024

the effect has been significant; JinkoSolar, JA Solar, Risen, and others have pulled back from further investment,[243] while LONGi, responsible for over 37% of Malaysia's solar PV production capacity, has also suspended its expansion plans. Chinese manufacturers account for nearly 80% of Malaysia's total solar PV production capacity, and they have responded by simply shifting production to currently tariff-exempt countries such as Indonesia and Laos.

Since mid-2023, some 23GW of new cell and module production capacity was added in Indonesia and Laos — equivalent to nearly half the solar PV capacity the US installed in 2024. Both countries' governments are actively attracting this investment. For example, in November 2024, Indonesia and China signed a US$10bn agreement to collaborate on VRE, batteries, and the digital economy in Beijing. On the same day, Indonesian nickel company PT Merdeka Battery Materials announced a deal with China's GEM to construct a US$1.8bn plant for producing nickel material used in batteries.[244] On 17 March 2025, Chinese EV maker, Xpeng, announced that it would build production facilities in Indonesia, it's first overseas plant.[245] US trade policy has effectively accelerated Chinese diversification into third-country clean technology manufacturing.

A similar phenomenon is happening in MENA. Saudi Arabia is leading the region in attracting investment from Chinese solar PV companies, but the region as a whole is seeing multi-billion-dollar investments from Chinese companies — see Figure 5.2.

Figure 5.2: Solar Manufacturing by Country and by Company (GWAC)



Source: MESIA[246]

Chinese companies are moving aggressively into the region. They are attracted by free trade zones, affordable land, zero tariffs, strong government support, growing local demand and a strategic position to service emerging markets and Western markets. As Helen Li, President

[243] Magzter, China solar panel makers close plants, scale back production in Malaysia as US tariffs bite, 21 January 2025
[244] Asia-Financial, China-Indonesia Sign $10bn in Deals on EVs, Batteries, Solar, 11 November 2024
[245] CNEVPOST, Xpeng forays into Indonesia, to start local production in H2 2025, 17 March 2025
[246] MESIA, Solar Outlook Report 2025, January 2025

of China's Trina Solar, said in November 2024, "It's not just building a factory, it's a strategic investment for the country to look at their green energy. We like to work in those markets where people have a vision of where they want to be."[247] Three months later, in February 2025, TrinaTracker, a subsidiary of Trina Solar opened a 3GW pa solar PV tracker factory in Jeddah, Saudi Arabia.[248] The Saudi Authority for Industrial Cities and Technology Zones supported the project through a land lease agreement.

Close by in Egypt, in December 2024, China's Elite Solar began construction on a US$150m 2GW pa cell and module factory in the country's 'Suez Canal Economic Zone' (SCZONE),[249] which is an area specifically designed to attract foreign investment with US$3bn worth of enabling infrastructure such as ports, waterways and roads.[250] SCZONE also provides financial incentives such as customs exemptions for products exported to multiple regions globally.

Elite Solar is aiming to expand to 8GW of production capacity in Egypt over time. The company's chairman, Derek Liu, said the venture will "position Egypt as a central hub for photovoltaic manufacturing in the Middle East and North Africa."[251] This 2GW project was part of a larger US$1bn deal signed in Beijing between SCZONE and six other Chinese companies aiming to produce other material inputs for solar PV and green hydrogen.

By 2030, Chinese companies are set to control the majority share of module manufacturing capacity in MENA as they do in SEA. For the host countries, the drivers to attract this investment are straightforward: They need to deploy VRE generation quickly to meet their climate targets and growing energy demand. Chinese companies offer a one-stop solution with affordable financing, proven technology, established supply chains, expertise, and fast deployment. Host countries are actively capturing this investment through providing land, capital, and policy support. Chinese companies are not considering jurisdictions with the possibility of increased tariff barriers.[252]

Policymakers in other jurisdictions should take note: imposing trade barriers on China will only redirect investment to other regions poised to benefit from its technological leadership. China is the energy gift horse of this century—why shut the stable door? Many nations are already positioning themselves by offering generous incentives. To stay competitive, other countries must actively attract this opportunity. Effective policy measures should include zero tariff barriers, investment in industry hubs and zones, expanding investment rules to facilitate JVs and partnerships, expansion of VRE generation to ensure low-cost electricity, generous land leases, and a stable, supportive investment environment.

[247] PV-Tech, 'In the future, the supply chain will be diversified', says Trinasolar, 26 November 2024
[248] PV-Tech, TrinaTracker opens 3GW manufacturing facility in Saudi Arabia, 19 February 2025
[249] Renewables Now, China's Elite Solar breaks ground on 2-GW solar factory in Egypt, 18 December 2024
[250] Reuters, Suez Canal Economic Zone set for rapid expansion – chairman, 6 November 2024
[251] Renewables Now, Egypt's SCZONE lines up Chinese projects, incl 2-GW solar cell factory, 10 September 2024
[252] Reuters, Exclusive: BYD considers Germany for third plant in Europe, 17 March 2025

Section 5.1: Chinese Manufacturing Facilities Outside the EU, US and India

China's rapid establishment of solar PV and battery manufacturing capacity in strategic locations across ASEAN and MENA from late 2024 signals a clear shift towards decentralising its technology supply chains. This new wave of investment highlights China's targeted strategy of selecting partner countries with favourable regulatory and policy environments and proximity to key markets. Policymakers in other jurisdictions should emulate these countries' approaches and actively engage with China. However, establishing robust governance frameworks that ensure economic benefits are maximised without compromising national sovereignty, democratic principles, safety, or long-term energy security is also vital.

Chinese Companies are Developing a Portfolio of Manufacturing Projects in SEA

Thornova Solar, the US subsidiary of China's Sunova Solar, began production in its 2.5GW module facility on the island of Batam in Indonesia in November 2024. The company plans to supply PERC and n-type modules to the US market by mid-2025.[253]

December 2024 saw China's Elite Solar begin production in its own Indonesian facility, only seven months after the factory's site was selected.[254] The company has not publicly disclosed the factory's annual production capacity.

December 2024 saw Deye Inverter announce it would invest US$150m in a solar PV equipment and battery factory in Malaysia.[255] The company has not yet released detailed capacity figures.

In January 2025, China's REPT Battero announced it plans to invest US$140m into an 8GWh pa lithium-ion battery plant in Indonesia, focusing on EV and energy storage batteries.[256] Noting that Indonesia has world leading nickel resources.

January 2025 also saw Zhuhai CosMX break ground on its Rmb2bn (US$280m) battery manufacturing project in Kulum City, Malaysia.[257] Production is expected to commence by the end of 2025. The company has not released the factory's final operational capacity.

Chinese Companies are Moving Aggressively into MENA

October 2024 saw China's Hainan Drinda New Energy Technology advancing its planned US$250m 5GW pa cell facility by entering a land agreement with the Sohar Port and Freezone. This facility is the first 5GW of a 10GW solar manufacturing portfolio in Oman. Sohar Port and Freezone require zero import or re-export duties, no personal income tax, provides corporate tax holidays of up to 25 years whilst allowing direct access to the Gulf States and bypassing the Strait of Hormuz.[258]The zone also allows 100% foreign ownership of projects; however, it is recommended that host country companies retain a majority stake in any venture to safeguard national interests.

[253] PV-Magazine, Thornova Solar starts solar module production in Indonesia, 18 November 2024
[254] PV-Magazine, EliTe Solar opens solar cell production facility in Indonesia, 11 December 2024
[255] PV-Magazine, Chinese PV Industry Brief: Deye to build inverter factory in Malaysia, 17 December 2024
[256] PV-Magazine, China's REPT Battero to build battery factory in Indonesia, 15 January 2025
[257] EnergyTrend, Zhuhai CosMX Launches Rmb 2 Billion Battery Project in Malaysia, 25 January 2025
[258] SOHAR Port and Freezone, Welcome to the Gateway of the Gulf, 7 March 2025

In December 2024, JA Solar announced it will invest Rmb3.96bn ($US540m) in a massive 6GW cell plus 3GW module pa facility also in Oman's Sohar Port and Freezone.[259] This followed JA Solar and the UAE's Global South Utilities signing an MoU with the Egyptian government to build a 2GW cell facility and a 2GW module facility in Egypt in November 2024.[260]

These projects highlight Chinese companies and the Chinese government's active pursuit of developing manufacturing footholds in growing markets. They also highlight host countries' establishment of positive investment environments via fiscal and regulatory incentives to attract this investment. For policymakers in other jurisdictions, these effective approaches can be followed. However, potential host countries must safeguard their sovereignty, democratic values, and principles even when pursuing collaboration with international partners such as China. Projects perceived as externally driven or misaligned with national values or interests can quickly erode social license—the implicit public approval critical for long-term legitimacy and stability. While cooperation can bring significant benefits—such as shared knowledge, resources, and innovation—it does not need to come at the cost of compromising a nation's autonomy. Policy settings, investment rules and requirements should be calibrated to ensure this.

[259] List Solar, JA Solar Launches $540M Manufacturing Hub in Oman, 31 December 2024
[260] PV-Magazine, JA Solar plans 2 GW solar cell, module factory in Egypt, 22 November 2024

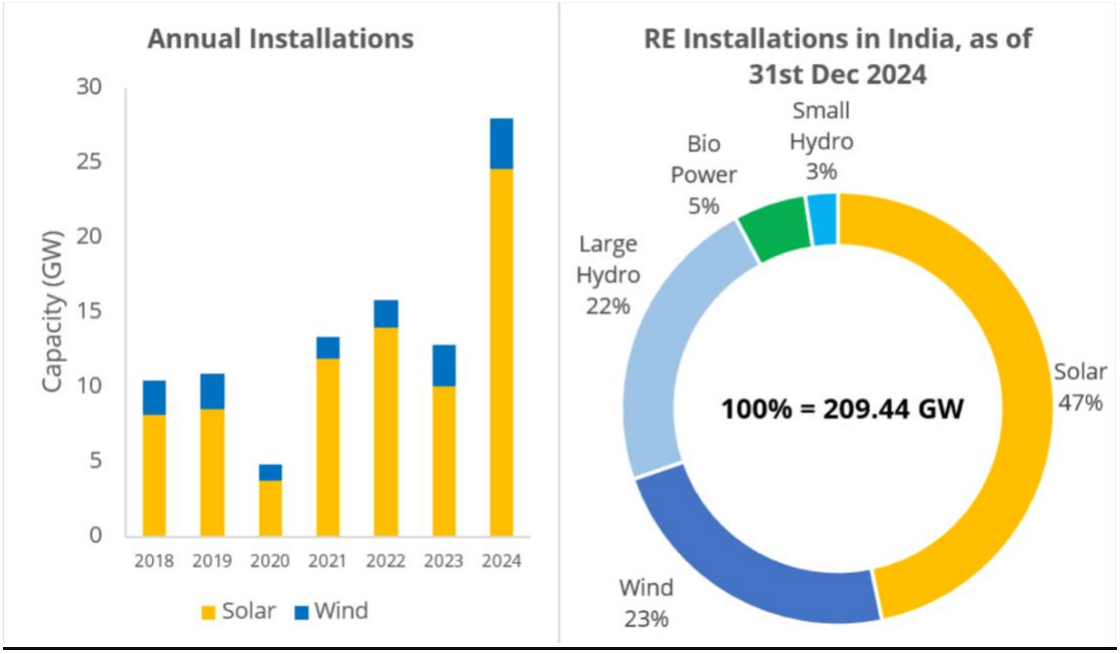
Section 6: India

After years of slow deployment, 2024 marked a turning point for India. A record 24.5GW of solar PV was installed, with cumulative deployments now a total of 100GW. India is now on track to meet its 2030 renewable energy target. While domestic solar PV module manufacturing is rapidly expanding, hitting 80GW at the end of 2024, the country remains heavily reliant on Chinese solar wafers and cells, even as its manufacturers are heavily exposed to the growing risk of US trade sanctions, particularly as Indian exports to the US surge. With the return of US protectionism under President Trump, India can reduce external dependencies by doubling down on driving domestic solar installation rates.

India's Solar PV Installations Rally

In 2021, at COP26 in Glasgow, Indian Prime Minister Narendra Modi committed to deploy a cumulative 500GW of non-fossil fuel generation capacity by 2030.[261] Two years later, these dreams were in doubt. 2023 was a slow year for VRE deployment in India, with total installations falling by 19% yoy to an annual deployment of only 13GW, well short of the 50GW pa required to achieve the 2030 target.[262] Solar PV, in particular, fell by 44% yoy with just 7.5GW deployed — see Figure 6.1.[263] After several years of faltering installations, the Government of India's (GoI) 2030 target appeared out of reach.

Figure 6.1: Annual VRE Installations & VRE Installations by Share in India (Dec 2024)



Source: CEA, MNRE, JMK Research[264]

[261] Mercom India, India Aims to Become Carbon Neutral by 2070, Sets 500 GW Non-Fossil Energy Target for 2030, 2 November 2021
[262] Ministry of New and Renewable Energy, Press Release on Renewable Energy Targets, 5 April 2023
[263] Mercom India, Q4 2023 India Solar Market Update, January 2024.
[264] JMK Research, Annual Solar Installations: India Adds 24.5 GW in 2024 - JMK Research & Analytics, 9 January 2025

However, 2024 was a different story entirely. Over the year, India added 24.5GW of solar PV (75% utility-scale[265]) and ~3.4GW of wind capacity.[266] Twice the amount of VRE deployed in 2023. VRE now accounts for 209GW of total installed generation capacity, with 35GW of additions projected for 2025[267] and a record 73GW of utility-scale renewables tendered in 2024.[268] Signs are positive as India crosses a significant milestone with 100GW of solar PV installed across the country — see Figure 6.2. The country is on track to hit 50GW pa installations as soon as 2026. Solar PV continues to dominate installations in the VRE segment, making up 88% of all capacity added.

Progress in India is very promising, but there are still significant issues still being addressed, such as the very slow finalisation of power purchase agreement (PPA) tendering awards into binding agreements with the associated state Discoms.[269]

Figure 6.2: India's Total installed Solar PV Capacity

Source: NSEFI[270]

The development of Adani Green Energy's mammoth 30GW (26GW of solar PV and 4GW of wind) Khavda plant in Gujarat is representative of the positive momentum behind solar PV in India (see Section 9).[271] CEF sees no sign of this trend abating, owing to solar PVs' versatility, rapidly deflating costs, scalability, positive policy drivers (see Section 1.4), and now accelerating deployment with BESS in hybrid systems.

Hybrid Systems and BESS Installations are Now Competitive in India

[265] The Economic Times, India Added 24.5 GW Solar and 3.4 GW Wind Capacity in 2024, sets new record, 9 January 2025
[266] JMK Research, India Achieves Record Growth with 24.5 GW Solar Capacity in 2024, 9 January 2025
[267] Economic Times, India's power demand set to grow 5.5% in FY25, renewables to drive 35 GW addition in FY25, 21 January 2025
[268] PV Tech, India tenders record 73GW utility-scale renewables as challenges arise, 6 March 2025
[269] ET EnergyWorld, Pending PPAs result of excess RE bids, low discom demand: Stakeholders tell govt, 10 March 2025
[270] NSEFI, Outlook Planet, India's 100 GW Solar Installations to Inspire Global Energy Transition, Says NSEFI, 8 February 2025
[271] Business Standard, Adani Green's Khavda Power Plant: World's Largest, 5x the Size of Paris, 11 April 2024

Although only a fraction of the current market, hybrid systems (solar PV and wind with BESS) are showing signs of increasing momentum in India. Two years ago, India was deploying 10MW BESS systems.[272] In December 2024, Reliance NU Suntech won a 930MW Solar PV plus 465MW/1,860MWh BESS contract with the Solar Energy Corporation of India (SECI). This is more than 46 times the average BESS size two years earlier. Reliance won with an estimated first-year tariff of ₹3.53/kWh (US$0.041/kWh) and an approximate levelised cost of electricity of ~US$0.030/kWh.[273] Record low hybrid tariffs were also achieved in India in 2024; the lowest tariff was recorded at ₹2.99/kWh (US$0.036/kWh) in GUVNL's 500MW wind-solar hybrid auction, conducted in January 2024.[274] Recent tenders in India combining solar PV and BESS now outcompete coal-fired generation on a cost basis.[275]

Between November 2023 and October 2024, India conducted auctions for 27.93GW of hybrid systems. Auctions were held for 21.78GW of solar power and 2.65GW of wind power capacity during the same period.[276] This reflects a growing emphasis on hybrid projects to enhance India's VRE supply. Policy may also accelerate this trend; in addition to the existing BESS Viability Gap Funding scheme,[277] the Indian Central Electricity Authority has mandated that VRE projects include at least 10% BESS capacity[278], potentially increasing this requirement to 40% over time.[279] Avenar Capital forecast that although only 0.2GW of BESS has been deployed to date, up to 66GW could be installed by 2032.[280]

Indian Solar PV Manufacturing is on Track

India's accelerating installation rates are enabled by a significant build-out of domestic solar PV manufacturing capacity. At the end of 2024, India's solar PV module manufacturing capacity stood at 80GW, while cell capacity grew to 7GW. [281] India added 11GW of module capacity and 2GW of solar cell capacity in the first half of CY2024.[282] Positively, much of the new manufacturing capacity is in advanced, high-quality solar PV technologies.[283]

Over the last several years, the GoI has introduced various initiatives to enhance domestic solar PV production. These include the Production Linked Incentive (PLI) scheme, mandating domestically produced modules in projects receiving Ministry of New and Renewable Energy subsidies, giving preference to 'Made in India' products in public procurement, and implementing basic customs duties and tariffs on overseas solar PV products. In 2024, these policies bore fruit.

