

Clean Technology Diffusion Under Conditions of Interlocking Global Crises

Hunter Hughes

hunterhghsr@gmail.com

H Heuristics

Research Article

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Navigating a Changing World

Clean Technology Diffusion Under Conditions of Interlocking Global Crises

How Emerging Economies Can Sustain Structural Transformation

Amid Debt, Climate, and Geopolitical Pressures

H Heuristics · Hunter Hughes

Research Report · September 2026

Abstract

Clean technology is arriving in emerging economies faster than at any point in history. In March 2026 China exported a record 68 gigawatts of solar panels in a single month, and Africa is on course to install about 17 GW in 2026, up 45 per cent. Yet the World Bank's June 2026 outlook projects that developing economies other than China and India will by 2028 have made almost no progress in closing the income gap with advanced economies for nearly a decade. This report asks why technology is spreading while structural transformation stalls, and what governments and lenders can do about it.

The report argues that debt, climate and geopolitical pressures should be analysed as one interlocking system rather than three separate problems. Six documented links connect them: fiscal stress starves adaptation; disasters force borrowing; energy shocks widen import bills; financing constraints deepen supplier dependence; the transition raises the strategic value of minerals; and fragmentation slows technology transfer. Low- and middle-income countries sent US\$741 billion more to creditors than they received in 2022–24, official development assistance fell 23 per cent in 2025, and adaptation finance meets about one-twelfth of estimated need.

The central contribution is the balance-sheet sort. Clean-technology diffusion has two stages, arrival and embedding, and three layers: distributed consumption technology financed by households and firms, network and system infrastructure financed by the sovereign and the utility, and production capacity financed by foreign investment and constrained by trade. The three pressures fall on these balance sheets unevenly. The distributed layer is largely insulated from sovereign debt stress and accelerated by energy insecurity; the network layer is throttled by debt and exposed to climate damage; the production layer is caught between finance and geopolitics. Left alone, the result is diffusion without transformation.

Evidence from five country configurations supports the argument. Pakistan added roughly 7 GW of net-metered solar in six years while power-and-gas circular debt reached PKR 5.2 trillion. Ethiopia used an import ban to convert foreign-exchange scarcity into electric-vehicle adoption. India built about 217 GW of module capacity against annual demand of 55–60 GW and only 35 GW of cell capacity. Indonesia and Morocco show mineral-processing and foreign-anchored routes into the production layer, each with a distinct concentration risk. An illustrative calculation shows that the same solar plant is 28 to 58 per cent more expensive at emerging-economy costs of capital than at European ones.

The report concludes with a strategy built around seven principles and a three-horizon roadmap: do not tax the layer that works; treat grid finance as the priority use of concessional money; reform tariffs without penalising early adopters; break the debt-climate loop with pre-arranged instruments; diversify dependence without autarky; build production in stages behind demand; and measure embedding rather than arrival.

Keywords: clean technology diffusion; structural transformation; sovereign debt; climate adaptation finance; geopolitics; cost of capital; emerging economies; energy security; industrial policy

JEL classification: O33, O14, O19, F34, Q55, Q48; technological change and diffusion; industrialisation; international lending and debt problems; energy policy

Data and method: This report synthesises institutional and peer-reviewed research, drawing mainly on World Bank, IMF-related, UNCTAD, OECD, IEA, IRENA, UNEP and Ember publications available to September 2026. Several 2026 figures are forecasts or preliminary estimates and may be revised. Country cases illustrate configurations rather than a sample; the scores in Figures 7 and 9 are qualitative judgements, and Figure 4 is an illustrative calculation with stated assumptions.

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1. Introduction: A Record Year for Solar, a Lost Decade for Convergence

In March 2026 China shipped a record 68 gigawatts of solar panels in a single month, and fifty countries set all-time import records. In the same season the World Bank told developing economies to expect nearly a decade of no progress in closing the income gap. Both facts are true, and the distance between them is the subject of this report: clean technology is arriving faster than at any moment in history, yet the structural transformation that technology is supposed to serve is stalling.

The proposition at the heart of development economics is that late-comers can grow faster than leaders by adopting what already exists. For the last two decades the falling cost of solar panels, batteries, electric two-wheelers and digital payments has made that proposition look stronger than at any point since the postwar industrial catch-up. The International Renewable Energy Agency puts the global weighted-average cost of utility-scale solar electricity at roughly US\$43 per megawatt-hour, about 90 per cent below its 2010 level, and BloombergNEF reports lithium-ion pack prices of US\$108 per kilowatt-hour. Technology of that price is no longer a rich-country luxury. It is the cheapest source of new electricity across most of the developing world.

The macroeconomic setting, however, has turned against the countries that could benefit most. The World Bank's June 2026 *Global Economic Prospects* forecasts global growth of 2.5 per cent for 2026, the weakest since the pandemic, with developing economies at 3.6 per cent and the Middle East conflict pushing Brent crude to an average of about US\$94 a barrel. Forecasts for two-thirds of economies were cut relative to January. Developing economies other than China and India, the Bank warns, will by 2028 have spent nearly a decade making no progress in narrowing the per-capita income gap with advanced economies. Behind that headline sits a debt burden that has been compounding for years: the World Bank's *International Debt Report 2025* records US\$741 billion of net financial outflows from low- and middle-income countries between 2022 and 2024, the largest negative transfer in more than fifty years of data.

Three pressures, in other words, are bearing on emerging economies at once: a debt overhang that has consumed fiscal space, a climate system that is imposing physical costs while the money to adapt has not arrived, and a geopolitical environment in which energy, minerals, tariffs and aid have all become instruments of strategy. Each has an extensive literature. What has received far less attention is how they interact with the specific problem of getting clean technology to spread through an economy and, more importantly, of turning that spread into structural change.