India's module manufacturing capacity is three times the 2024 domestic solar PV installation rate. The current manufacturing base positions the country with enough supply to achieve

[272] Mercom India, Tender Issued for Five BESS Projects in Uttar Pradesh, 27 October 2022; PV Magazine India, Battery Energy Storage in 2022, December 29, 2022
[273] The Economic Times, Reliance Nu-Suntech Bags 930 MW Solar Project with 1860 MWh Storage System from SECI, 12 December 2024
[274] Renewable Watch, Tariff Trends: Review of Renewable Energy Tender Auctions, 17 December 2024
[275] PV Magazine, India to Mandate Energy Storage for Solar, Wind Projects, December 18, 2024.
[276] Renewable Watch, Vision 2030: The Way Forward for India's Clean Energy Transition, 1 December 2024
[277] Ministry of Power, Press Release on Clean Energy Goals,6 September 2023
[278] PV-Tech, India advises co-location of energy storage with solar PV, 20 February 2025
[279] PV Magazine, India to Mandate Energy Storage for Solar, Wind Projects, 18 December 2024.
[280] The Economic Times, Storage Projects in Green Energy Sector to be Focus Area in 2025, 31 December 2024
[281] ET Energy World, India's battery storage to reach 66GW by 2032, ₹5 lakh crore investment opportunity, 19 February 2025
[282] Mercom India, Robust Solar Project Pipeline Drives India's Module Manufacturing Capacity, 8 October 2024
[283] VRE Global, Indian-Made: Fueling Renewables Growth through Domestic Manufacturing, [6 January 2025

the target of 50GW of VRE installations per year by 2030 (40GW solar and 10GW wind) and India's ambitions to be energy secure. However, the 7GW of cell manufacturing capacity remains a constraint to energy security, with Indian solar PV module manufacturers relying heavily on Chinese cells. This highlights the need for targeted policy interventions in 2025.

In a positive sign of continuing prioritisation of domestic manufacturing growth, the GoI announced the 'National Manufacturing Mission' as part of its 2025-26 Union budget. This mission focuses on five areas – ease and cost of doing business, upskilling for in-demand jobs, Micro, Small & Medium Enterprises, availability of technology, and quality products.[284] It remains to be seen what policy reform will underpin this mission's effectiveness.

However, in the interim, to further support clean tech production, the GoI has instituted customs duty exemptions on key mineral inputs to solar PV and BESS products[285] and halved customs duties on solar cells and modules.[286] The GoI is also finalising a US$1bn subsidy plan to support wafer and ingot production.[287] CRISL, an Indian Research Agency, now forecasts that solar cell manufacturing capacity will reach 50-55GW by 2027, a five-fold increase from 10GW at the end of 2024.[288]

The strength of the US-China Trade Relationship is Uncertain

However, expanding India's solar PV manufacturing capacity may be more challenging in 2025. In 2024, India progressed significantly from being a net importer to an exporter of solar PV. According to IEEFA and JMK Research & Analytics, the export value of solar PV surged 23-fold, reaching US$2bn in 2024 compared to 2022.[289] With President Donald Trump's return to the White House, Indian solar PV exports and planned and existing manufacturing capacity could face headwinds.

Most of India's solar PV exports are shipped to the US, which accounted for 97% of exports in 2023 and 99% in 2024. Any policy changes in the US could significantly impact Indian solar PV manufacturers relying on the market, as some manufacturers ship up to 50% of their total production volume (and at 50-60% higher premiums) to the US.[290] Mercom India's projection of surpassing 172GW of module and 80GW of cell manufacturing capacity by 2026 may collide with geopolitical reality.[291]

While President Trump has not explicitly targeted India in recent statements, he has no qualms about targeting allies for any perceived trade imbalances. In February 2025, he threatened a 25% universal tariff on Mexican and Canadian goods.[292] As a result, uncertainty has rattled the equally vulnerable Indian market.[293] In response, the GoI began preparing

[284] Ministry of Finance (India), National Manufacturing Mission to Support Small, Medium, and Large Industries Under "Make in India" Announced in Union Budget 2025-26, 1 February 2025
[285]Money Life, Budget 2025: Indirect Tax and Customs Duty Reforms, 1 February 2025
[286] Evrim Agaci, India's Budget 2025 Unleashes Major Clean Energy Initiatives, 2 February 2025
[287] Economic Times, India mulls $1 billion subsidy plan to boost solar manufacturing, 25 February 2025
[288] Economic Times, Solar cell capacity to expand 5x to more than 50 GW by FY27: CRISIL, 6 February 2025
[289] IEEFA, Indian Solar PV Exports Surging, 11 November 2024
[290] IEEFA, Indian Solar PV Exports Surging, 11 November 2024
[291] Mercom India, State Solar Manufacturing in India: 1H 2024, December 2024
[292] White & Case, Policy Watch: Status of US 25% Tariffs on Mexican Imports, 4 February 2025
[293] Reuters, Indian shares succumb to uncertainty over Trump's tariff plans, 21 January 2025

retaliatory measures,[294] while in early February 2025, Prime Minister Modi met with President Trump to offer concessions, proactively aiming to prevent tariff escalation.[295]

President Trump also has a history of retrograde VRE policy actions. In 2017, during his first term, he instituted a 30% tariff on solar PV imports,[296] and early in his second term, he has made supporting domestic US fossil fuels a policy priority[297] and rescinded administration support for offshore wind developments.[298] On 19 February 2025, President Trump also criticised the possibility of the US' Tesla Motors building a factory in the country, signalling his oppositional stance on US investment in India's clean technology sector and trade.[299]

To avoid being trampled by an out-of-control US Mustang, CEF anticipates a GoI focus on bolstering Indian domestic demand for solar PV products from their manufacturing base. This domestic focus also has other benefits. Prime Minister Modi and the GoI can continue to meet growing energy consumption through plentiful supplies of VRE and they can create millions of jobs annually for new labour market entrants.[300] In a positive sign that this strategy is taking hold, in December 2024, the GoI extended their requirement to use locally produced modules in government-supported solar projects to cells. The requirement commences in June 2026.[301] Anti-dumping measures on imported solar cells and modules from Vietnam and China were also recently introduced to further support domestic production.[302] CEF also anticipates the GoI pursuing closer trade ties with other destination markets, as we are now seeing with the finalisation of a trade deal with the European Union.[303]

India Solar PV Company Examples

Tata Power

While renewed US protectionism represents an obstacle for Indian solar PV manufacturers, some positive developments occurred last year. Tata Power Company Ltd (TP), one of India's largest and most established solar manufacturers, significantly expanded its manufacturing capacity. In September 2024, Tata Power (TP) opened the next phase of its 4.3GW solar module and cell factory in Tamil Nadu, primarily catering to domestic markets. TP is now assessing expanding the facility by 4GW in the coming year. The company, which is pursuing significant solar generation capacity developments, is performing well, with a Q2 FY2024/25 EBITDA growing 17% yoy to a record level and net profit growth of 41% yoy.[304]

[294] Financial Express, Exclusive: India mulls retaliatory tariffs as Trump's trade war looms, 23 January 2025
[295] Al-Jazeera, Key takeaways from Donald Trump's meeting with India's Narendra Modi, 14 February 2025
[296] Asian Power, Trump 2.0 Could Thump India's Solar Ambition, December 2024
[297] The Guardian, Trump Vows to 'Unleash' Oil and Gas Drilling as He Rolls Back Climate Rules, 20 January 2025
[298] Hart Energy, Trump's Executive Order Delivers Blow to US Offshore Wind, 21 January 2025
[299] Reuters, Trump says unfair to US if Musk builds Tesla factory in India, 20 February 2025
[300] The New Indian Express, 46.7 million new jobs created in FY24, total jobs up by 6 percent: RBI, 9 July 2024
[301] Reuters, India Mandates Use of Locally Made Solar Cells for Clean Energy Projects by June 2026, 10 December 2024
[302] PV Magazine, India Imposes Antidumping Duties on Solar Glass from China, Vietnam, 6 December 2024
[303] WEF, The EU and India are close to finalizing a free trade agreement. Here's what to know, 7 March 2025
[304] Tata Power, Tata Power Achieves Highest Ever Quarterly PAT of ₹ 1,533 Crore in Q2FY25; up 51% YoY, January 2025

Waaree Renewable Technologies

In 2024, Waaree Renewable Technologies Ltd became India's largest solar PV module manufacturer by capacity, with a total of 13.3GW operational in June.[305] Waaree also started trial production of its 5.4GW solar cell manufacturing factory in Gujarat on 6 January 2025.[306] The company has focused on the US market, becoming India's most export-oriented solar manufacturer. Waaree inaugurated a 1.6GW module manufacturing facility in the US on 22 January 2025.[307] With the plant, the company aims to mitigate risks from potential US tariff increases on Indian imports, a strategy other export-oriented Indian manufacturers could pursue. Waaree's strategy is paying off; the company's revenue grew 86% yoy, with net profit up 44% yoy over Q3 FY2024/25.[308]

Avaada Electro

March 2025 saw Avaada Group start building a 5 GW integrated TOPCon solar cell and module plant at Ecotech in Greater Noida, Uttar Pradesh. Avaada has also opened a 1.5 GW TOPCon module factory Dadri in Noida, near New Delhi, India.[309]

Reliance Industries

Troubling, though, was progress on the Reliance Industries Ltd's' Dhirubhai Ambani Green Energy Giga Complex. Reliance Industries is one of India's largest conglomerates and has been at the forefront of India's solar PV manufacturing surge. As part of the complex, Reliance Industries first announced plans for the first 5GW phase of a 20GW integrated solar cell and module production facility in 2021, leveraging the GoI's PLIs.[310] While progress has been reported,[311] the completion timeline for the first phase has been pushed back to March 2025 from March 2024.[312] While the company is healthy financially with a 7% increase in net profit and a 7% increase in revenue yoy over Q3 FY2024/25,[313] Reliance is significantly trailing the development time of Chinese solar PV manufacturers who regularly commission plants in 18 months and at many times the scale.

After a halting few years, India's solar PV installation rate is accelerating, its manufacturing capacity is growing, and there is a positive trend towards deploying hybrid systems. This reflects the GoI refining its policy settings to support the clean technology sector growth. However, Indian manufacturers' reliance on US demand for their solar PV products is a significant risk given the trade uncertainty the new Trump administration has unleashed. They now risk being trampled underfoot by the out-of-control US Mustang. For policymakers in other jurisdictions, India's fine-tuned policy approach should be emulated.

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[305] PVTime, Breaking News, 5.4GW! Waaree Energies Starts Solar Cell Production in India, 9 January 2025

[306] Taiyang News, India Solar PV News Snippets: Trial Production For Waaree's 5.4 GW Cell Fab & More, 7 January 2025

[307]Economic Times, Waaree Energies begins commercial production at US solar module plant, 22 January 2025

[308] Economic Times, Waaree Renewable reports ₹1,121 cr revenue, eyes 23 GW solar bids, 16 January 2025

[309] PV Magazine, Avaada building 5 GW solar cell plant, opens 1.5 GW module factory in India, 10 March 2025

[310] Desh Gujarat, Mukesh Ambani announces 5,000 acres Dhirubhai Ambani Green Energy Giga Complex at Jamnagar, 24 June 2021

[311] PV-Tech, Reliance Industries plans to commission 10GW solar manufacturing plant this year, 3 September 2024

[312] Reuters, India's Tata Power prefers domestic market over lucrative solar exports, CEO says 6 December 2024

[313]Mint, Reliance Industries Q3 Results Highlights: RIL net profit rises 7.3% to ₹18,540 crore, revenue up 7% YoY, 17 January 2025

However, India should also serve as a cautionary tale of becoming too reliant on any one jurisdiction in this new era of geopolitical instability.

Section 7: The United States

The US solar PV and BESS sectors experienced historic growth in 2024 with 49GW of solar PV and 11.9GW of BESS added. Meanwhile, solar PV module manufacturing has surged to 52GW from just 7GW two years earlier. This investment was fuelled by the Inflation Reduction Act (IRA). The US manufacturing 'Mustang' was unleashed to try to catch China. However, the new US administration's decision to freeze clean technology manufacturing funding and impose new tariffs on Chinese imports will likely drive cost inflation for energy consumers and cause capital flight, with firms like KORE Power already cancelling BESS factories. More hospitable jurisdictions are now poised to absorb diverted US investment. The US now risks cementing its trailing position in the energy transition way behind China.

The US will likely exit 2025 with 55-60GW pa of solar module manufacturing capacity (assuming ~10GW of manufacturing proposal cancellations), ironically with more than half of this built in the last 2 years by Chinese firms.

US Solar PV Installations Surge, Maintaining Market Dominance

Clean technology incentives in the US were massively expanded by the passage of the IRA in 2022, combined with the fast-improving cost competitiveness of VRE, spurring substantial solar PV deployment across the US. In 2024, the US added 49GW of new solar PV capacity across residential, C&I and utility scale deployments,[314] a 33% increase yoy.[315] At over 80% of all new generation installed, [316] solar PV leapt ahead in 2024 — see Figure 7.1. Like in 2023, sunny Texas, California, and Florida led capacity installation. With 226GW of solar PV now operational, a further 142GW of planned solar PV is in the project pipeline.[317] Given rapid technological acceleration and continued cost deflation, solar PV will likely maintain this leading position for the foreseeable future.