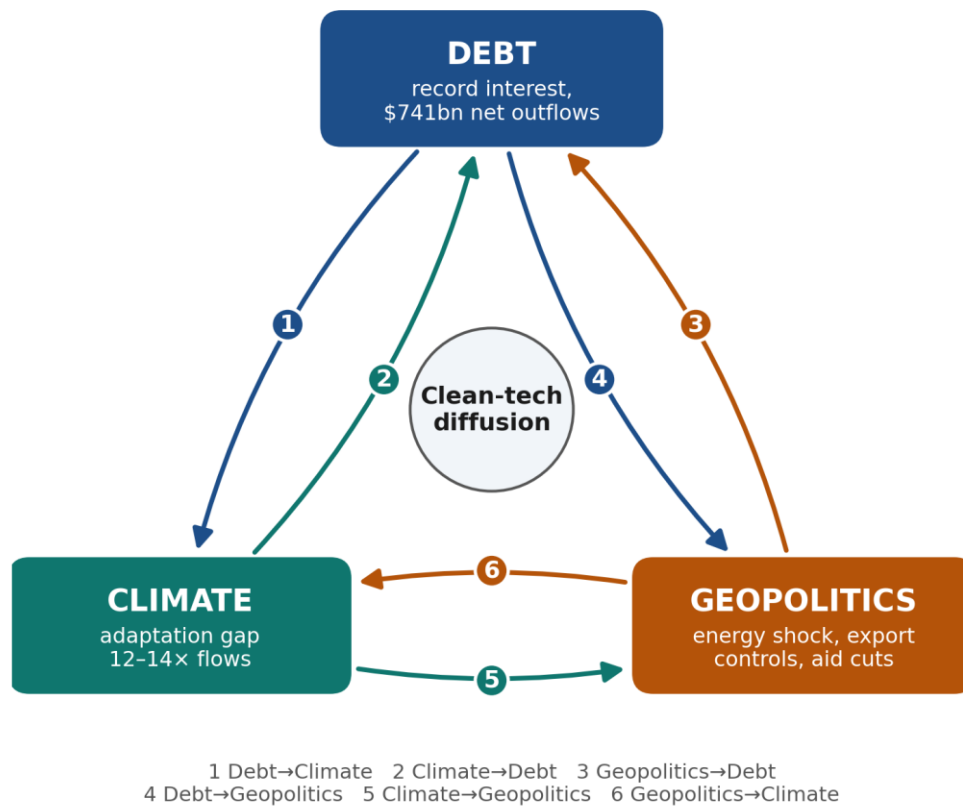


Figure 1. Three interlocking pressures and the six transmission links between them.

H Heuristics. Conceptual schematic; link evidence is documented in Section 7 and Table 3.

1.1 What this report argues

Four claims run through what follows. First, that clean-technology diffusion has two stages that are routinely conflated: *arrival*, meaning imports and installation, and *embedding*, meaning the grids, finance, supplier firms, skills and industrial capacity that convert cheap equipment into productivity and jobs. The 2026 evidence shows arrival accelerating while embedding lags.

Second, that the three crises do not fall evenly on all technologies. They fall on **balance sheets**. Technology that is paid for by households and small firms on their own balance sheets, such as rooftop solar, batteries and electric two-wheelers, is largely insulated from sovereign debt stress and is in fact accelerated by energy insecurity. Technology that depends on the sovereign or the state utility, such as transmission grids, storage at scale, public transport and utility-scale procurement, is squeezed by the same debt stress. Technology that depends on foreign direct investment and trade access, such as clean-technology manufacturing and mineral processing, is exposed to geopolitics. The report calls this sorting mechanism *the balance-sheet sort*.

Third, that the sort produces a specific and dangerous asymmetry. The layer that thrives, distributed consumption technology, is the layer that delivers energy security and household savings but the least structural transformation. The layers that starve, the network and production layers, are the ones through which catch-up has historically occurred. Left to itself the crisis environment therefore tends to produce

diffusion without transformation: a country that imports cheap solar but does not build the grid, the supplier base or the financial system that would let it capture the value.

Fourth, that the response is a matter of sequencing and instrument design rather than of overall budget size. Protecting the diffusion already under way, repairing the network layer's balance sheet, and building selective production capacity are three different tasks with different owners, different financing and different timelines. Attempting all three with one instrument, or ignoring one, produces the failure modes documented in Section 10.

1.2 What this report is not

This is not a forecast of any country's growth, and the illustrative figures, in particular Figures 1, 2, 9, 10 and 11, are constructed to make an argument legible rather than to estimate a parameter. It is not an energy-system model. Nor is it a claim that clean technology is unaffordable or that the transition should be delayed: the evidence points the other way, and the question is how to make the transition durable. The report is also written in September 2026, while the Middle East conflict and its price effects are still unfolding. Where a number is a forecast or a preliminary estimate the text says so, and readers should expect some of the 2026 figures to be revised.

2. Framework: Diffusion, Structural Transformation and Three Balance Sheets

Before asking how crises affect diffusion it helps to be precise about what is diffusing and what it is supposed to change. This section defines the two stages of diffusion, splits the economy into three layers that respond differently to stress, and explains why the balance sheet, rather than the technology, is the natural unit of analysis.

2.1 Diffusion has two stages: arrival and embedding

The economics of technology diffusion has long distinguished between whether a technology has reached a country and how intensively it is used. Comin and Mestieri's work on the great divergence found that adoption lags across countries have narrowed sharply over the past two centuries, while gaps in the intensity of use have widened, and that the two together account for a large share of the income divergence between rich and poor countries. Arrival has largely solved itself; the intensive margin is where the difference lies.

Clean technology sharpens the distinction. A rooftop solar array can arrive in a week. But converting cheap electrons into structural change requires that the local grid can absorb them, that firms can use reliable power to run machinery at full duty cycle, that a financial system can lend against the assets, and that domestic suppliers can install, service and eventually manufacture the equipment. Those are embedding conditions. They accumulate slowly, they depend on institutions rather than imports, and they are exactly what the World Bank's World Development Report 2024 has in mind when it argues that countries stall in the middle-income range because they keep investing without moving on to *infusion* and *innovation*.

Structural transformation, the reallocation of labour and capital from low-productivity to high-productivity activities, is the outcome that embedding is meant to deliver. It is also the outcome that has become harder to achieve. Dani Rodrik's work on premature deindustrialization documents that manufacturing's share of employment and output has peaked earlier and at lower levels in developing countries since the 1980s, closing off the classic route from farm to factory in much of Latin America and Sub-Saharan Africa. Clean technology raises a real possibility of a new manufacturing opportunity, but only if arrival is followed by embedding.

2.2 Three layers of the clean-technology economy

The report divides the clean-technology economy into three layers. The division is not a taxonomy of technologies for its own sake; it is chosen because each layer is financed by a different balance sheet, and therefore reacts differently to debt, climate and geopolitical pressure.