Wood Mackenzie forecasts that the installation rate will likely plateau due to ongoing challenges of labour availability, interconnection delays, and equipment constraints, resulting in annual installations of 40-50GW from 2025 to 2035.[318]

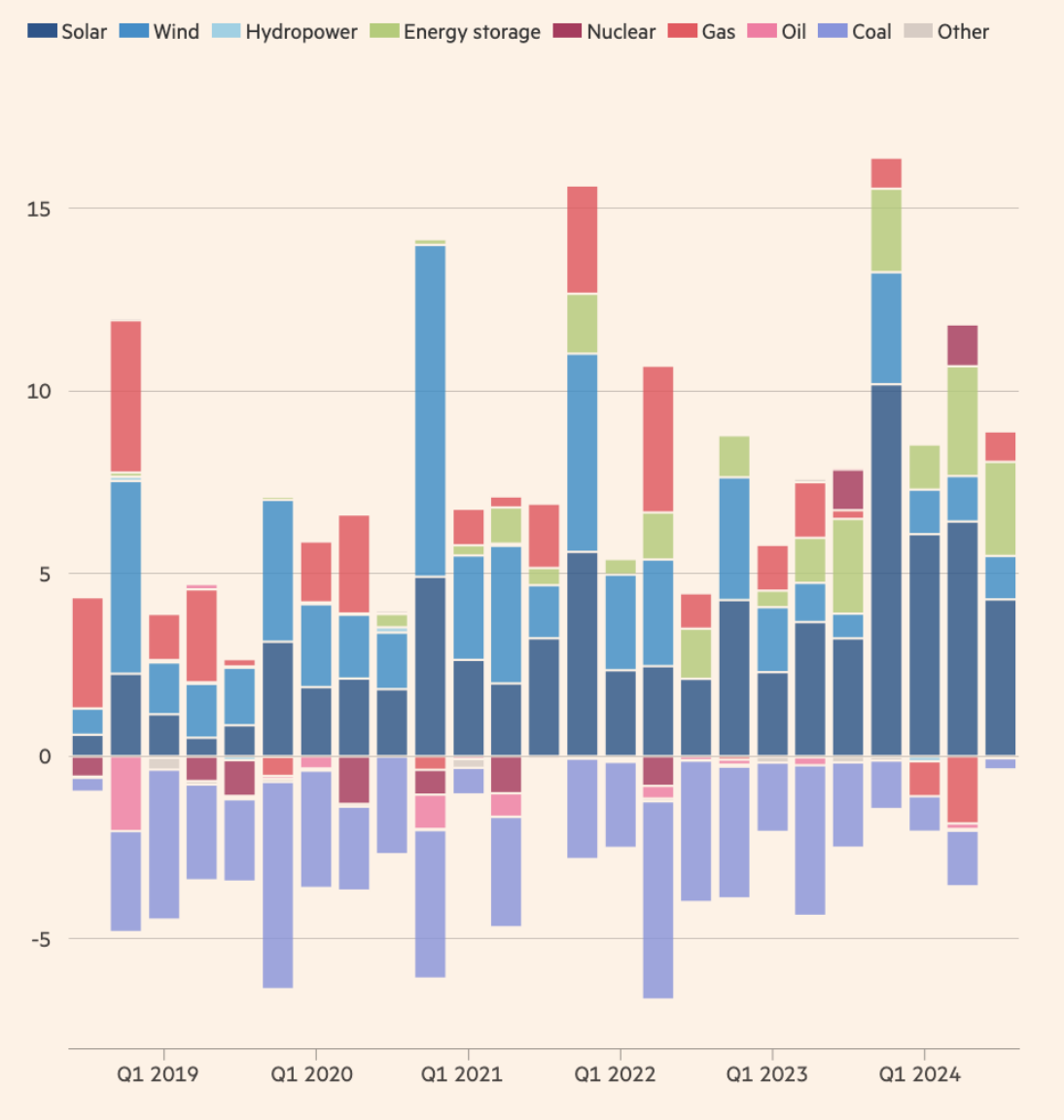
The US Energy Information Administration (EIA) forecasts 2025 utility solar installs of 32.5GW, supported by a US record install of 18.2GW of BESS, combined representing 82% of gross additions, [319] before considering closures of 12.3GW of end-of-life coal, oil and gas plants in 2025 alone.[320]

Given the policy changes enacted by the new US administration (discussed below), CEF considers this a realistic assessment. Despite this slowdown, solar PV will likely continue to exert unprecedented pressure on the viability of thermal generation, particularly fossil gas, the largest source of electricity in the US. This trend is evident in the 25 February 2025 announcement from Energie, stating that it would withdraw two fossil gas peaker plants

[314] PV Tech, US adds record 49GW of solar capacity in 2024, 24 February 2025
[315] SEIA, Solar Installations Skyrocket in 2023 in Record-Setting First Full Year of Inflation Reduction Act, 6 March 2024
[316] Office of Energy Projects (US), Energy Infrastructure Update For December 2024, 6 February 2025
[317] SEIA, Major Solar Projects List, 21 January 2025
[318] PV Magazine, U.S. solar installations forecast to decline 1% annually through next decade, 11 March 2025
[319] EIA (US), Solar, battery storage to lead new U.S. generating capacity additions in 2025, 24 February 2025
[320] EIA (US), Planned retirements of U.S. coal-fired generating capacity to increase in 2025, 25 February 2025

from Texas' energy fund program due to procurement constraints. Engie, regarded as a gas 'giant' for its extensive fossil gas portfolio, has now dedicated 75% of its future capex to investing in VRE globally and is targeting 35GW of VRE installations in North America by 2030.[321] Similarly, Aegle Power's fossil gas peaker plant proposal failed to meet due diligence requirements for the same program.[322] The US Energy Information Agency (EIA) expects the share of fossil gas generation to drop from 43% in 2024 to 39% in 2026.[323]

Figure 7.1: Change in US Power Generation Capacity by Quarter and Source (GW)



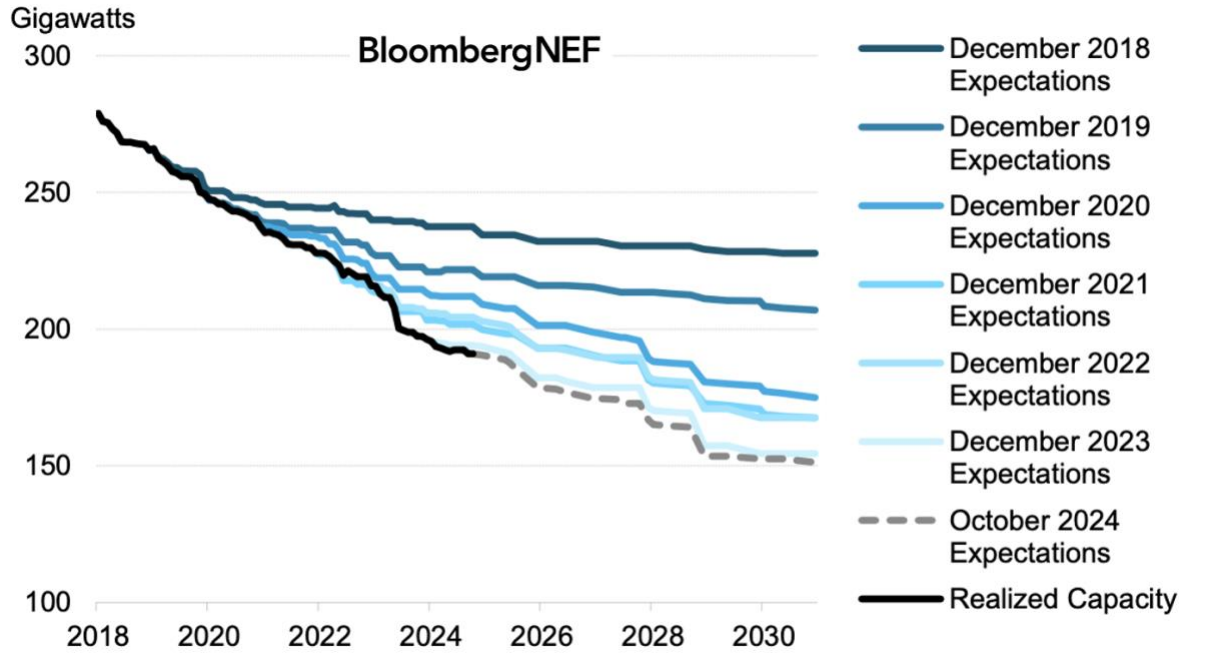
Source: Financial Times via BNEF[324]

The US has seen a rapid and sustained shutdown of coal fired power plants over the last decade. Coal fired power generation's share has dropped from 50% of the US electricity sector total in 2008 to a record low of just 15% in 2024, and BNEF forecasts this decline will

[321] Taiyang News, Engie Targets 95 GW Renewable Energy Capacity By 2030, 4 March 2025; Recharge News, Gas giant Engie is doubling down on renewables, 1 March 2025
[322] Latitude Media, Engie's pulled project highlights the worsening economics of gas, 25 Februrary 2025
[323] EIA (US), STEO February 2025 Short-Term Energy Outlook, 6 February 2025
[324] Financial Times, Donald Trump's cuts to renewables risk US energy crisis, 4 February 2025

accelerate out to 2030 on current utility plans – Figure 7.2. VRE's share of US generation share has tripled in this time to 24% in 2024, the leading driver of coal's decline.

Figure 7.2: US realised and planned coal capacity expectations (GW)



Source: BloombergNEF[325]

BESS Installations on a Growth Trajectory, but Trade Deterioration Poses Challenges

BESS installations in the US also grew over 2024, solidifying the US as the world's second-largest market. Wood Mackenzie projects the US deployed 12.3 GW/37.1GWh of BESS capacity in 2024 — up 33% yoy on a GW basis.[326] Growth in the US also remained heavily localised in California and Texas, which accounted for 93% of the installed grid BESS capacity in 3QCY2024.

The first week of March 2025 saw the ERCOT power in Texas set records for most wind production (28,470MW), most solar production (24,818MW), and greatest battery discharge (4,833MW). Only two years ago, the most that batteries had ever injected into the ERCOT grid at once was 766MW. Now the battery fleet is providing nearly as much instantaneous power as Texas nuclear power plants, which contribute 5,000MW.[327] March 2025 also saw the world's consistently biggest investor in VRE, NextEra Energy, Inc., announce it would invest US$3.8bn in new BESS over just the two years of 2026-2027, and launch a long-duration energy storage (LDES) program.[328]

While China dominates in total BESS capacity deployed across 2024 (almost triple the US on a GW basis), the average US BESS project is currently larger.[329] This is highlighted by the

[325] BNEF SEIA Factbook 2025, March 2025
[326] PV-Magazine, U.S. energy storage installations grow 33% year-over-year, 19 March 2025
[327] Canary Media, Texas broke its solar, wind, and battery records in one spring week, 10 March 2025
[328] EnergyStorage.News, Florida Power & Light to spend US$3.8 billion on new BESS in 2026-2027, launches LDES pilot, 13 March 2025
[329] Volta Foundation, Battery Report (2024), January 2025

Edwards & Sanborn 875MW solar PV plus 821MW/3,280MWh BESS, commissioned in January 2024 in California.[330] In 2024, the average discharge duration of US grid-scale BESS also grew from 3 hours to 3.1 hours, reflecting continued US investor appetite for larger, longer-duration BESS and mirroring a global trend.

Despite this positive momentum, Wood Mackenzie forecasts a 10% CAGR for BESS over 2025 and 2028.[331] CEF believes this forecast is too conservative given the new US administration's recent uniform 20% tariff increase on Chinese goods.[332] Since 92% of lithium-ion BESS projects deployed in 2024 contained cells from China, [333] the tariff increase is expected to increase BESS prices by ~35%,[334] incentivising domestic US content supply. Compounding this, the new administration's freezing of BESS manufacturing funding under the IRA and Department of Energy Loan Program Office (DoE LPO) has introduced immediate uncertainty about financing for announced domestic production and, therefore, supply.

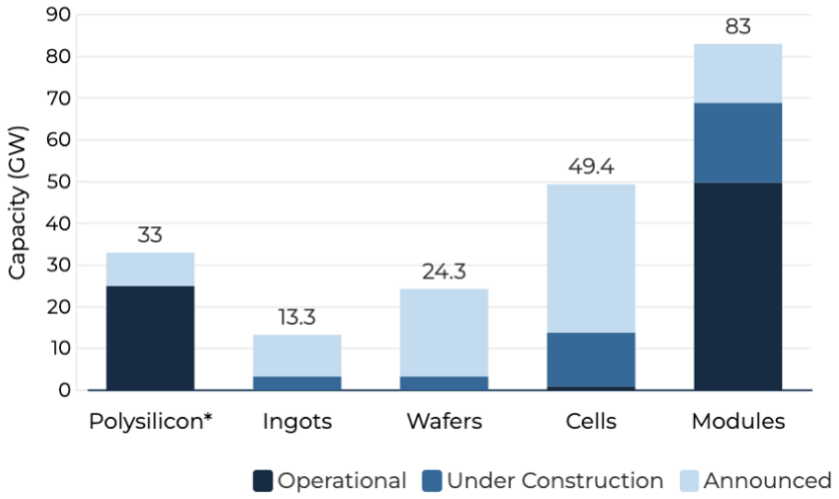
The IRA's Transformative Impact on US Solar Manufacturing

According to the Solar Energy Industries Association (SEIA), since the introduction of the IRA in 2022, more than US$40bn has been announced for solar PV manufacturing across the US.[335] Of this, a total of US$8.7bn worth of facilities are operational, US$16.2bn are actively under construction, and an additional US$15.2bn is allocated to projects currently in development. Overall, 121 manufacturing facilities have been established, driving a 600% increase in domestic solar module production capacity—from 7GW in 2022 to 51.7GW today. Wood Mackenzie forecasts module capacity to reach 66GW in 2025.[336] Given the removal of IRA and DoE LPO financial support and aggressive price competition, CEF would expect almost all announced but yet-to-be-built proposals to be cancelled outright or deferred, such that a 55-60GW end-2025 target is, in our view, more realistic.

This explosive capacity growth is the inevitable outcome of a well-designed and effectively executed industrial policy, including significant tariff protection—which raises energy costs for all consumers. This has successfully attracted significant investment, ironically with half of this new onshore manufacturing capacity built by Chinese solar PV firms (25-30GW pa in total). However, while module manufacturing capacity has surged, the US still relies heavily on imported ingots, wafers, and cells. To achieve greater supply chain independence, the successful execution of announced capacity expansions will be crucial—see Figure 7.2.

[330] ESS-News, California solar-plus-storage project with world's largest BESS fully online, 24 January 2024
[331] Wood Mackenzie, Energy Storage Monitor, December 2024
[332] BBC, Trump's 10% tariff on China begins as Beijing plans retaliation on US energy and cars, 5 February 2025; BBC, What are tariffs and why is Trump using them?, 13 March 2025
[333] RhoMotion, What the Trump Presidency means for the EV and battery industry, 6 November 2024
[334] CEA, ESS Price Forecasting Report, 14 January 2025
[335] SEIA, Solar & Storage Supply Chain Dashboard, February 2025
[336] EE News, Trump hates wind. Is solar also in trouble?, 24 January 2025

Figure 7.2: Total US Solar Supply Chain Capacity by Component and Status (2025)



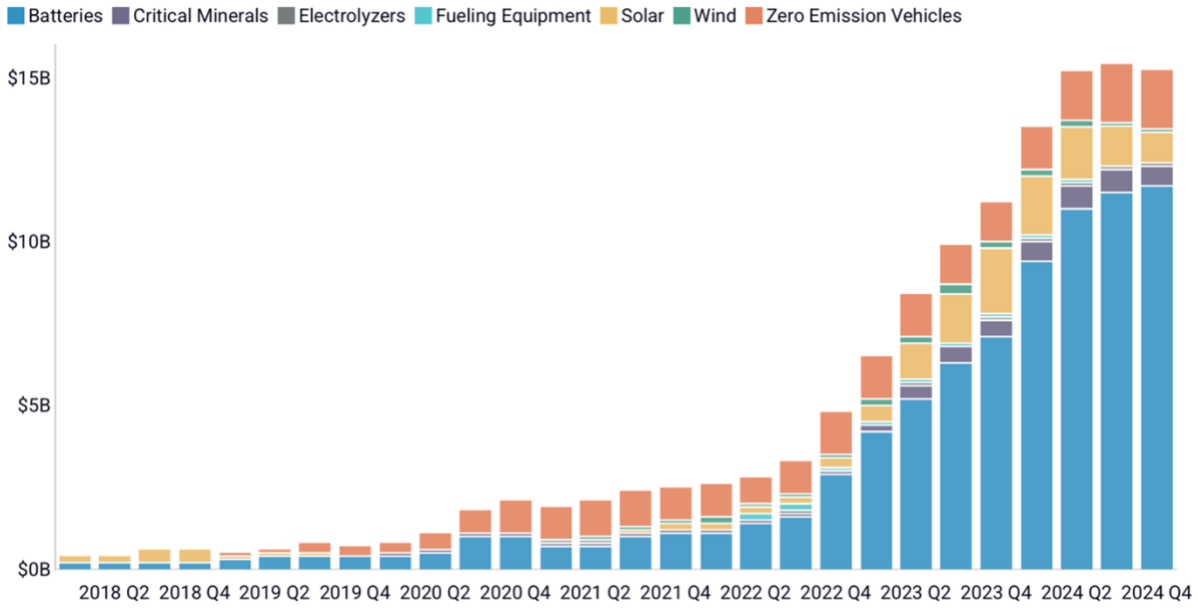
Source: SEIA

The IRA spurred a reinvigoration of US solar manufacturing, driving the reopening and expansion of domestic production facilities. For example, after filing for bankruptcy in 2017, in November 2024 Suniva restarted its 1GW pa solar cell factory in Georgia after receiving federal support under the IRA.[337] Similarly, January 2025 saw ES Foundry open its South Carolina cell factory, the first US cell facility to be opened in 14 years. Suniva cited the positive support provided by the IRA as the key enabler. ES Foundry is aiming for 1GW pa capacity by the end of the year, and possibly 3GW in the medium term.[338]

The US IRA as spurred a resurgence in US cleantech manufacturing, but Figure 7.3 shows the vast majority of this investment has been in battery and EV capacity, much in partnership with South Korea and Japan, given effective sanctions against most Chinese battery investments.