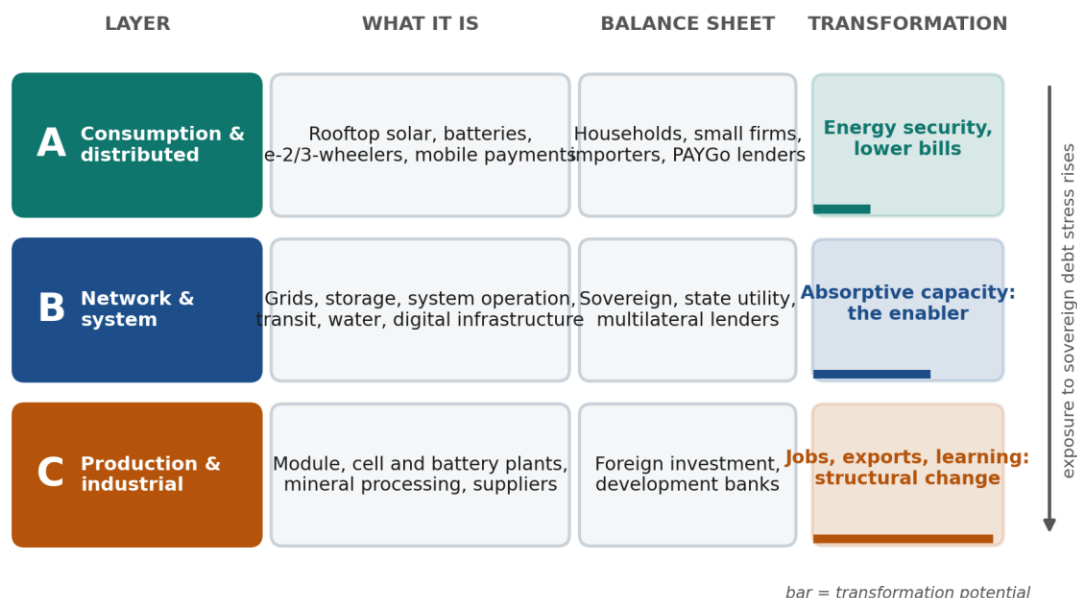


Figure 2. The three layers of clean-technology diffusion, the balance sheet that funds each, and the structural transformation each can deliver.

H Heuristics. Conceptual schematic.

Table 1. Three layers of the clean-technology economy

Layer	Examples	Who carries the balance sheet	What it delivers
A. Consumption and distributed	Rooftop and commercial solar, home batteries, e-2/3-wheelers, efficient appliances, mobile payments	Households and small firms; importers and installers; retail credit and pay-as-you-go finance	Energy security, lower bills, reliability. Modest but real productivity gains for small firms
B. Network and system	Transmission and distribution, storage, system operation, public transit, water and irrigation networks, digital public infrastructure	The sovereign and the state utility; multilateral lenders; long-tenor debt	Absorptive capacity: the ability of the whole economy to use cheap clean power at scale
C. Production and industrial	Module, cell and battery manufacturing, mineral processing, green industrial parks, component supply chains	Foreign direct investment, development banks, export credit, industrial-policy incentives	Structural transformation: jobs, exports, learning, supplier depth

Layers are analytical categories; many technologies (for example an e-bus fleet) span more than one.

2.3 Why the balance sheet, not the technology, is the unit

Ranking technologies by cost or emissions abatement, as most clean-technology assessments do, hides the variable that determines whether diffusion survives a crisis. A solar panel bought by a shopkeeper for cash in Lahore and a transmission line financed by a state utility in Karachi are both ‘clean technology’, but they sit on completely different balance sheets. The shopkeeper’s decision responds to the electricity tariff, the exchange rate and the panel price. The utility’s decision responds to its receivables, its guarantees from the

sovereign, the cost of its dollar borrowing, and the fiscal space of a government that is spending more on interest than on health.

This is the logic behind the report's central hypothesis. If diffusion is sorted by balance sheet, then the aggregate diffusion numbers that dominate headlines, panels imported, gigawatts installed, vehicles sold, will overstate resilience, because they are dominated by the layer that is least exposed. The layers that are most exposed are the ones whose failure shows up later and in different statistics: curtailment, blackouts, circular debt, unfinished factories.

3. The Interlocked Crises in 2026

The three pressures are not hypothetical or long-run. Each has moved sharply in the last eighteen months, and each is documented in primary data. This section sets out where they stand in September 2026.

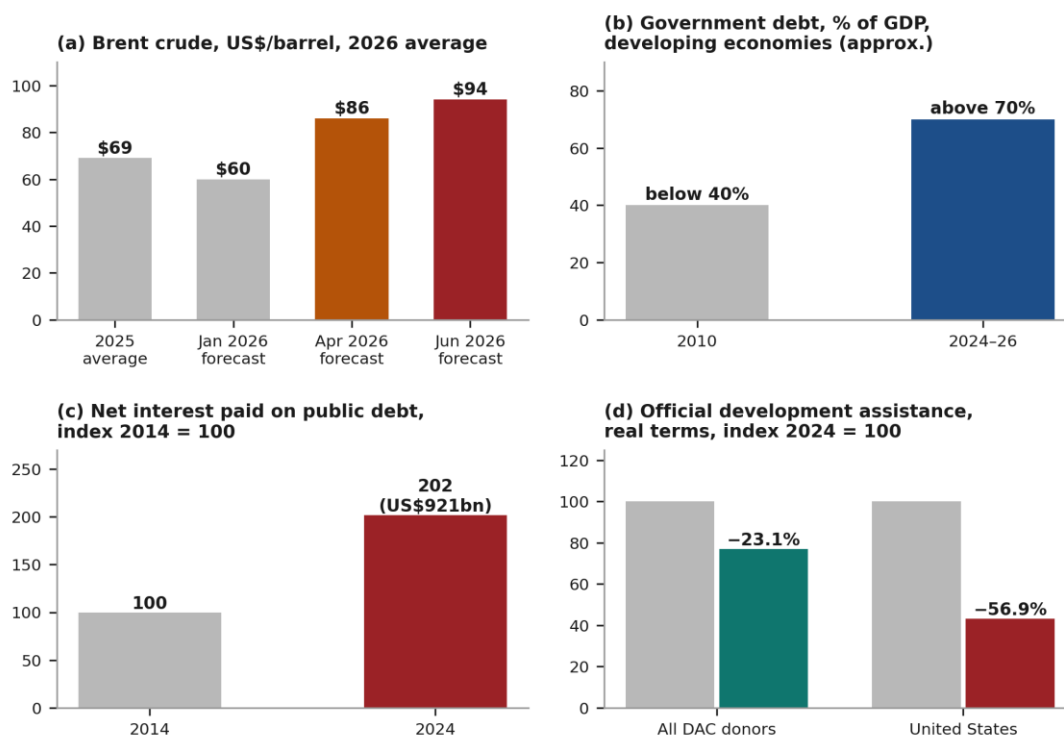


Figure 3. Four indicators of the 2026 crisis environment for emerging and developing economies.

World Bank Commodity Markets Outlook (April 2026); World Bank Global Economic Prospects (June 2026); UNCTAD A World of Debt 2025; OECD preliminary ODA data (April 2026). Panel (a) shows successive forecast vintages; panel (b) uses the Bank's stated approximations of 'below 40%' and 'above 70%'.

3.1 An energy-price shock on top of a weak recovery

The trigger for much of the 2026 deterioration was the war in the Middle East. The World Bank's April 2026 Commodity Markets Outlook projected the largest surge in energy prices in four years, with energy prices up 24 per cent for the year, fertilizer up 31 per cent and urea, the most widely used nitrogen fertilizer, up about 60 per cent. The Bank's central case put Brent at US\$86 a barrel, US\$26 higher than its January forecast; by June the *Global Economic Prospects* average had moved to about US\$94. Growth in emerging and developing economies was revised from 4.0 to 3.6 per cent, inflation was revised up by a full percentage point to 5.1 per cent, and 70 per cent of commodity importers were expected to see weaker growth than previously forecast. If oil stays above US\$100 for long, the Bank estimates up to 45 million additional people could face acute food insecurity.

The shock hit an economy with little slack. The June Global Economic Prospects projects global growth of 2.5 per cent in 2026, recovering only to 2.8 per cent in 2027, about 0.4 percentage points below the 2010s average. Growth in the Gulf itself is forecast near zero this year. Regional outlooks for 2026 range from 6.3 per cent in South Asia and 4.2 per cent in East Asia and the Pacific to 4.0 per cent in Sub-Saharan

Africa, 2.2 per cent in Latin America, and 1.6 per cent in the Middle East and North Africa. The Bank has said it could make US\$50 to 60 billion immediately available and scale support to US\$80 to 100 billion over fifteen months, an acknowledgement that the crisis is being treated as a balance-of-payments event rather than a passing price movement.

3.2 A debt burden that pre-dates the shock

The energy shock arrived on top of an already heavy debt load. The Bank's *International Debt Report 2025* shows external debt of low- and middle-income countries at a record US\$8.9 trillion at the end of 2024, with IDA-eligible countries owing US\$1.2 trillion. Between 2022 and 2024 those countries paid US\$415 billion in interest alone and transferred US\$741 billion more to creditors than they received in new financing. New bond issuance was priced near 10 per cent, roughly double pre-2020 levels. Restructurings reached US\$90 billion in 2024, the highest since 2010, a sign of how much was being worked out rather than resolved.

UNCTAD's *A World of Debt 2025* measures the fiscal consequence. Developing countries' net interest payments on public debt reached about US\$921 billion in 2024, up 10 per cent in a year and up 102 per cent over a decade. A record 61 developing countries spent 10 per cent or more of government revenue on interest, and 3.4 billion people, more than 40 per cent of humanity, lived in countries that spent more on interest than on either health or education. The Global Economic Prospects adds that government debt in developing economies has risen from under 40 per cent of GDP in 2010 to over 70 per cent.

3.3 Climate damage and an aid system in retreat

The climate pressure is best measured not by temperature but by the widening gap between what adaptation requires and what it receives. The UN Environment Programme's *Adaptation Gap Report 2025* puts developing countries' adaptation finance needs at US\$310 to 365 billion a year by 2035, against international public flows of about US\$26 billion in 2023, a gap of roughly twelve to fourteen times. At COP30 in Belém parties agreed to at least triple adaptation finance by 2035 from the roughly US\$40 billion goal for 2025, a decision widely criticised for its distant horizon, absent baseline and non-binding wording, and a Baku-to-Belém Roadmap set out a path to US\$1.3 trillion a year in climate finance by 2035 without settling how to reach it.

The aid system that was expected to fill part of the gap contracted instead. The OECD's preliminary data show that official development assistance from DAC members fell 23.1 per cent in real terms in 2025 to US\$174.3 billion, or 0.26 per cent of their combined income, the largest annual contraction in the history of the statistic. The United States accounted for three-quarters of the fall, with its ODA down 56.9 per cent, and humanitarian assistance dropped 35.8 per cent. For countries that had built parts of their energy and adaptation programmes on grant and concessional finance, the marginal dollar became scarcer at the same moment the marginal risk became larger.

3.4 Concentrated supply chains and contested trade

The third pressure is the political economy of the technology itself. The International Energy Agency's *Global Critical Minerals Outlook 2026* finds that geographic concentration has deepened, especially in refining, where China processes between 60 and 90 per cent of lithium, cobalt and rare earths, and that

China's use of export controls has tripled since 2023. As of 2026 controls touch antimony, gallium, germanium, refined graphite, rare earths and lithium iron phosphate battery technology, among others. Prices for base metals such as aluminium, copper and tin rose by roughly a third between January 2025 and April 2026, with copper at record highs. The IEA estimates that China's rare-earth controls put about US\$6.5 trillion of downstream output outside China at risk.

UNCTAD's *Global Trade Update* describes a more restrictive and uneven trade landscape in which tariffs are used to pursue industrial and strategic objectives, with frequent policy shifts raising uncertainty and depressing investment; smaller and less diversified economies are the most exposed. For a country trying to build a clean-technology export base, this is a hard environment: the market it wants to sell into is politically contested, and the inputs it needs to buy are subject to controls.

4. The Debt Channel: Why Fiscal Stress Becomes a Diffusion Tax

Debt does not stop clean technology from being adopted. It changes who can adopt it, on what terms, and at what stage the process stalls. This section traces four mechanisms and quantifies the one that matters most: the cost of capital.