[337] Reuters, Solar manufacturer Suniva resumes production of American-made cells, 8 November 2024
[338] Clean Energy, Breathing New Life Into American Solar Manufacturing: ES Foundry Opens New SC Solar Cell Facility, 11 February 2025

Figure 7.3: US Cleantech Manufacturing Investments by Technology (2023 $bn)



Source: Rhodium Group-MIT CEEPR Clean Investment Monitor

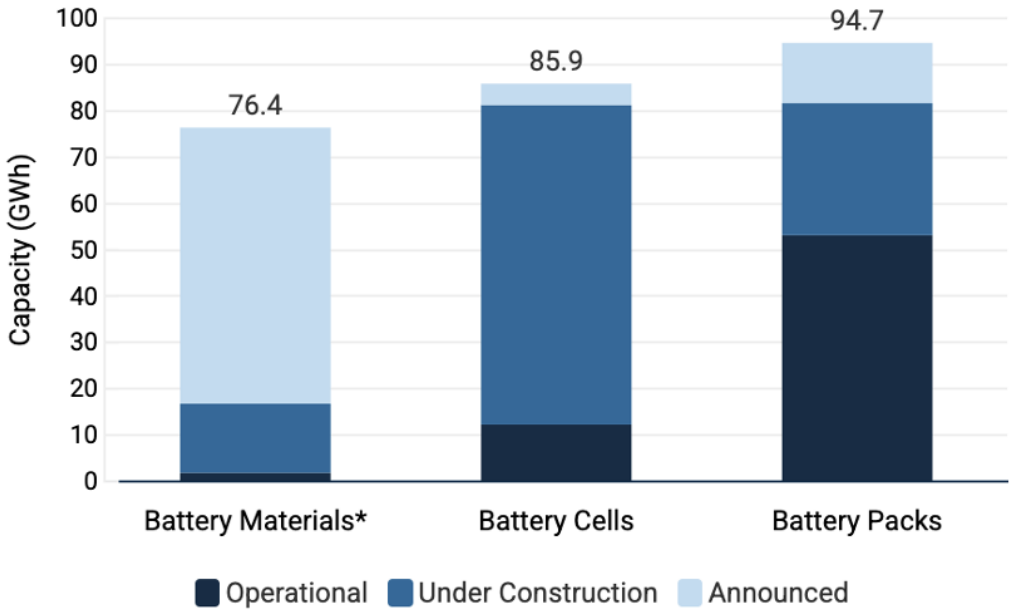
The IRA's Role in Accelerating US BESS Manufacturing Growth

A similar trend has been unfolding in the US BESS sector, where the IRA has triggered a rapid manufacturing expansion across operational and planned capacity. Since 2022, the US has attracted more than US$110bn in operational and planned EV and BESS manufacturing investments.[339] The US now has a significant pipeline of BESS manufacturing facilities under construction — see Figure 7.4.

The US BESS manufacturing market showed signs of growing momentum in late 2024. On 15 October 2024, Lyten, a US BESS startup, announced a US$1bn commitment to build a 10GWh pa lithium-sulphur battery factory in Nevada.[340] China's Canadian Solar also committed US$712m for a 3GWh pa BESS plant in Kentucky in November 2024.[341] 11 days later, the US DoE awarded a US$6.6bn loan to US car manufacturer Rivian to establish an EV factory in Georgia [342] (although this is threatened by building financial distress[343]). A week after that, in December 2024, the DoE approved a substantial loan of US$7.5bn for a joint venture between Stellantis and Samsung SDI, named StarPlus, which will establish two EV battery manufacturing plants in Indiana.[344] The project is expected to produce approximately 67GWh of batteries annually, enough for 670,000 EVs.

Figure 7.4: Total US Storage Supply Chain Capacity by Component and Status (2025)

[339] RhoMotion, The evolution of the US Battery Belt, what does the future hold?, 10 December 2024
[340] Financial Times, $1bn US battery plant plan shows race to reduce reliance on China, 15 October 2024
[341] AP News, Company announces nearly $712 million project in Kentucky to make batteries used to store energy, 16 November 2024
[342] The Verge, Rivian gets $6.6 billion government loan to build its EV factory in Georgia, 27 November 2024
[343] The Electric Viking, Can Rivian avoid joining Nikola in bankruptcy after losing $4.7 Billion? 24 February 2025
[344] The Verge, Stellantis and Samsung to get $7.54 billion federal loan for two EV battery factories, 4 December 2024



Source: SEIA

March 2025 saw the world's consistently biggest investor in renewable energy, NextEra Energy, Inc., just announce it would invest US$3.8bn on new BESS in just the two years of 2026-2027, including the launch of a long-duration energy storage (LDES) program.[345]

The New US Administration is Creating a Challenging Investment Environment

The continued rapid growth in the US solar PV and BESS manufacturing base is now unlikely, putting at risk much of the 160GWh pa BESS capacity Rhomotion has forecast to come online in 2025. In January 2025, President Trump issued an executive order halting clean technology manufacturing funding enacted under the IRA and Infrastructure Investment and Jobs Act.[346] This has threatened over ~US$165.8bn of announced clean technology investment and effectively pulled the U.S. manufacturing Mustang from the race—mid-stride, despite it being uninjured and fully capable of competing. Before this, manufacturers were already under intense price pressure from established Chinese manufacturers, and many relied on federal government support to be cost-competitive and for access to finance. For example, the DoE found that US BESS prices would still be higher than China's, even with tariffs and IRA subsidies.[347]

Premier Energies

The market is feeling the immediate impact of the administration's actions. February 2025 saw India's Premier Energies Ltd announce it was reviewing its planned 1GW pa cell manufacturing plant in the US. The company had partnered with Canada's Heliene in 2024 in proposing the facility; however, Premier Energies stated that the project has been put on hold until there is greater clarity regarding the administration's plans for the IRA.[348]

[345] EnergyStorage.News, Florida Power & Light to spend US$3.8 billion on new BESS in 2026-2027, launches LDES pilot, 13 March 2025
[346] White House, Unleashing American Energy, 20 January 2025
[347] DoE, Identifying Risks in the Energy Industrial Base: Supply Chain Readiness Levels. January 2025
[348] PV-Tech, Premier Energies halts solar cell plant in the US amidst policy uncertainty, 4 February 2025

KORE Power

February 2025 saw South Korea's KORE Power announce the cancellation of its planned US$1.2bn 12GWh pa lithium-ion battery factory in Arizona.[349] This facility was set to become the first US-owned lithium-ion battery manufacturing plant and would have created 3,000 local jobs.[350] The company had been awarded a US$850m loan from the DoE in 2024 to fund the project. However, the new administration froze DoE loans in January 2025.

FREYR Battery Inc.

February 2025 saw Norway's FREYR Battery follow KORE Power and cancel its US$2.6bn 34GWh pa battery factory in Georgia. The incentives and support provided through the IRA drove the proposal to establish the plant in Georgia rather than Norway.[351] December 2024 saw FREYR Battery finalise its US$340m acquisition of Trina Solar's newly operational 5GW solar module factory in Texas.[352] The acquisition was announced November 2024, the day Vice President Harris conceded to Trump and only a week after the factory had opened.[353] Trina Solar has mitigated rising anti-China risks associated with policy changes.

First Solar

March 2025 also saw First Solar US announce plans to cut its Vietnam and Malaysian thin film solar manufacturing capacity by a combined 1GW pa.[354]

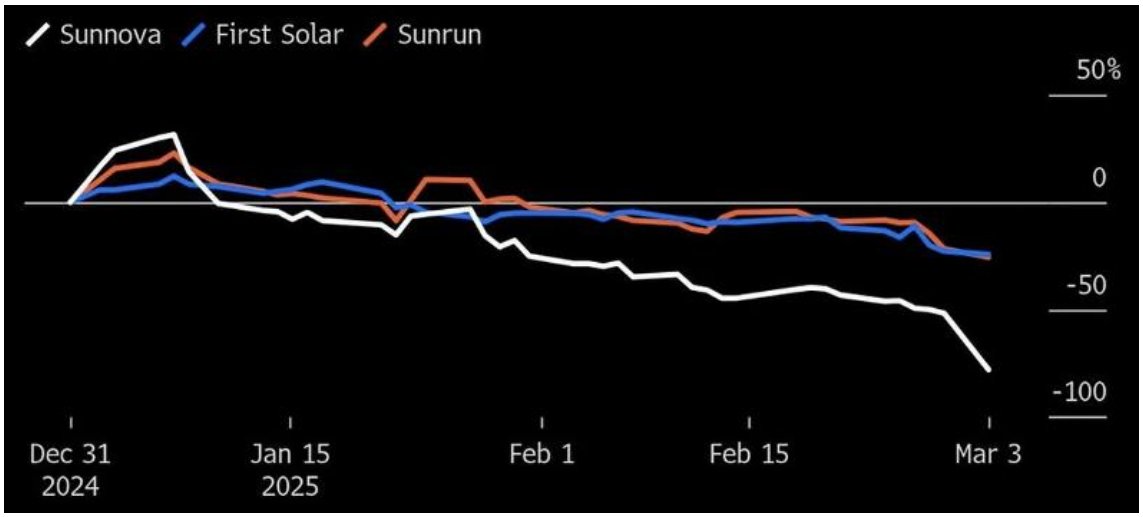
Sunnova Energy International Inc.

On 3 March 2025, Sunnova, a Texas-based manufacturer of solar PV products since 2012, announced that there was substantial doubt whether it could remain in business, citing an inability to meet its obligations.[355] In September 2023, the DoE provided Sunnova with a US$3bn partial loan guarantee for a loan program for low-income US households to install solar PV.[356] The company also benefited from manufacturing tax credits under the IRA However, DoE loans have now been frozen, and the continuation of manufacturing tax credits remains uncertain. Sunnova's share price plummeted over 70% following the announcement — see Figure 7.5. Similarly, First Solar and Sunrun, though grappling with different challenges, have also experienced declines, reflecting the broader impact of policy upheaval.

The new US administration's actions have created an extremely challenging investment climate for new solar PV and BESS manufacturing, leaving the existing newly established manufacturing facilities operating at average 50% utilisation rates. Investors will now likely seek more stable and predictable environments elsewhere, pivoting to jurisdictions that actively welcome and incentivise clean technology investment. With its well-established supply chains and supportive industrial policies, Chinese joint ventures globally are poised to become the primary beneficiary of this shift.

[349] Canary Media, Kore Power has a new plan after canceling $1.2B battery plant in Arizona, 7 February 2025
[350] Electrek, KORE Power kills $1 billion Arizona EV battery factory plans, 4 February 2025
[351] Fast Company, Why a Norwegian battery firm is building a plant outside of Atlanta , 17 February 2024
[352] FREYR Battery, FREYR Battery Closes Transformative Acquisition of Trina Solar's US. , 24 December 2024
[353] PV-Magazine, Freyr to acquire Trina Solar US. manufacturing assets, 7 November 2024
[354] List solar, First Solar Reduces Vietnam, Malaysia Output by 1 GW, 5 March 2025
[355] CNET, Sunnova Energy: Another Big Solar Installer Teeters on the Edge of Bankruptcy, 3 March 2025
[356] DoE, Financing Supported by LPO's Project Hestia Recognized by IFR Awards 2023, 6 February 2024

Figure 7.5: US Solar PV Share Prices First 3 Months of 2024



Source: Financial Post via Bloomberg[357]

For policymakers in other jurisdictions, the US's retreat on clean technology policy should prompt a discussion of how to become an investment jurisdiction of choice using innovative, stable, forward-looking and enduring policy measures. Instead of inflationary, blunt, and disruptive tariff increases, approaches such as joint ventures, industry hubs, legislated tax incentives to attract Chinese manufacturers in partnership with local clean technology champions, and local content requirements to support domestic suppliers should be considered.

[357] Financial Post, Sunnova's 71% Stock Plunge Heralds US Solar State of 'Chaos', 3 March 2025

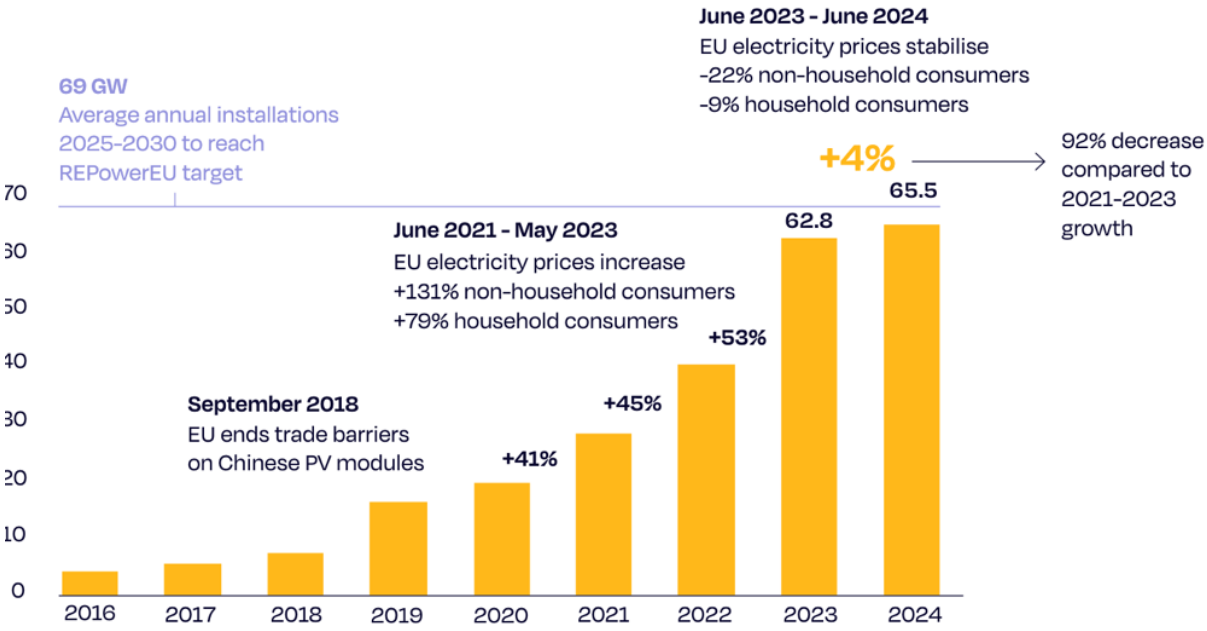
Section 8: European Union

The European Union's (EU) solar PV sector and policymakers face a dilemma in 2025. Last The European Union's (EU) solar PV sector and policymakers face a dilemma in 2025. Last year, the EU made significant progress on solar installations, surpassing the halfway mark toward the REPowerEU 2030 target of 600GW of cumulative solar PV installations. However, the EU's solar manufacturing base is being decimated by China's ongoing aggressive solar module price deflation. EU policymakers are adapting with the recent Clean Industrial Deal, which is expanding financial and regulatory support for EU clean technology manufacturers.

The EU is on A Promising Trajectory Towards its VRE Targets

In 2024, the EU achieved record solar PV installations of 65.5GW — Figure 8.1, bringing its total solar capacity to 338GW—four times the amount of a decade ago.[358] This was highlighted by a record 16.2GW of solar PV installations in Germany alone in 2024. Germany delivered a country-wide 62.7% renewable generation record for the year.[359] However, at 65.5GW total new installations across the EU for the year, this represents just a 4% yoy increase from 2023, a significant slowdown from the 53% yoy growth achieved relative to 2022. This cooling in the rooftop reflects a correction after the unprecedented energy price hikes of the Russian gas crisis turbocharged solar adoption across the continent.