4.1 Four mechanisms

Table 2. How sovereign and corporate debt stress reaches clean-technology diffusion

Mechanism	How it works	Evidence
Cost of capital	Clean technology is capital-intensive. Its levelised cost is highly sensitive to the discount rate, so a higher country-risk premium is a technology-specific tax.	IEA: utility solar WACC 4.7–6.4% in North America and Europe versus 8.5–9% in Kenya and Senegal and 9.5–11% in other emerging economies.
Fiscal crowding out	Interest displaces public investment in grids, transit and water. Layers B and C rely on the budget.	UNCTAD: 61 countries spend at least 10% of revenue on interest; 3.4bn people live where interest exceeds health or education.
Utility balance-sheet failure	Subsidised tariffs, unpaid receivables and sovereign-backed contracts turn the utility into a shock absorber, so it cannot invest.	Pakistan's power-and-gas circular debt reached about PKR 5.2 trillion in 2026; the power sector missed its IMF target.
Foreign-exchange and import stress	Imported equipment is paid for in dollars. A weak currency raises the local price of every panel and inverter and shrinks the pool of borrowers.	IDR 2025: net outflows of US\$741bn in 2022–24; new bond coupons near 10%, double pre-2020 levels.

Sources: IEA Cost of Capital commentary; UNCTAD A World of Debt 2025; World Bank International Debt Report 2025; IMF and Pakistani press reports (2026).

4.2 The cost of capital as a technology-specific tax

The most direct of the four is the cost of capital. A solar plant is a large up-front cost that then produces power with almost no fuel cost; a gas plant is a smaller up-front cost followed by fuel purchases for twenty-five years. When the interest rate rises, the first is penalised much more than the second. The IEA's Cost of Capital Observatory collects the evidence. Its survey of utility-scale solar projects puts the weighted average cost of capital at 8.5 to 9 per cent in Kenya and Senegal, between 9.5 and 11 per cent in South Africa and other emerging economies in the sample, and between 4.7 and 6.4 per cent in North America and Europe. The IEA calculates that bringing emerging-economy costs of capital to European levels would lower financing costs for solar projects by about US\$1 trillion cumulatively to 2050 under existing pledges.

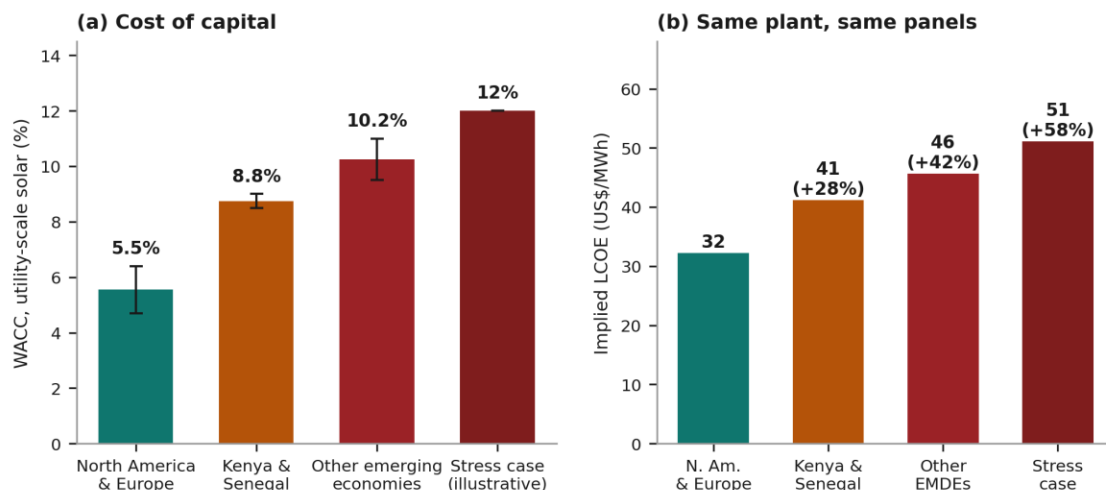


Figure 4. The same solar plant at different costs of capital: WACC by region (panel a) and the implied levelised cost of electricity (panel b).

WACC ranges from IEA Cost of Capital Observatory (mid-points shown); LCOE computed by H Heuristics using a capital-recovery factor, assuming US\$691/kW installed cost (IRENA 2024 global average), 22% capacity factor, 1.5% annual O&M and a 25-year life. The 12% case is an illustrative stress scenario.

Figure 4 turns the ranges into a simple calculation. Holding the plant constant and changing only the financing, the implied levelised cost rises by about 28 per cent at the Kenya and Senegal mid-point, about 42 per cent at the mid-point for other emerging economies, and about 58 per cent under a 12 per cent stress case. That is not a technology problem: the panel is the same. It is a country-risk problem being charged to the technology. And because the cost of capital is itself partly a function of debt distress and climate exposure, the levy falls hardest on the countries with the most to gain from cheap power. Research by Buhr, Volz and colleagues at SOAS estimated the climate-vulnerability premium on sovereign borrowing costs of the most exposed developing countries at about 117 basis points.

4.3 The two-tier consequence

The debt channel does not operate uniformly. Households and firms that can pay in cash, or borrow on short-tenor pay-as-you-go terms, avoid the sovereign's cost of capital altogether and buy at global prices. Everything that requires long-tenor, low-cost, local-currency finance, which means the utility, the grid, the public transport authority and the factory, is priced off the sovereign. This produces what Section 8 will call the balance-sheet sort: a two-tier diffusion process in which the decentralised tier grows on the strength of falling prices and the centralised tier is throttled by the cost of money.

Foreign direct investment, the other source of long-tenor capital, is not filling the gap. UNCTAD's World Investment Report 2025 recorded a 2 per cent fall in FDI to developing economies, to about US\$877 billion, and a 26 per cent fall in international project finance. The IEA's World Energy Investment 2026 adds that emerging and developing economies other than China account for under 30 per cent of global energy investment and 20 per cent of power-sector investment despite holding two-thirds of the world's population, that only 67 per cent of their energy projects are financed from commercial sources against 85 per cent in advanced economies, and that clean-energy investment is growing 4 per cent a year outside China compared with 7 per cent in advanced economies and China.

5. The Climate Channel: Physical Risk, Adaptation Gaps and the Resilience Dividend

Climate change reaches clean-technology diffusion through three routes: it damages the assets and systems that diffusion depends on, it raises the price of the money used to build them, and, less obviously, it makes some clean technologies more valuable because they double as adaptation. The net effect is not uniformly negative.