Figure 8.1: EU Annual Solar PV Installed Capacity



Source: SolarPower EU[360]

While the rooftop segment faced a 2% yoy decline, utility-scale solar grew to 42% of the market, attributed to a drop in module prices, balance of system cost reductions and expanded policy support for utility-scale projects.[361] However, grid bottlenecks, slow

[358] SolarPower Europe, EU Market Outlook for Solar Power 2024-2028, December 2024
[359] PV Magazine, Germany deploys 16.2 GW of solar in 2024, 8 January 2025
[360] SolarPower Europe, EU Market Outlook for Solar Power 2024-2028, December 2024
[361] PV-Tech, European module prices continue to decline in December, says sun.store in latest pv.index report, 6 January 2025

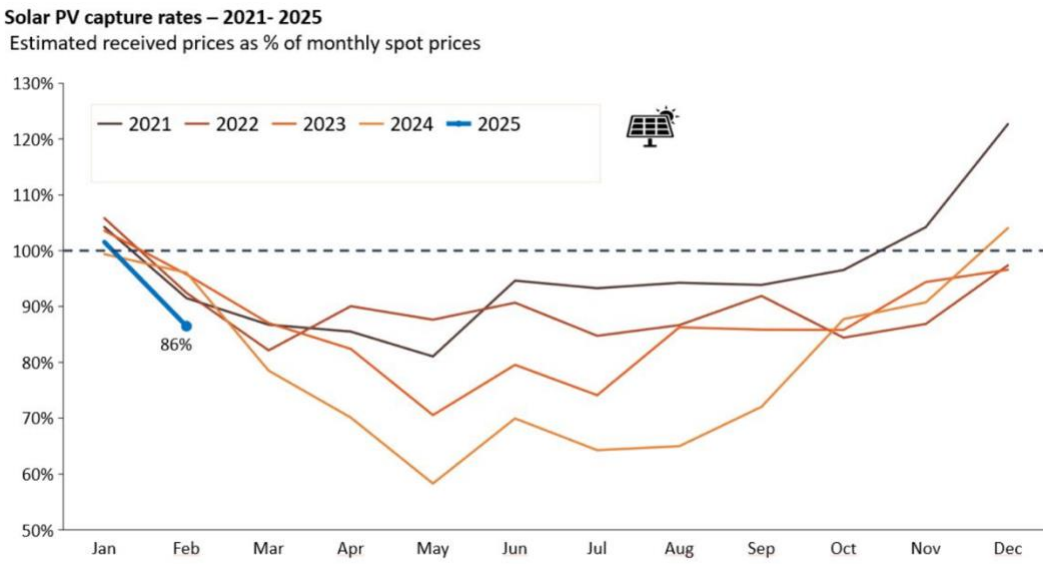
permitting, and a lack of energy storage still challenge rapid utility-scale solar deployment. While the EU is experiencing a general slowdown in installation rates, according to SolarPower Europe, it is still on track to meet its REPowerEU target of 750GW by 2030. To maintain this momentum whilst reducing fossil fuel dependence and lowering consumer electricity prices, the EU has responded by releasing it's 'Affordable Energy Action Plan,' on 26 February 2025, introducing eight key policy measures to achieve these goals.[362]

In 2024, Europe's solar industry saw unprecedented growth in solar generation, with an annual increase of 54TWh (+22% yoy) compared to 2023, an acceleration from the previous year, which saw a 40TWh solar increase.[363]

Solar PV is Driving Electricity Price Deflation in Germany

Energy regulators often cite the grid stability problems of minimum on grid demand and the resulting lower and even negative electricity prices from ever-higher solar power generation penetration – Figure 8.3. CEF views this as a positive, with the resulting price volatility opening up arbitrage opportunities as a massive enabler of BESS to accelerate the progressive decarbonisation and deflation of electricity systems world-wide.

Figure 8.3: German Electricity Price Deflation from Solar Accelerating



Source: Rystad Energy, March 2025

Solar PV Manufacturing is at a Crossroads

While solar installation is on track, EU manufacturing remains fundamentally challenged. The EU has attempted to reinvigorate domestic EU manufacturing to diversify its solar supply chain and support energy independence. In 2024, the EU passed the Net Zero Industry Act (NZIA), which aims to achieve a recently updated target of 30GW pa solar PV component production capacity across the supply chain by 2025.[364] The NZIA was underpinned by policy incentives to drive domestic manufacturing. However, tariffs and

[362] European Commission, Action Plan for Affordable Energy: Unlocking the true value of our Energy Union to secure affordable, efficient and clean energy for all European, 26 February 2025
[363] Carboncredits, Europe's Solar Industry Saw Record Growth and Innovations in 2024, 27 January 2025
[364] ETIP Photovoltaics, PV Manufacturing in Europe: understanding the value chain for a successful industrial policy, May 2023

other protections like those enacted by the US [365] and India [366] were conspicuously absent and have exposed EU solar PV and battery manufacturers to low-cost Chinese alternatives.

Over the last two decades, Chinese firms have developed an integrated supply chain, built vast economies of scale, can access low-cost labour, and use advanced automated technology, creating significant competitive advantages. This has intensified pressure on high-cost European manufacturers; as a result, debt-financed European solar PV factories continue to struggle to break even and falling module prices make profitability even more elusive and loss-making likely.[367] Market exits such as solar PV wafer manufacturer NorSun in December 2024[368] and the struggles of the EU's only solar glass manufacturer, Indian-owned GMB Glasmanufaktur Brandenburg GmbH, which has been forced to reduce staff hours and wages dramatically, epitomise the harsh reality in the sector.[369] 14 March also saw module manufacturer Aleo Solar, operational since 2002 in Germany, announce it would close its Prenzlau facility due to unsustainable price competition.[370]

Progress on even existing proposals is slowing. The 3Sun gigafactory, discussed in CEF's Solar Pivot report of 2023, was slated to reach a capacity of 3GW of cells and modules pa by the end of 2024. Still, no updates have confirmed the achievement of this milestone. Similarly, Iberdrola's 1.6GW module facility in Spain, announced in April 2023, has seen no updates in 18 months, nor any developments reported on FuturaSun's 2GW solar module gigafactory in Italy since the project announcement in March 2023. These delays underscore a gap between aspiration, delivery and the reality of competing with Chinese companies. As a result, the EU remains far from its 30GW target across the solar supply chain, with only 14.1GW of manufacturing capacity for modules and 2GW for cells.[371]

In CEF's view, EU manufacturing closures are more likely than the new capacity (see Figure 8.2) that has been announced being built. Exemplifying this sentiment, March 2025 saw Aleo Solar, a subsidiary of Sino-American Silicon Products Group, announce it would close its German solar manufacturing plant at Prenzlau, with the likely loss of 110 jobs after 25 years of operation.[372]

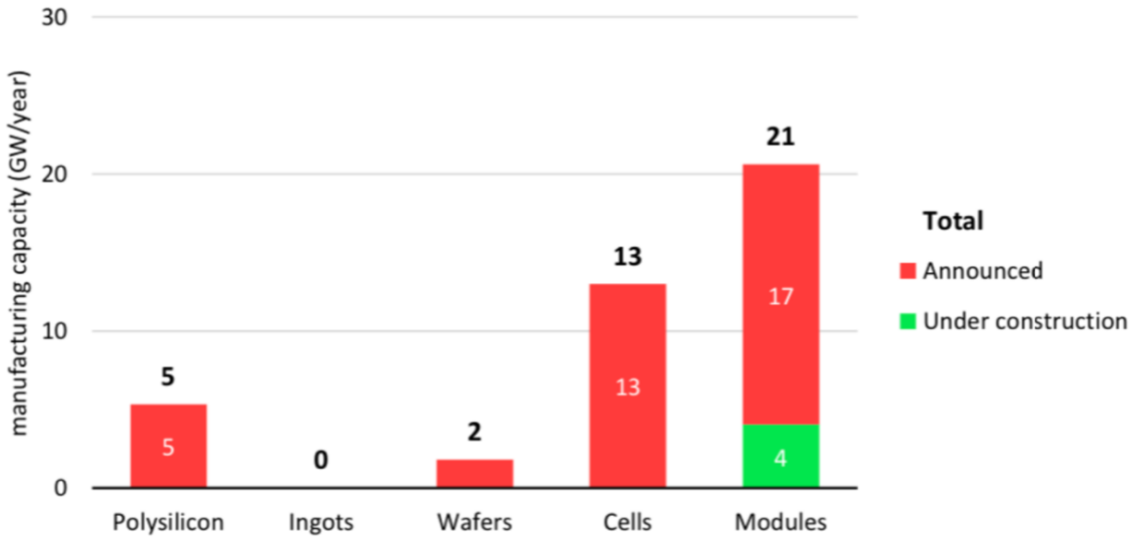
In response to these challenges, the EU revealed its 'Clean Industrial Deal' in February 2025,[373] containing policy and legislation to increase demand for EU clean technology products, lower production costs through cheaper VRE-based electricity, and expand capital subsidies available for clean tech manufacturers. The European Commission is also considering implementing local content requirements to favour European companies in clean technology contracts.[374] March 2025 also saw SolarPower Europe launch the International Solar Manufacturing Initiative (ISMI) to advocate for development cooperation policies to boost European competitiveness in solar manufacturing and to secure public

[365] Reuters, US sets tariffs for solar panels from Southeast Asian nations, 30 November 2024
[366] Reuters, Exclusive: India considers cutting solar panel import tax to make up domestic shortfall, 31 May 2024
[367] Financial Times, Solar-panel maker Meyer Burger to cut fifth of its workforce, 18 September 2024
[368] Taiyang News, European Solar Wafer Maker NorSun Filing For Bankruptcy, 18 December 2024
[369] Taiyang News, Manufacturer Cuts Down Staff Work Time, 14 Janaury 2025
[370] PVTime, Breaking News Aleo Solar to Close Local PV Module Production Line in Germany, 14 March 2025
[371] SolarPower Europe, EU Solar Manufacturing Map, January 2025
[372] PV Magazine, Aleo Solar to halt production at PV module factory in Germany, 10 March 2025
[373]European Commission, Clean Industrial Deal, 26 February 2025
[374] SCMP, To rival China, EU seeks to favour European companies for hi-tech contracts, 29 January 2025

financing from the EU Global Gateway strategy, European Development Finance Institutions (DFIs) and Export Credit Agencies (ECAs) to realise concrete manufacturing projects and export opportunities in building a stronger and more resilient global solar PV supply chain.[375]

In CEF's view, this policy response to Chinese dominance is timely, necessary and unavoidable. However, local content rules must be carefully designed to avoid unintended consequences. Instituting overly restrictive requirements risks driving up energy costs for EU consumers and businesses, potentially making solar PV deployment more expensive and slowing the VRE transition.

Figure 8.2: EU Solar PV Manufacturing Capacity in the Pipeline (Sep 2024)



Source: REI[376]

Still, there have been some new developments, with €33m in state aid allocated to SC Heliomit SRL for a 1.5GW solar panel factory in Bârlad, Romania. The project is part of a broader Romanian government plan that includes financing two smaller solar manufacturing projects with a combined 200MW annual capacity.[377] Encouragingly, in October 2024, we also saw EU Innovation Fund capital grants earmarked for a proposed 1.5GW pa Trina Solar PV factory in Spain.[378]

March 2025 saw Europe's leading inverter firm SMA Solar announce CY2024 revenues -20% yoy to €1.5bn and gross profit (EBITDA) drop to an entirely unsustainable −€16m, from €311m EBITDA in CY2023.[379]

[375] SolarPower Europe launches new initiative for European solar manufacturers to tap into global markets, 4 March 2025
[376] REI, Progress in Diversifying the Global Solar PV Supply Chain, December 2024
[377] PV-Magazine, Romania finances 1.5 GW solar panel factory, 8 January 2025
[378] PV-Magazine, European Commission invests in 3GW of solar PV manufacturing from Trina Solar and FuturaSun, 28 October 2024
[379] SMA Solar, SMA Group publishes preliminary, non-audited figures for 2024, 5 March 2025

Northvolt AB

The bankruptcy of Sweden's Northvolt, which was meant to be the crown jewel of European battery energy storage manufacturing, is emblematic of the challenges European manufacturers face. Northvolt aimed to produce up to 60 GWh of batteries annually, sufficient to supply one million EVs, but went bankrupt in November 2024 with debts of US$5.85bn to service[380] — despite Northvolt enjoying significant policy, financial (US$15bn raised) and customer support (US$55bn of orders from companies including VW, BMW and Scania).[381] Still, the venture was mismanaged and technologically challenged, and unable to push past a 6% capacity utilisation rate in their first factory in Skellefteå.[382]

The company was weighed down by an excessively ambitious multi-site at once growth strategy, a lack of track record, logistical challenges caused by the factory's remote location, safety concerns, and competition with proven Chinese suppliers.[383] As a result, Northvolt could not scale production fast enough to meet customer demand, with BMW cancelling US$2.15bn of orders in mid-2024.[384] Northvolt now adds to a trend of cancelled European gigafactory projects, with companies withdrawing almost 176GWh of planned manufacturing capacity amid an EU-wide EV sale slowdown.[385] This is equivalent to nearly the entire EU operational manufacturing capacity of 190GWh. A further 600GWh of the 1,800GWh project pipeline faces significant issues.[386] The sting of a $15bn loss for financiers, unrealised dreams of the Swedish battery juggernaut, and the risk of other projects folding is a strong clarion call for a different strategic approach.

CATL 宁德时代

Over the last decade, China consistently invested in modern manufacturing, scaling up, and technology improvement to become the global leader in battery production and now accounts for nearly 70% of global battery manufacturing capacity.[387] Contemporary Amperex Technology Co. Ltd. (CATL) and BYD are the Chinese global market leaders. European manufacturers and policymakers should consider a pivot; forming joint ventures with leading Chinese manufacturers can help avoid another Northvolt.

Having developed a small German battery factory and another in Hungary, China's CATL has expanded its EU base by constructing a €4.1bn 50GWh pa battery plant in Spain[388] in joint venture with Stellantis, to be operational in 2026. CATL plans to establish this Spanish factory to avoid likely tariff barriers against Chinese-sourced imports. CATL was also attracted by low labour and energy costs as well as significant Spanish government policy support. Chinese companies like CATL operating in the EU are projected to supply up to 65% of the region's lithium iron phosphate (LFP) batteries by 2030.[389]

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[380]Financial Times, Northvolt chief warns of faltering green transition after battery maker's bankruptcy, 22 November 2024
[381]Financial Times, 'There was so much promise': How Northvolt tumbled into bankruptcy, 23 November 2024
[382] Benchmark Minerals, Northvolt files for bankruptcy in US as CEO steps down, 22 November 2024
[383] Kitco, Northvolt crisis may be make or break for Europe's EV battery ambitions, 23 November 2024
[384] LeMonde France, Northvolt's downfall, a symbol of acute European stalling, 6 November 2024
[385] Benchmark Minerals, EU 2030 battery pipeline falls 176 GWh amid EV slowdown, 27 September 2024
[386]Interact Analysis, Problems hamper over 30% of European Li-Ion battery projects, September 2024
[387] FDI Intelligence, Northvolt collapse lays bare Chinese EV supremacy, 25 November 2025
[388] Reuters, Stellantis, China's CATL to invest $4.33 bln in EV battery factory in Spain, 11 December 2025
[389]Benchmark Minerals, Stellantis-CATL JV to bolster Europe's LFP build out, 10 December 2024

Policymakers should take note of the EU's forced policy readjustment. The EU has recognised that developing domestic solar PV and BESS manufacturing to mitigate geopolitical risk requires moving beyond protectionist measures, which may offer short-term insulation but risk driving up costs, slowing deployment, and increasing consumer electricity prices. The EU is now pivoting to expanding support through industrial policy.

Rather than attempting to compete directly with established Chinese manufacturers, a pragmatic strategy CEF sees emerging in the EU and beyond that other jurisdictions can replicate includes joint ventures with leading Chinese firms in industrial hubs with low energy costs and competitive labour markets like Spain, Hungary, Turkey and Portugal. This approach leverages their advanced technology, industry expertise, and established supply chains while strengthening local manufacturing capacity and derisking major projects. Government support through stable, long-term policy frameworks and financial incentives are essential to reducing business uncertainty and attracting this private investment.

Section 9: Global Solar Breakthroughs

China is building a stable full of world-leading solar PV and BESS projects by pushing the limits of deployment in scale, speed and location. Projects like the 100GW Great Solar Wall in Inner Mongolia and the 4GW Ruoqiang Solar Project showcase its ability to deploy VRE at an unmatched scale and speed. China is also pioneering solar PV in diverse environments with the world's first 1GW open-sea plant in Shandong. Other projects like the 2GW Oasis de Atacama solar PV and 11GWh BESS project in Chile and the 30GW Khavda Renewable Energy Park in India are starting to replicate this ambition. Noting that the Chinese gift horse of clean technology manufacturing is supplying the BESS for Chile's biggest project.

Large-scale Solar and Wind Development in Deserts are Key to China's Energy Transition

In recent years, China's construction of large-scale wind and solar farms in its desert regions has accelerated at extraordinary speed and scale, supported by regional long-distance grid transmission expansion, to promote the clean and low-carbon energy transformation.