5.1 Damage to the network layer

The network layer is the most physically exposed. Transmission lines, substations and hydropower reservoirs are long-lived, fixed in place and designed for a climate that is changing. Hydropower-dependent systems face drought risk that undermines the reliability on which their low-carbon advantage rests. Heatwaves reduce the capacity of lines and transformers at the same moment that cooling demand peaks. Storms and floods destroy distribution assets that then have to be rebuilt by utilities whose balance sheets are already stretched. Swiss Re's *sigma* 1/2026 reported that roughly half of 2025's natural-catastrophe economic losses were insured, a record share, which is a reminder that the remaining half, and nearly all of the losses in emerging economies, fall on public and household balance sheets. Protection gaps in emerging markets typically run to 80 to 90 per cent of losses uninsured.

The macroeconomic evidence is that poor countries pay more for the same heat. Dell, Jones and Olken found that a 1°C rise in temperature reduces growth in poor countries by roughly 1.4 percentage points with no significant effect in rich countries, working through agriculture and industry. The mechanism matters for diffusion because it implies that climate stress acts on exactly the sectors, industry and agriculture, in which technology is meant to raise productivity.

5.2 The adaptation gap as a financing constraint

The adaptation gap is best understood as one more claim on a scarce pool of fiscal capacity. Every dollar that a government or utility must spend on post-disaster reconstruction, or on adapting existing infrastructure, is a dollar that is not available to extend the grid or subsidise a first-of-a-kind factory. The UNEP figures in Section 3 imply that developing countries need US\$310 to 365 billion a year by 2035 and were receiving US\$26 billion in 2023. Even the Belém commitment to triple adaptation finance would leave the gap large.

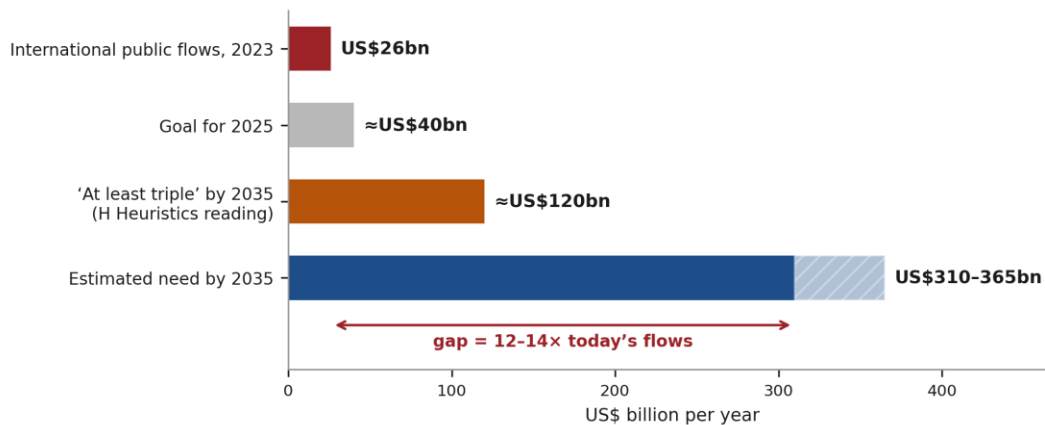


Figure 5. The adaptation-finance gap: international public flows and commitments versus estimated need (US\$ billion per year).

UNEP Adaptation Gap Report 2025 (need and 2023 flows); COP30 decisions as reported by Carbon Brief (2025 goal of about US\$40bn; tripling by 2035 taken as US\$120bn, an H Heuristics reading of 'at least triple'). The need is shown as a range.

The gap has a second-order effect. When climate finance for adaptation is scarce, countries borrow to rebuild. That borrowing raises debt, which raises interest costs, which further reduces the space for adaptation, a loop the report documents in Section 7. Mechanisms designed to break the loop are emerging: climate-resilient debt clauses that pause repayments automatically when a disaster strikes were triggered by Grenada and St Vincent and the Grenadines after Hurricane Beryl in 2024, and the Sevilla Commitment adopted at the 2025 Financing for Development conference endorsed them alongside a wider scaling-up of debt-for-development swaps. They are still the exception.

5.3 The resilience dividend of decentralised clean energy

Not everything about the climate channel is a headwind. Distributed solar with battery storage is a form of adaptation. A grid that fails in a storm or a heatwave leaves a household with rooftop solar and a battery with lights, refrigeration and communication; a clinic with a solar-plus-storage system keeps vaccines cold. This is why energy insecurity and climate exposure, in combination, are pushing households and firms toward the layer that thrives. The 2026 evidence from Pakistan, discussed in Section 10, is the clearest case: consumers abandoned an expensive and unreliable grid for panels and batteries because the private economics, not any climate objective, were compelling.

The implication is that the climate channel, like the debt channel, has a two-tier structure. It penalises the network layer, whose physical assets are exposed and whose adaptation must be publicly financed. It rewards the distributed layer, which offers resilience as a by-product. Left alone, the climate channel therefore reinforces the same sort that the debt channel creates.

6. The Geopolitical Channel: Accelerant and Constraint

Geopolitics is the only one of the three pressures that acts on clean-technology diffusion in both directions. It has pushed importing countries toward solar as a matter of energy security, and it has simultaneously made the supply chains behind that solar, and the industrial ambitions that could follow it, more hazardous.

6.1 Energy insecurity as an accelerant

The 2026 oil and gas shock drove the fastest import surge in the technology's history. Ember's [analysis of Chinese export data](#) shows that solar exports reached 68 GW in March 2026, double February's level and 49 per cent above the previous record set in August 2025, with fifty countries hitting all-time import highs. Exports to Africa rose 176 per cent in a month to 10 GW; Asia's reached 39 GW. Nigeria's imports rose 519 per cent in the month, Ethiopia's 391 per cent, Kenya's 207 per cent and India's 141 per cent. Part of the surge was defensive buying ahead of an April change to Chinese export tax rebates that Ember estimated added about 9 per cent to panel costs, but the broader pattern is consistent with a shock-driven flight to energy sources that do not need imported fuel.

The African data are striking because they were already trending upward. Ember reports that China's panel exports to Africa rose [48 per cent in 2025, from 12.7 GW to 18.8 GW](#), and forecasts that the continent will install [about 17 GW of solar in 2026, up 45 per cent](#), with 36 of 54 countries setting records and roughly three-quarters of recent growth coming from distributed systems. South Africa's share of continental solar imports has fallen from more than half to under a fifth as the boom has spread to countries such as the Democratic Republic of Congo, Zimbabwe and Egypt. The additions would generate about 23 TWh a year, roughly the continent's average annual growth in electricity demand over the previous decade.

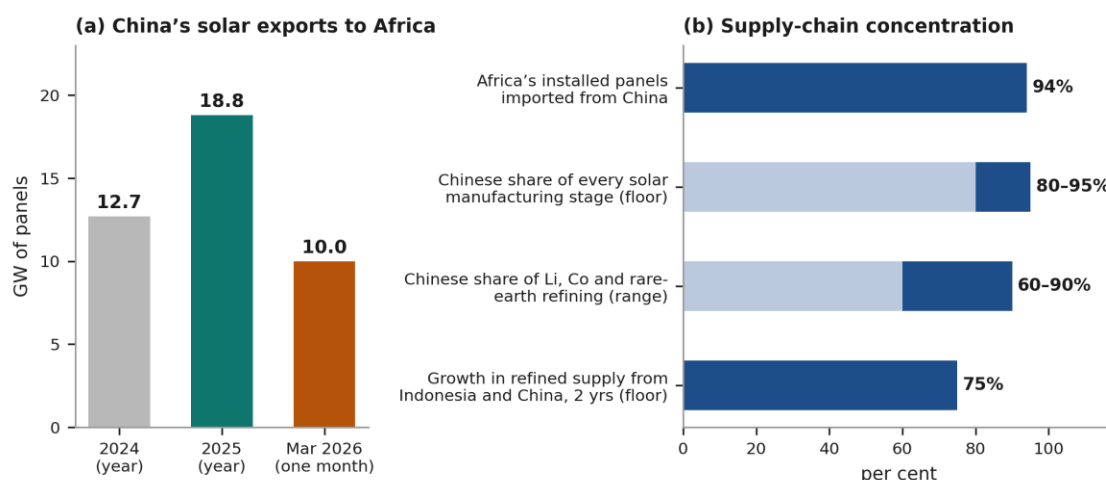


Figure 6. Arrival is booming and dependence is deepening: China's solar exports to Africa (panel a) and concentration indicators along the supply chain (panel b).

Ember (2026) for exports and the 94% import share; IEA Global Critical Minerals Outlook 2026 and IEA Solar PV Global Supply Chains for processing shares. Panel (a) shows annual totals for 2024 and 2025 and the single month of March 2026. Panel (b) shows the lower and upper bounds of reported ranges where a range is given.

6.2 Dependence as a constraint

The other face of the same trade is dependence. Ember's analysis attributes 94 per cent of the panels installed across Africa to imports from China, and the IEA's *Solar PV Global Supply Chains* found China accounting for more than 80 per cent of every manufacturing stage. The same holds for batteries and the minerals behind them, where processing shares of 60 to 90 per cent and a tripling of export controls since 2023 turn what had been a theoretical vulnerability into an operating risk. A country that relies on a single supplier for the technology on which its electricity system is being rebuilt has bought cheap power and accepted a strategic exposure in the same transaction.

This does not make dependence irrational. For a fuel importer facing an oil shock, a panel that pays for itself within a few years is a rational purchase even if all of it comes from one country. But dependence has a cost that shows up when the terms of trade change: when export rebates are altered, when a control is placed on a component, or when a bilateral relationship deteriorates. And it interacts with debt. The country that finances imports with dollar borrowing and depends on one supplier for its energy hardware has two channels through which a shock can arrive.

6.3 Trade fragmentation and the retreat of concessional finance

Two further geopolitical developments bear on production-layer ambitions. First, tariffs and industrial policy in the large economies have made export markets less predictable: UNCTAD's trade analysis shows that uneven tariff increases have altered market access sharply and that firms are relocating production and diversifying suppliers, so that nearly two-thirds of global trade now takes place within value chains being reshaped by geopolitical tension, industrial policy and new technology. A country seeking to build a clean-technology export industry must plan for a market whose rules may change.

Second, the contraction in official development assistance described in Section 3 removes a source of the risk-absorbing capital that production-layer projects tend to require. Concessional finance, guarantees and first-loss capital are exactly the instruments that enable a first factory or a first transmission corridor to reach financial close. When they shrink, the projects that survive are those that private balance sheets can carry unaided, which again favours the distributed layer.

7. The Interlocks: Why the Crises Amplify Each Other

If the three pressures acted independently, the response would be three separate programmes. They do not. Each feeds the others through channels that can be documented, and it is the feedback, not the level of any one pressure, that makes the environment hard to escape.

Figure 1 sketched six links. Each is a documented mechanism rather than a speculation. Table 3 sets them out with the evidence for each.

Table 3. Six transmission links between debt, climate and geopolitics

Link	Mechanism	Evidence
1. Debt → Climate	Fiscal stress and a high country-risk premium starve adaptation and clean-infrastructure investment, leaving countries more exposed to the next hazard.	UNEP: adaptation need US\$310–365bn a year versus US\$26bn of flows; SOAS estimate of ~117bp climate-vulnerability premium on sovereign borrowing.
2. Climate → Debt	Disasters destroy assets and revenue, forcing emergency borrowing and reconstruction at commercial rates.	Debt-pause clauses triggered by Grenada and St Vincent after Hurricane Beryl (2024); Swiss Re: emerging-market protection gaps of 80–90%.
3. Geopolitics → Debt	Energy and food price shocks widen import bills, weaken currencies and raise borrowing costs.	World Bank CMO (April 2026): energy +24%, fertilizer +31%; EMDE inflation revised to 5.1%; 70% of commodity importers face weaker growth.
4. Debt → Geopolitics	Financing constraints make countries dependent on a few suppliers, creditors and concessional-finance providers.	94% of Africa’s installed panels imported from China; ODA down 23.1% in 2025 (OECD) shrinks alternative finance.
5. Climate → Geopolitics	The transition raises the strategic value of minerals and clean-technology supply chains, prompting controls and tariffs.	IEA: China’s export controls tripled since 2023; rare-earth controls put ~US\$6.5tn of downstream output at risk.
6. Geopolitics → Climate	Fragmentation slows technology transfer, raises equipment costs and diverts finance from adaptation and mitigation.	UNCTAD: uneven tariffs and policy uncertainty depress investment; COP30 adaptation pledge lacks baseline and binding wording.