In October 2021, President Xi announced at the Kunming Biodiversity Conference that China would speed up its planning and construction of large-scale wind and solar energy bases in its desert regions.[390] One month later, the government announced a list of the "First Batch of Large-scale Wind Power and Photovoltaic Base Construction Projects Focusing on Deserts, Gobi and Wasteland Areas", outlining 50 planned projects with a planned installed capacity of 97GW in 18 provinces/autonomous regions. China's 14th Five-Year Plan for Renewable Energy Development called for the development of large-scale "photovoltaic sand control" new energy bases under a "photovoltaic+" multifunctional model.[391]

In January 2025, it was reported that by the end of 2024, the first batch of projects with an installed capacity of 92GW had been built, and 91GW was put into production.[392] Given the challenges of building and maintaining large-scale PV installations and supporting grid transmission infrastructure in harsh desert conditions, the mobilisation of innovation, industry, policy and governance to achieve this cannot be overstated.

Inner Mongolia Renewable Energy Cluster

Inner Mongolia has become a priority region for China's energy transformation and security. A massive cluster of large-scale solar and hybrid projects dubbed "the Great Solar Wall" has emerged. Since 2022,[393] construction of large-scale wind, solar and energy storage bases in Inner Mongolia, each planned to have 12GW of renewable energy capacity and 4GW of supporting coal-fired power (or supported by hydro rather than coal if in the South West), have been underway, enabled by six UHV DC transmission lines.[394] Notably, the Kubuqi Desert Ordos Central and Northern New Energy Base, which commenced construction in

[390] Reuters, China to speed up desert wind, solar construction in northwest – Xi, 12 October 2021
[391] 14th Five-Year Plan for Renewable Energy Development, p. 31
[392] NEA, Pan Huimin: Introducing the current construction progress of my country's first batch of "Shagohuang" large-scale wind power and photovoltaic bases, 23 January 2025
[393] Chinese Government, Inner Mongolia steadily promotes the construction of the "Shagohuang" large-scale wind power and photovoltaic base project, 25 November 2023
[394] China Power, State Grid North China Branch starts DC power grid connection service for "Shagohuang" new energy base in Inner Mongolia, 21 January 2025

December 2022 by China Three Gorges and Inner Mongolia Energy Group, has a planned capacity of 16GW, including 8GW of solar and 4GW of wind.[395]

A year later, the 1 GW first phase of the project was connected to the grid.[396] Once fully completed (expected by 2030), the total site area will cover 2,000km^2 capable of providing 40,000GWh of clean electricity to the Beijing, Tianjin and Hebei region every year.[397] It is expected to save 6Mtpa of standard coal and reduce carbon emissions by 16Mtpa.[398] As at December 2024, Chinese officials say 5.4GW have been installed on the site.[399]

On 29 November 2023, China's largest single PV + sand control project within the cluster, the Kubuqi Desert 2GW solar + sand control project developed by China Three Gorges, was connected to the grid[400] and purportedly strives to ecologically restore and manage 67km² of desert.[401] This project follows the multifunctional "PV + ecological restoration + rural revitalisation" model which reportedly seeks to combat rising desertification,[402] while driving industrial and local economic development through promoting traditional medicinal herb farming and animal husbandry.[403]

4GW Ruoqiang Solar PV Project in Xinjiang

Xinjiang, another major desert region in China and strategic energy base, has also seen a massive rollout in large-scale wind and solar projects in recent years. In December 2024, the 4GW Ruoqiang solar project located in Xinjiang's Taklamakan Desert was linked to the grid, becoming China's largest single-unit solar project to date. Like the Kubuqi Desert energy base, it is also designed to combat desertification and promote ecological restoration. The Ruoqiang solar project features over 5 million PV panels covering 76 km² with an investment of US$1.5bn.[404] Taking just over a year to build,[405] this project again highlights the blinding speed of China's renewable energy transformation.

The project is also the first to use single-site heterojunction technology on a large scale. Once it is put into operation, it is expected to generate 6,900GWh of electricity per year and save over 2Mtpa of raw coal and reduce carbon emissions by 6Mtpa.[406]

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[395] Chinese Government, Inner Mongolia steadily promotes the construction of the "Shagohuang" large-scale wind power and photovoltaic base project, 25 November 2023
[396] China Three Gorges Corporation, New energy: Kubuqi Desert governance welcomes new opportunities,1 March 2024
[397] Inner Mongolia Autonomous Region Government, "Chasing the Wind and the Sun" Gathering New Energy - One of the series of reports on "Rebuilding an Industrial Inner Mongolia" in the field of new energy, 13 December 2024
[398] China Three Gorges Corporation, New energy: Kubuqi Desert governance welcomes new opportunities,1 March 2024
[399] Inner Mongolia Autonomous Region Government, The vast "blue ocean" builds a green barrier - Observation on the photovoltaic sand control project in Inner Mongolia, 16 December 2024
[400] NEA, The construction of a new energy system is accelerating, 12 January 2024
[401] China Three Gorges Corporation, Kubuqi PV Baw Project
[402] Carbon Brief, Explainer: How China's renewables rollout boosts its 'war on sand', 12 December 2024
[403] Inner Mongolia Autonomous Region Government, The vast "blue ocean" builds a green barrier - Observation on the photovoltaic sand control project in Inner Mongolia, 16 December 2024
[404] PV-Tech, Huasun facilitates grid connection of world's largest single-site HJT project in China, 27 December 2024
[405] China Electric Power News, My country's largest single-unit capacity "Shagohuang" photovoltaic project successfully connected to the grid, 20 December 2024
[406]China Workers Network, Xinjiang "Shagohuang" photovoltaic project achieves a win-win situation of "ecology + industry", 2 January 2025

World's Largest Open Sea Floating Solar PV Plant, 1GW, Dongying, Shandong Province

Floating photovoltaics (FPV) has been a fast-growing source of renewable electricity globally in the past 17 years since the first commercial systems were installed. At the end of 2023, cumulative installed global FPV capacity reached 7.6GW across 63 countries, predominantly in Asia, with many more projects under development.[407] The increase in FPV installations, along with advancements in technology, has brought down costs, while similar to land-based PV, FPV installation size and power density have been increasing.[408]

China has been leading FPV installation capacities since 2017 and comprises almost half of the cumulative installed capacity as at 2023.[409] In 2019, a global floating solar market report commissioned by the World Bank noted that China was the only country in the world to have built installations of tens to hundreds of MW and highlighted the strategic land use constraints that FPV help overcome.[410] Recently, China has not only completed the installation of a world-first GW capacity FPV facility but has achieved this scale for the first time in the open sea, notwithstanding the harsh conditions of the marine environment.

In November 2024, State-owned China Energy Investment Corporation announced it had successfully activated a 1GW FPV solar plant, installed 8km off the coast of Dongying in Shandong Province. Once completed, it will be largest of its kind in the world, [411] overtaking the 440MW FPV plant off the coast of Taiwan.[412] It spans a sea area of 1,223 hectares and features over 2,900 FPV platforms installed using world-first, large-scale offshore steel truss platform fixed pile foundations. It also includes a 66kV offshore cable paired with an onshore cable, marking a first for the Chinese market.[413] On completion, the annual power generation is expected to reach 1,780GWh.[414] This will save 503,800t of standard coal per year and reduce carbon emissions by 1.3Mtpa.[415]

Like many other Chinese solar projects adopting the "PV +" model, the project combines solar power generation with fish farming to enhance the economic value of the marine area.[416] This concept of aquaculture-photovoltaic integration, known as agrivoltaics, has already been applied in the EU, the US and parts of Asia. It typically integrates traditional agricultural practices such as crop production, livestock farming and fisheries with solar PV installations, maximizing the use of available space.[417]

Shandong Weiqiao Pioneering Group is continuing to participate in the new energy revolution occurring in China. This includes the Binzhou 2GW PV – aquaculture project in the northern coastal area of Shandong Province, to combine the solar farm with a fisheries

[407] Solar Energy Research Institute of Singapore, SERIS Flagship Projects
[408] Progress in Energy, Global floating PV status and potential, 25 November 2024
[409] Solar Energy Research Institute of Singapore, SERIS Flagship Projects
[410] World Bank Group, Energy Sector Management Assistance Program, Solar Energy Research Institute of Singapore, Where Sun Meets Water: Floating Solar Market Report, 2019, p. 9.
[411] China National Energy Administration, The world's largest offshore photovoltaic project is connected to the grid, 15 November 2024
[412] The Energy Mix, Taiwan Opens World's Largest Offshore Floating Solar Plant, Soon to be Outdone by China's 1-GH Project, 14 November 2024
[413] PV-Tech, China's CHN Energy completes world's largest open sea floating solar PV project, 14 Nov 2024
[414] REGlobal, CHN Energy activates 1 GW offshore solar plant in China, 15 November 2024
[415] China NEA, The world's largest offshore photovoltaic project is connected to the grid, 15 November 2024
[416] PV Tech, China's CHN Energy completes world's largest open sea floating PV project, 14 November 2024
[417] World Resources Institute, Dual Harvest: Agrivoltaics Boost Food and Energy Production in Asia, 23 May 2024

activity. This will be increased to 5GW when fully developed, developed to underpin a 50% decarbonisation of the China' Hongqiao Group's massive aluminium refinery by 2026 relative 2020 levels, as part of a long term strategy of net zero by 2055, or earlier. The solar panels are mounted above the shallows in an area covering 83 square kilometres – Figure 9.1 to 9.2.

Figure 9.1: aerial view of the Shandong Weiqiao Pioneering 2 GW PV

Source: REI

Figure 9.2: aerial view of the Shandong Weiqiao Pioneering 2 GW PV

Source: REI

In recent years, China's global solar manufacturing companies have begun to expand their FPV manufacturing internationally by building or planning to build medium-to-large (larger than 1MW) FPV installations in countries in the Global South, such as Vietnam, Thailand, Indonesia, the Philippines and Zimbabwe. To date, some of the larger projects include:

- a 192MW FPV plant at Cirata Hydropower reservoir in West Java, Indonesia, activated in November 2023, being the largest FPV plant in Southeast Asia;[418]
- a 220MW FPV in Languna, Philippines, with construction set to begin in early 2025;[419] and
- a proposed 1GW FPV installation on the Kariba Dam in Zimbabwe, the largest man-made lake in the world,[420] with construction expected to commence in 2026.[421]

India is also deploying large-scale FPV plants, with its largest project to date being the Omkareshwar Floating Solar Park in Khandwa District currently under construction with a planned capacity of 600MW, of which 278MW have been commissioned as of January 2025.[422]

Tidal flat solar – Tianwan 2GW Solar+Nuclear and Huadian Laizhou 1GW Solar + BESS

Coast solar-storage developments are playing an increasingly important role in China's clean energy strategy, capitalizing on the sunlight-rich conditions of tidal flat regions to reduce the risk of strategic land use conflict, particularly close to major load centres.

In May 2024, construction commenced on China's largest offshore solar power station, the US$1.4bn Tianwan 2GW Tidal Flat PV Demonstration Project in Lianyungang, Jiangsu Province, with full capacity grid connection expected in 2025.[423] Developed by China National Nuclear Corporation (CNNC), the power station covers a sea area of 1,868 hectares and will use the 'warm drainage area of the nuclear power plant' to carry out 'PV + nuclear power' multi-energy complementarity.[424] It is expected to save 0.7Mtpa of standard coal and reduce carbon emissions by 1.8Mtpa.[425] Post project completion, it will be coupled with the CNNC Tianwan Nuclear Power Base to form a clean energy base with a total installed capacity of over 10GW,[426] which is one of the largest in the world.

January 2025 saw China's largest single tidal flat PV and storage project to date connected to the grid.[427] Spanning 1,200 hectares on the salt-alkali tidal flats of Bohai Bay, the Huadian

[418] People's Daily Online, Chinese company builds floating solar plant in Indonesia, contributes to Indonesia's green development, 22 May 2024
[419] Power Philippines, Blueleaf advances Php 15B floating solar project in Laguna, 20 December 2024
[420] PV-Tech, China's CHN Energy completes world's largest open sea floating PV project, 14 November 2024
[421] Power Technology, Power plant profile: Kariba Dam Floating Solar PV Park, Zimbabwe, 21 October 2024
[422] Solar Quarter, Union Minister Pralhad Joshi Visits Omkareshwar Floating Solar Park, Highlights India's Renewable Energy Progress, 6 January 2025
[423] Taiyang News, China Solar PV News Snippets: DMEGC's Modules For China's Largest Offshore PV Project & More, 29 October 2024
[424] People's Daily, Construction of the country's largest offshore photovoltaic power station begins,14 October 2024
[425] Power Technology, China's CNNC begins work on 2GW offshore solar farm in Jiangsu, 20 May 2024
[426] China Electric Power News, https://mbd.baidu.com/newspage/data/dtlandingsuper?nid=dt_4716698408019805745&sourceFrom=search_a, 20 May 2024
[427] South China Morning Post, China's solar farms spread into new regions amid green energy push, 12 January 2025

Laizhou tidal flat PV Power Station in Shandong Province has a 1GW solar capacity with 200MW/400MWh of BESS.[428] The power station is expected to generate enough electricity to save 0.4Mtpa of standard coal and reduce carbon emissions by 1.2Mtpa.[429]

Once again adopting the multifunctional model of 'PV+', the project's integration with salt production purports to enhance the local salt farming economy.[430] The bifacial solar panels are installed over brine pools, and their reflection of the sunlight from the water surface reportedly boosts power output by 3% while generating heat that raises the brine temperature by 2°C, which enhances salt production.[431] Given the project's size – extending 12km from north to south and 7km from east to west – Huadian employs an AI-controlled drone inspection system for cleaning and maintenance of the PV modules.[432]

30 GW Khavda Renewable Energy Park, Gujarat – Adani Green Energy Limited

The Khavda Renewable Energy Park project in Gujarat, India with a planned capacity of 30GW is being developed by Adani Green Energy Limited (AGEL). Construction commenced in 2023 with the planned capacity expected to be operationalised by 2028. When completed, this would likely be the world's largest hybrid solar and wind renewable energy power plant (and largest regardless of energy source) spanning 538km² of barren land, five times the size of Paris and almost as large as Mumbai City.[433]

This is a hybrid clean energy project that will harvest electricity from both solar panels (26GW) and wind turbines (4GW). Once completed, it is expected to generate 81,000 GWh of clean electricity.[434]

In March 2024, AGEL announced that it had operationalised a cumulative capacity of 1GW solar energy in 12 months of commencing work on the site. The sheer scale of the project involved installing 2.4 million bifacial solar PV modules and significant infrastructure development including the construction of 100 km roads, 50 km of drainage, establishment of desalination and reverse osmosis plants to meet the drinking water requirements of project staff. In addition, a township was created to accommodate 8,000 workers. AGEL cites its deployment of innovative waterless robotic module cleaning systems for the entire plant to address dust accumulation and help conserve water in the arid Kutch region.[435]

The Khavda Renewable Energy Park project is a significant step to meeting the Indian Government's target of achieving about 50% (around 500GW) of cumulative power installed capacity from non-fossil fuel-based energy resources by 2030.[436] Khavda aims to be 14 times larger than the 2,245MW Bhadla Solar Park at Jodhpur, Rajasthan, the largest fully

[428] ENCS, China's largest tidal flat photovoltaic energy storage station begins operation, 7 January 2025
[429] CCTV News, China's largest tidal flat solar power station goes into operation, 7 January 2025; South China Morning Post, China's solar farms spread into new regions amid green energy push, 12 January 2025
[430] China Energy News, The country's largest tidal flat photovoltaic power station is put into operation, 7 January 2025
[431] South China Morning Post, China's solar farms spread into new regions amid green energy push, 12 January 2025
[432] PV magazine, Huadian, PowerChina switch on 1 GW of solar on salt-alkali tidal flats, 24 January 2025
[433] Adani Green Energy, Adani Green Energy operationalizes 1,000 MW (1 GW) of the 30,000 MW Khavda renewable energy park, 11 March 2024
[434] PV magazine, Adani Green starts generating at world's largest planned renewables park, 20 February 2024
[435] Adani Green Energy, Adani Green Energy operationalizes 1 GW of the 30,000 MW Khavda renewable energy park, 11 March 2024
[436] Government of India Ministry of Power, 500GW Nonfossil Fuel Target

operational Indian industrial solar park. India's growth in solar generation in 2023 pushed the country above Japan to become the world's third-largest solar power generator.[437]

CY2024 saw India install a record 24.5GW of solar, +140% yoy (including rooftop).[438]

At the end of 2024, India's cumulative renewable power capacity stood at 209GW, with solar installations comprising a share of 47%.[439] To accelerate the expansion of its power transmission network, India is planning to invest ₹9.2 trillion (US$107bn) through to 2032 in grid T&D upgrades to triple its clean power capacity by that time.[440]

2GW Solar + 11GWh BESS Facility, Chile – Grenergy Renovables

The Oasis de Atacama solar-plus-storage project located in Northern Chile, which is being built by independent Spanish energy producer Grenergy Renovables (Grenergy), is set to have a total capacity of 2GW of solar plus 11GWh of BESS.[441] It is the most ambitious renewable energy project in South America and demonstrates Chile's prioritisation of BESS development to optimise its vast solar power resources and address rising curtailment due to transmission restrictions.[442] It will likely be the world's largest operating BESS installation, at least until Saudi Arabia's proposed 5GW solar and 19GWh BESS hybrid project is built.[443]

Construction of the US$2.7bn project began in November 2023. It is structured in seven phases that are set to produce 5.5TWh of energy annually.[444] It was reported that the first phase was scheduled to be connected by the end of 2024 and the new phases to be completed and powered between 2025 and 2026.[445]

In October 2024, Grenergy announced that it had contracted CATL to supply 1.25GWh of BESS for Phase 4 of the project. CATL will provide more than 220 of its EnerX BESS containers, featuring over 7,100 lithium iron phosphate and lithium-ion battery modules.[446] BYD is supplying batteries for previous phases which total 3GWh of BESS capacity.[447] In December 2024, Grenergy reported that the batteries for Phase 3 (Víctor Jara) that were being produced by BYD were expected to be delivered during the first half of 2025.

As at January 2025, the first three phases are under construction, comprising a cumulative 451MW solar plus 2.5GWh of BESS, which already places Oasis de Atacama among the largest hybrid BESS projects in the world. [448] January 2025 saw Grenergy announce it had secured an additional ~US$324m to finance Phase 4 of the project (Gabriela) which will develop 269MW of solar power and 1.1GWh of BESS.[449]

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[437] Ember, India country profile, 18 November 2024
[438] JMK Research & Analytics, India adds record 24.5 GW of solar power capacity in CY2024, 9 January 2025
[439] Renewables Now, Wind, solar capacity additions in India gain momentum in 2024, 16 January 2025
[440] Economic Times, India eyes private capital for $107 billion grid expansion, 7 January 2025
[441] PV magazine, First phase of 2 GW/11 GWh solar-plus-storage project in Chile nears completion, 13 December 2024
[442] Energy Storage News, Grenergy raises US$324 million for Phase 4 of 'world largest' solar-plus-storage project in Chile, 8 January 2025
[443] Energy Storage News, Saudi Arabia: 2GWh BESS project 'marks potential for energy cooperation with China', 21 January 2025
[444] Recharge News, 'World's largest' battery project gets fresh financial boost, 17 December 2024
[445] PV-Tech, Grenergy sells first three phases of Oasis de Atacama project, 18 December 2024
[446] Grenergy, Grenergy and CATL seal their first 1.25 GWh deal for Oasis de Atacama, 29 October 2024
[447] PV magazine, In Chile, BYD will supply 3 GWh of batteries for Oasis de Atacama, 12 September 2024
[448] Energy Storage News, Grenergy raises US$324m for Phase 4 solar-plus-storage project , 8 January 2025
[449] Grenergy Renovables, Grenergy secures close to $1 billion in financing for Oasis de Atacama, 6 January 2025

Section 10: Implications for Australia

In the face of China's expanding technology and manufacturing dominance, the US has now entirely left the playing field. This leaves Australia in a challenging position. Australia must 'thread the needle' to safeguard its national interests in this new era of geopolitical upheaval. In 2024, Australia saw a surge of projects in the solar PV pipeline, with solar PV and BESS projects reducing coal generation usage to historic lows. State and federal policies—like the Capacity Investment Scheme (CIS) —are driving this growth. However, a federal Coalition opposition plan for a speculative, taxpayer-funded nuclear fleet risks injecting massive uncertainty aimed to delay and undermine VRE deployments, with inevitable increased energy costs for all consumers.

Australia must focus on proven solar PV and BESS hybrid systems that outperform traditional thermal and nuclear generation in both cost, capital risks and deployment speed. With low-cost energy from solar PV and BESS, Australia can power an expansion of value-added clean technology manufacturing and processing to replace the loss of royalties, corporate tax and employment from the progressive decline of fossil fuel exports. This will also diversify the solar PV supply chain to provide insurance against a global trade crisis. March 2025 saw Rio Tinto, Australia's largest energy user, give this strategy an enormous business endorsement.

Australia should collaborate and partner with China to achieve these aims. Initiatives such as the 'Solar Sunshot' program facilitated by ARENA and SunDrive's joint venture with China's Trina Solar, show that the country can lay the groundwork to start to rebuild a domestic clean technology manufacturing ecosystem. Australia can do this without compromising democratic values and principles with appropriate investment safeguards. Expanding on these initiatives with targeted industrial incentives, realistic local content policies, and further trade agreements is essential to securing Australia's future as a competitive, low-cost, clean energy exporter and innovator.

Solar PV and BESS Deployments Are Transforming Australia's Energy Landscape

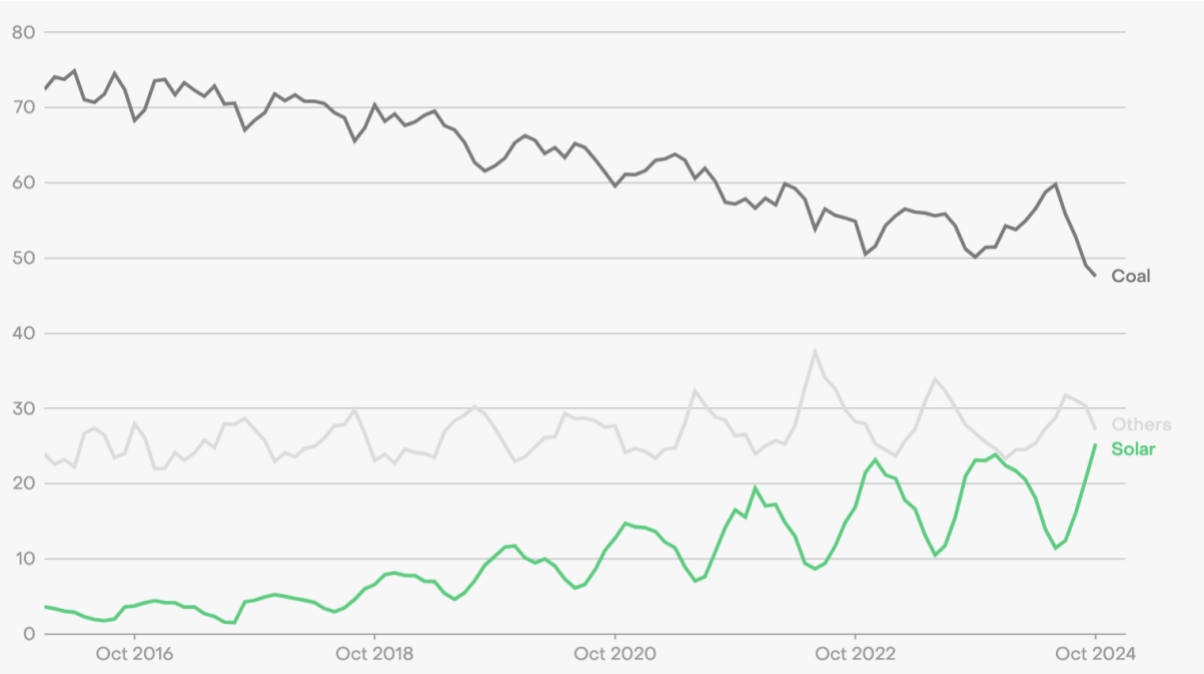
After a prolonged energy installation slowdown caused by the previous federal government haphazard and retrograde policy approach, Q4CY2024 saw solar PV alone generate 25% of Australia's electricity for the first time in history, while coal-fired power was reduced to a record low — see Figure 10.1.[450] This was supported by a considerable addition of 3.15GW of rooftop solar PV over CY2024.[451] By 4QCY2024, 18.7GW of solar PV projects were progressing through the NEM grid connection process, an increase of 22% yoy.[452]

At the same time, 3.9GW/13.5GWh of BESS was added to the NEM.[453] In 1QCY2025, the 850MW/1,680MWh NSW Waratah Super Battery, not even fully operational, had already prevented blackouts. On 9 December 2024, the first phase of Origin Energy's 700MW/2,800MWh Eraring BESS was also commissioned.[454] By the end of 2024, 18.1GW of

[450] Ember, Australia reaches record solar, generating a QUARTER of its electricity from solar in October 2024, 13 October 2024
[451] CER, Quarterly Carbon Market Report December Quarter 2024, 14 March 2025
[452] AEMO, Quarterly Energy Dynamics Q4 2024, January 2025
[453] AEMO, 2024 Electricity Statement of Opportunities, August 2024
[454] ESS-News, Origin energises the first stage of the 2.8GWh Eraring BESS in Australia, 10 December 2024

BESS projects were progressing through the grid connection process, a 97% yoy increase.[455] In 4QCY2024, 46% of all generation capacity in the NEM was from renewable energy. March 2025 modelling conducted by the Clean Energy Investment Group estimated that without this VRE generation over 2024, wholesale prices would have been up to AUD$80/MWh higher. This translates to the average household paying an extra AUD$417 on their electricity bills pa.[456]

Figure 10.1: Electricity Generation in Australia (%)

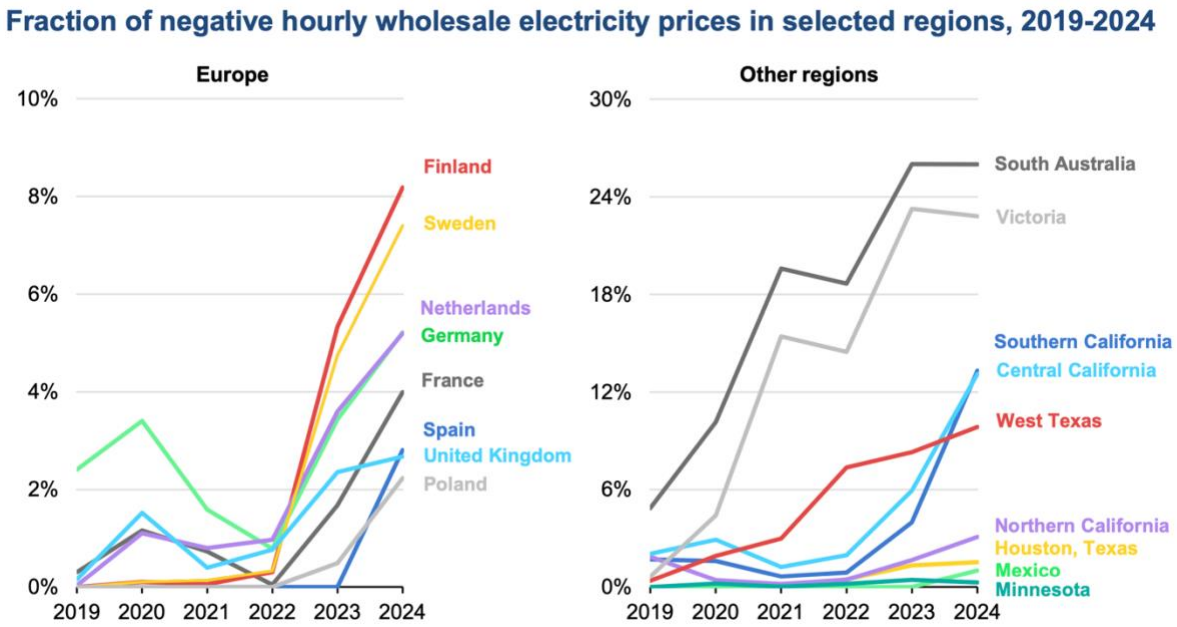


Source: Ember

Further, the IEA and AEMO have consistently referenced the negative aspects of 'too much' solar PV, resulting in minimum on-grid electricity demand and the resulting often negative wholesale electricity prices. South Australia (26% of the year) and Victoria (22-23%) led the world in 2024 – Figure 10.2. CEF notes that with the power of BESS and behind-the-meter storage, including EVs, this should be regarded as a massive system positive. Time-shifting demand to when power is cheap and time-shifting cheap VRE into high-priced peak demand periods will transform electricity markets.

[455] ESS-News, AEMO: BESS applications to Australia's NEM rise by 97% yoy in Q4 2024, 12 February 2025
[456] CEIG, The cost of no renewables: The unaffordable alternative, March 2025

Figure 10.2: Wholesale Electricity Prices Are Increasingly Negative



Source: IEA Electricity Report 2025

The Western Australian Wholesale Energy Market (WEM) has been slower to transition to VRE, with almost a third of its electricity from by VRE over 2024 but shows signs of increasing momentum with the recent re-election of Labor to state government with a mandate to boost home battery usage and talk of more utility-scale renewables. The state government also signed a Renewable Energy Transformation Agreement with the federal government in July 2024 that will underwrite 6.5TWh of new VRE generation. WA is also benefitting from direct policy support through the CIS,[457] with four new BESS totalling 654GW/2,600MWh announced as part of WA's first (and oversubscribed) CIS tender.[458] All will be operational by 2027.

In a further sign of forward momentum in the state, late October 2024 saw the commissioning of stage 1 of the 500MW/2,000MWh Collie BESS, the first of three mega-BESS projects in the state.[459]

Policy Programs Are Driving Installation Rates and Should be Expanded

State and federal energy policies are catalysing much of this deployment. State schemes such as NSW's Electricity Infrastructure Roadmap and firming tenders, Victoria's Renewable Energy Target, and the Queensland Energy and Jobs Plan provided strong market signals by providing financial incentives and as a result have effectively crowded in private investment. State reverse auctions under these programs are routinely oversubscribed.

The federal government's CIS, the largest support scheme for 32GW of firmed renewables across the nation, is also a critical driver. The CIS follows a contract for difference (CfD) model, where the federal government supports investment in new VRE and BESS projects by

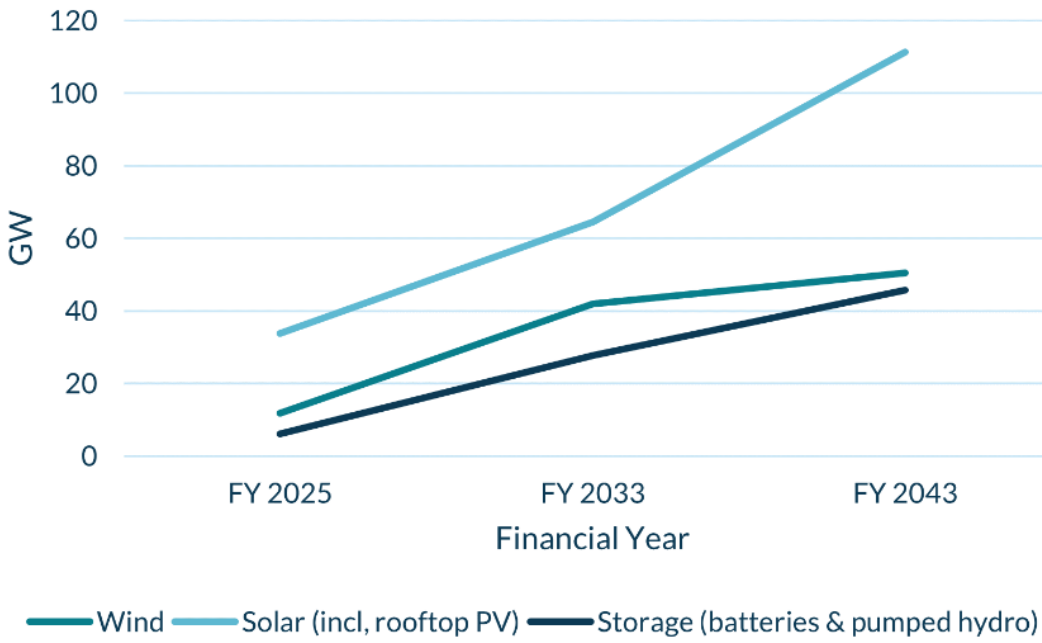
[457] PV-Tech, Western Australia eyes 6.5TWh of solar and wind with new Federal agreement, 23 July 2024
[458] RenewEconomy, Four new giant batteries to be built in W.A. as world's biggest isolated grid navigates transition from coal, 20 March 2025
[459] Neoen, Neoen's Collie Battery Stage 1 begins operating and delivering grid reliability services in Western Australia, 29 October 2024

underwriting them through competitive auctions. The first auction was oversubscribed by an astounding 567%, receiving 40GW of VRE and energy storage proposals.[460] 2.75GW of solar PV and 3.5GW of BESS were awarded, with solar PV accounting for 63% of the total. Due to the extraordinary interest in the first auction, the second auction will expand from 6GW of VRE and BESS to 10GW.[461] This is a powerful indication of both the efficacy of this policy and the appetite for investment in Australian VRE developments. With the collective efforts of state and federal government and business, the Australian clean technology 'Brumby' is gathering pace in this global horse race.

Australia is on track to meet its 82% VRE by 2030 target with 46% RE generation in 4QCY2024; however, sustained policy support, investment, and streamlined planning and evaluation are crucial to maintaining momentum to reach this goal.[462]

Cornwall Insight is now forecasting the total installed capacity for VRE and BESS is expected to rise from 52GW in 2025 to 208GW by 2043 in the NEM, up threefold— see Figure 10.2.[463]

Figure 10.3: NEM installed capacity forecasts – per financial year (GW)



Source: PV-Tech via Cornwall Insight

Of this, 78GW will be solar PV. Projects like the 720MW solar PV plus 2.88GWh BESS X-Elio North Burnett Renewable Energy Hub will contribute to this growth.[464] At a conservative 8% CAGR, this is eminently achievable. It should be accelerated by continuing to increase the size of already oversubscribed CIS and state tenders, as well as streamlining permitting and environmental evaluation. The federal government's March 2025 release of the 'National

[460] PV-Magazine, Australia's CIS Tender 1 to deliver 2.75 GW of solar, 11 December 2024
[461] PV-Tech, Australia's NEM to add 150GW of solar PV, wind and energy storage by 2043, 31 October 2024
[462] CEF, Australia is seeing an Acceleration in our Electricity Sector Transition, putting our 82% Renewables by 2030 Target in reach, 17 December 2024
[463] PV-Tech, Australia's NEM to add 150GW of solar PV, wind and energy storage by 2043, 31 October 2024
[464] ESS-News, X-Elio plans Australian 720 MW/2.88 GWh solar-and-battery project, 22 January 2025

Renewable Energy Priority List' that fast-tracks over 22GW of VRE projects is an encouraging step in this direction.[465]

Plans for Nuclear are a Costly Distraction Threatening Australia's National Interest

Lessons from other international jurisdictions show that ensuring a stable commercial, regulatory, and policy environment is critical for attracting investment. Australia will need to decarbonise the electricity sector, deliver affordable, clean energy to businesses and consumers, as well as reindustrialise the nation in an era of declining fossil fuel revenue.

March 2025 saw Australia's largest energy consumer, Rio Tinto, announce investment commitments to accelerate its pivot to affordable, low emissions reliable energy. Rio Tinto signed a deal with Edify Energy to provide firmed VRE generated electricity to its Gladstone smelters and refineries.[466] The deal involves supply from a 600MW solar plant and 600MW/ 2,400MWh BESS,[467] building on the largest solar and wind PPAs in Australian history. Combined, Rio Tinto have contracted a combined 2.7GW of VRE generation and 2.16GWh of BESS firming capacity, representing 80% of the industrial electricity demand and 30% of the firming requirements. Combined, the long-term PPAs will translate to a 70% reduction in Scope 1 and 2 emissions embedded in the value-added aluminium products, abating 5.6Mt of CO_2-e annually.

Pursuing an extraordinarily costly and slow, taxpayer-funded fleet of speculative nuclear generation assets, as proposed by the federal Coalition opposition, would delay investment in VRE capacity by injecting huge uncertainty and risk into business investment decisions and government planning. Pursuing nuclear power would be akin to burdening Australia's clean technology Brumby's saddlebags with lead (or uranium) in the race of the century. It would paralyse the federal parliament by creating a logjam of controversial legislation, spark a divisive national debate that would delegitimise current efforts, and devastate Australia's long-term budget position. Energy shortages, higher electricity costs,[468] rising greenhouse gas emissions,[469] and ballooning public debt[470] that prevents investment in other, more worthy programs will likely result. The only victors would be Australia's global competitors.

If Australia is to succeed in an era of Chinese clean technology supremacy, absolute political and institutional focus on deploying VRE must be continued, and plans for nuclear or even fossil fuel-powered boondoggles must be sidelined. In contrast, solar PV and BESS hybrid projects are now outperforming thermal generation in both deployment speed and cost in markets like India and Germany, a trend that will expand across regions. Australian policymakers should prioritise supporting hybrid solar PV plus BESS. Adding BESS defers the need for costly transmission upgrades, which are easily delayed by public pushback, thereby speeding up the transition whilst reducing electricity prices and emissions.

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[465] RenewEconomy, Federal and state governments give priority to 56 wind, solar, battery and transmission projects, 9 March 2025

[466] RenewEconomy, Rio Tinto signs massive solar and battery deal to help secure future of smelters and refineries, 13 March 2025

[467] RenewEconomy, Solar battery deal for giant smelter is a stunning game-changer for Australian energy, 14 March 2025

[468] Clean Energy Council, Renewables the cheapest path to lower Aussie energy bills, 4 March 2025

[469] Climate Change Authority, Assessing the impact of a nuclear pathway on Australia's emissions, 24 February 2025

[470] Climate Council, Economic meltdown: counting the real cost of Peter Dutton's nuclear fantasy, 20 December 2024

Advancing Australia's Solar PV Manufacturing and Clean Technology Export Capabilities

Australia's carbon-intensive economic landscape is shifting. According to the IEA, global demand for fossil fuels like oil are approaching their peak before 2030. As a result, there are growing implications for Australia's budgetary income from coal, gas, and oil royalties, as well as the jobs these industries support.[471] CEF notes the IEA has repeatedly underestimated the pace of this transition — see Section 1.4. Rapidly falling costs and technological acceleration of solar PV and BESS are already eroding the viability of fossil fuels, which some wrongfully assume will be competitive for 'decades to come.' Fossil fuels may yet be demanded over the long term but in ever-decreasing volumes. AU$250bn annually of Australia's carbon-intensive exports face progressive demand phase-down as our key trade partners progressively implement their Paris Agreement commitments.[472] As China's relentless expansion in clean technology continues, it is no longer a question of if but when these commodities are replaced.

Other jurisdictions' industrial policy efforts, such as the IRA in the US and NZIA in the EU, have also created a global capital vortex[473] that has drawn substantial investment flows to their jurisdictions. Meanwhile, Australia's decarbonisation and investment needs have only grown. Navigating this tectonic shift requires forward-thinking, innovative policy and strategy. It also necessitates a clear understanding that this transition is inevitable and accelerating, a race to attract investment and that strategic collaboration with our key trade partner in China is essential for success.

Recognising this, the Australian Parliament enacted the $22.7bn Future Made in Australia Act and policy package in November 2024, established the National Reconstruction Fund in 2023 and significantly expanded budgetary appropriations for key clean technology development agencies — ARENA and the Clean Energy Finance Corporation (CEFC).[474] Any dismantling or erosion of this legislative and policy architecture by a new government following the next federal election would have disastrous consequences akin to those experienced in the US with the Trump Administration's freezing of DoE loans and incentives under the IRA. Undermining Australia's investment reputation in this way would delay clean technology manufacturing, reindustrialisation, and VRE deployment, to the detriment of the nation's long-term economic and strategic interests. To safeguard progress, multipartisan support for the current policy direction should be actively pursued.

Part of the federal government's substantial policy push in 2024 included establishing a $1bn 'Solar Sunshot' program administered by ARENA. At the opening of the first phase of the program in August 2024, ARENA CEO Darren Miller said, "We need to build on our history of innovation and extend this into manufacturing across the solar supply chain. The demand for solar required to meet our net zero and renewable energy superpower goals is immense, and Australia has the opportunity to build resilience and unlock long-term economic opportunity."[475] The vision and pathway for establishing a solar PV supply chain in

[471] IEA, World Energy Outlook 2024, October 2024
[472] APVI, Silicon to Solar Foundations for Solar PV Manufacturing in Australia, December 2024
[473] SMH, Chalmers plans an Australian way to slash emissions, rebuild economy, 2 November 2023
[474] CEFC, CEFC welcomes additional $2 billion capital allocation from Australian Government, 14 February 2025
[475] ARENA, Solar manufacturing gets a Sunshot, 31 August 2024

Australia was established by the Australian Photovoltaic Institute's (APVI) pioneering 'Silicon to Solar Roadmap'.[476]

Building sovereign Australian solar PV manufacturing capability could be criticised in the context of Chinese manufacturing dominance and cost advantages as well as global overcapacity. Yet the current geopolitical and trade upheavals precipitated by the new US administrations trade manoeuvring indicate the value of diversifying our supply and starting to rebuild our domestic manufacturing capability to support domestic VRE deployment, particularly as Australia should as part of this treble to 15GW pa our solar PV demand. Right now, Australia sources 99% of solar PV from China.[477] Investing in domestic capacity is the long-term insurance needed to diversify our supply chains against future crises that could limit VRE imports and deployment, whilst enhancing our world leading universities' standing in solar engineering and technology development, whilst also building our domestic capacities in advanced robotics. This is especially critical as Australia approaches a key phase in its decarbonisation journey, with coal-fired plants retiring and industry requiring new VRE generation capacity.

One of the applications to the first round of the Solar Sunshot program is a joint venture between China's Trina Solar and Australia's SunDrive, which aims to build a 1.2GW pa module facility that would directly support 300 jobs.[478] Awarding funding to this JV would be a relatively modest investment but absolutely the right direction to take. Australian policymakers must understand that attempts at protectionism and going it alone are highly likely to be ineffective due to China's unmatched technology edge and manufacturing scale. As the US has shown, any ramping of tariffs would only push up prices for domestic energy consumers and slow VRE deployment. Collaborating through joint ventures like this will yield better economic and technological outcomes for Australia.

The Solar Sunshot program is a good starting point for robust government support of clean technology manufacturing in Australia. Other host countries are actively pursuing collaboration with Chinese manufacturers. This investment will go somewhere; it is Australia's choice, whether it will be invested at home or in ASEAN or MENA. Australia's Phase 1 is pursuing a solar PV module capability but lags in cell, polysilicon or wafer manufacturing. Lessons from other jurisdictions like India and the US show that a dependency along the supply chain can still create risks. Quinbrook Investment Partners is proposing significant investments in polysilicon capacity to remedy this. The company is seeking to establish a $8bn 250,000tpa green polysilicon facility in Townsville, Queensland. Yet the venture is precarious with volatile polysilicon prices caused by global oversupply. Bilateral Government support is necessary to ensure the project can weather unpredictable demand ensure that long-term Australia develops polysilicon capacity to leverage our potential global competitive advantage in low cost zero emissions electricity supply.

The benefits of further collaboration are manifold. While initial product costs may be higher in Australia than in other jurisdictions even after policy incentives, this strategy not a short-term profit maximisation business play—it is a long-term strategic public investment in expanding Australia's capacity both downstream and upstream and even across horizontal

[476] ARENA, Roadmap provides a pathway for domestic solar manufacturing, 2 February 2024
[477] Yahoo! News, COP29: 'Sinister' reality behind cheap solar panels and EVs imported into Australia, 12 November 2024
[478] PV-Magazine, Trina targets Australian-made solar modules by 2027, 5 November 2024

business and technology sectors such as into solar glass or recycling. We see this potential with the December 2024 announcement of the partnership between SunDrive and Australia's Capral Aluminium to provide aluminium for SunDrive's solar PV products.[479]

Partnering with an established Chinese manufacturer facilitates technological transfer from market leaders and the building up of domestic advanced manufacturing abilities, including in robotics. It will also be a strong factor in retaining IP and Australian tertiary graduates in the country and reversing the country's 'brain drain.' By nurturing a domestic clean technology manufacturing ecosystem, Australia also opens the door to developing unanticipated technological breakthroughs that can drive the industry and country forward over the next several decades. We see this potential with Quinbrook's partnership with China's CATL to produce groundbreaking long-duration (8+ hour) BESS systems to be deployed across Australia.[480] Similarly, the combination of SunDrive's innovative copper cells and Trina Solar's n-type cell technology shows that JVs with Chinese firms can drive innovation. Australia could be an innovation hub and test bed of world-beating clean technology. Australia can also begin to develop clean technology products for export that can offset the loss of revenue and employment from the inevitable demise of Australia's fossil fuel exports. With the retreat of the US, there is no better time than now to do this.

To achieve these aims, CEF recommends:

1. Continuing and expanding Australia's long-term energy frameworks, like the CIS, is critical for attracting private investment and rapidly deploying solar PV and BESS. Australia's advantage lies in its abundant, low-cost solar and wind resources. Leveraging these for affordable VRE generation will lower operational costs for energy-intensive manufacturing, such as polysilicon production.
2. Avoiding the policy volatility seen in the US, where fluctuating support has undermined investor confidence. Policymakers across the federal parliament and the next government must commit to Australia's direction as a clean technology manufacturing hub. Lasting, multipartisan support will provide the certainty investors need and reinforce Australia's reputation as a stable and attractive investment destination.
3. Ignoring distractions such as nuclear energy and further expansion of fossil fuel generation capacity is critical. Both are now rapidly becoming uncompetitive, slow to deploy and financially risky compared with solar PV and BESS hybrid systems, which are becoming dominant globally and must be a deployment focus. In so doing, Australia can enhance the utilisation of VRE assets and reduce the need for costly transmission upgrades that are slowing deployment. At the same time, a complete regulatory focus should be applied to streamlining planning and regulatory processes to accelerate the deployment of hybrid systems.
4. Disregarding protectionist measures like tariffs without complementary partnerships with Chinese manufacturers or other market leaders. Lessons from Northvolt in Europe clearly illustrate that protective tariffs with lacklustre industrial support are insufficient and counterproductive, driving up domestic energy costs and risking manufacturing delays and cancellations.

[479] PV-Tech, SunDrive Solar partners with Capral Aluminium for Australian solar PV supply chain, 6 December 2024

[480] PV-Magazine, Quinbrook seeks renewable power 'holy grail' with eight-hour battery tech, 6 March 2025

5. Pursuing joint ventures, like the Stellantis-CATL facility in Spain, with leading Chinese companies or other market leaders in non-sensitive solar PV manufacturing or critical infrastructure sectors. Drawing investment in these areas requires the Foreign Investment Review Board to provide clear, transparent criteria and communication for assessing proposals and supply chain due diligence, ensuring alignment with Australia's strategic interests. Non-sensitive sectors refer to areas of manufacturing and production that do not pose national security, data security, or sovereignty risks.
6. Designating Renewable Energy Industrial Precincts that leverage low-cost VRE generation, financial incentives, regulatory relief, import duty exemptions on equipment, and robust infrastructure—like those in Oman and Egypt—while incorporating investment safeguards, such as requiring that joint ventures be majority Australian-owned. This effort can be further underscored through trade deals with China or India, like Indonesia has utilised, to facilitate investment in Australia or provide easier access to export markets for Australia's new production capacity.
7. Extending FMIA Production Tax Credits to support an AU$0.5bn-$1bn incentive over five years to support solar PV manufacturing initiatives. This would enable the deployment of 2GW of annual capacity in polysilicon, cells, or wafers, with flexibility to scale to 5GW+ over the next 5-10 years. The long-term goal is to supply up to 25% of domestic demand across key solar PV components while also meeting the needs of our trading partners. FMIA regulations that apply to domestic manufacturing and downstream processing should also be enhanced.
8. Supporting clean technology manufacturing efforts by implementing carefully calibrated and realistic local content policies that require at least 10% local manufacturing content in VRE developments in the country, with the ability to scale over time to up to 30%. Overly stringent content requirements may unnecessarily push up costs and reduce industry competitiveness.
9. Safeguard liberal democratic values, principles, and institutions by establishing robust, enforceable investment guidelines from China or other nations. A loss of control or perceived erosion of values could create national security and foreign influence risks, as well as trigger a public backlash that would delegitimise and slow the transition—outcomes that Australia and the world cannot afford.