Sources as cited in Sections 3 to 6.

7.1 Two loops that matter most

Two of the six links close into loops that deserve particular attention. The first is the *debt-climate loop*: high debt raises the cost of adaptation finance and reduces its supply; unadapted infrastructure fails in the next disaster; reconstruction is financed by more borrowing at a higher premium. The Global Commission on Adaptation’s *Adapt Now* found that adaptation delivers benefit-cost ratios ranging from roughly 2:1 to 10:1, which means that the loop is not merely painful but avoidable at positive economic return. The tragedy is that the return accrues to the whole economy while the up-front cost falls on a fiscally exhausted government.

The second is the *energy-geopolitics loop*. A fuel importer hit by an oil shock buys solar to reduce exposure. The purchases come from a concentrated supply chain whose politics can also change. The country therefore substitutes one geopolitical dependence for another, and does so with dollars it has less of. Whether this substitution is beneficial depends on the relative volatility of the two risks, and the balance is

favourable in most cases because solar's fuel-free operation eliminates a recurring exposure in exchange for a one-off one. The point is not that the substitution is a mistake but that the exposure has moved and is still there.

7.2 What interlocking implies for policy design

Interlocking has a practical implication that is easy to miss. If the links were weak, sequential problem-solving would work: fix the debt, then adapt, then diversify. If they are strong, a policy that ignores the links can be undone by them. A programme to build transmission that is financed by commercial borrowing at 11 per cent adds to the debt stock that constrains the next programme. A solar-manufacturing subsidy that depends on export access can be stranded by a tariff. An adaptation plan financed by new loans can raise the debt-climate loop's gain. Designing for interlocks means choosing instruments, such as concessional and local-currency finance, contingent debt clauses and diversified supply, that weaken links rather than lean on them.

8. The Balance-Sheet Sort: Who Carries Diffusion Through the Crisis

Putting the three channels together yields the report's central result. Each crisis acts on each layer differently, and the differences line up with the balance sheet that funds the layer. The result is a sort: distributed technology passes through the crisis, network technology is held back, and production technology is caught between geopolitics and finance.

	Debt	Climate	Geopolitics	
Rooftop solar + batteries	0	+1	+1	A distributed
E-2/3-wheelers	0	0	+1	
PAYGo & mini-grids	-1	+1	0	
Transmission & distribution	-2	-2	-1	B network
Grid-scale storage & operation	-2	-1	-1	
Public transit & water networks	-2	-1	0	
Module, cell & battery plants	-1	0	-2	C production
Mineral processing	-1	0	-2	
Components & BOS supply	-1	0	-1	

Figure 7. The balance-sheet sort: net effect of each pressure on nine clean-technology categories, scored from strongly adverse (−2) to strongly favourable (+2).

H Heuristics qualitative assessment, based on the evidence in Sections 3 to 7. Scores are ordinal judgements, not estimates. Geopolitics is scored as a net of its accelerant and constraint effects; the split is discussed in Section 6.

8.1 Reading the heatmap

Three patterns stand out in Figure 7. The first is the top block. Rooftop solar with batteries, electric two- and three-wheelers and pay-as-you-go energy access score neutral to favourable on almost every pressure: debt has a limited effect because balance sheets are private, the climate channel rewards resilience, and geopolitics, net of dependence, is an accelerant. These are the technologies whose diffusion is visible in the 2026 data.

The second is the middle block. Transmission, storage at grid scale and public transit and water networks score adverse on debt and climate and weakly on geopolitics. Their failure mode is not that they are not built but that they are built late, at high cost, and unreliably. Pakistan's experience is the clearest example: consumers built 7 GW of net-metered solar in six years while the state's power and gas circular debt reached PKR 5.2 trillion. The grid is the scarce input.

The third is the bottom block. Clean-technology manufacturing and mineral processing score strongly adverse on geopolitics, moderately adverse on debt and neutral on climate. This is the layer where policy is most needed and where the crisis environment is most hostile. Industrial policy for these sectors has to contend with tariffs, export controls and a supplier that is itself pursuing overcapacity, as Section 9 shows.

8.2 Why the sort is self-reinforcing

The sort is not a one-time allocation; it reinforces itself. Because the distributed layer thrives, households and firms defect from the grid, leaving the utility with fewer paying customers and a higher share of fixed costs, which weakens its balance sheet further and makes the network layer harder to finance. Pakistan's Prosumer Regulations of February 2026, which replaced net metering with net billing at lower export prices, are an attempt to manage precisely this dynamic, and the fact that they were needed illustrates the point. Similarly, because the network layer is weak, the production layer is less attractive to investors who need reliable power; and because production-layer capacity is thin, the distributed layer remains dependent on imports. Each layer's weakness reduces the prospects of the next.

The sort should be read neutrally rather than as a criticism of distributed technology. The distributed layer is the part of diffusion that works, and in an environment of energy insecurity it deserves protection. The problem is that its success can mask the failure of the layers that matter for transformation, and that policy attention follows the headline numbers.

9. From Arrival to Production: Can Clean Technology Still Drive Structural Transformation?

Structural transformation is the test of whether diffusion has mattered. If cheap solar merely substitutes for imported fuel, it improves the balance of payments and household budgets but leaves the economy's composition unchanged. If it becomes a platform for new industries, it can do what manufacturing did for East Asia. The evidence for the second outcome is mixed, and the mixed evidence is informative.

9.1 The old route is narrower, and a new one is opening

The traditional route to catch-up ran through export manufacturing: workers moved from farms to factories, productivity in the factory sector converged on the frontier, and economies converged with it. Rodrik's finding that this route has narrowed matters for any claim that clean technology can revive it. Manufacturing's employment share now peaks at lower income levels, and automation reduces the labour content of each unit of output. The World Bank's June 2026 outlook nonetheless names energy transformation, together with AI and regional integration, as forces powerful enough to unlock faster progress in the next decade if countries prepare.

There are three reasons to think clean technology offers something the previous generation of industrialisers did not have. It is modular: manufacturing capacity can be added in units of a few gigawatts rather than through a single giant plant. It has a large and growing domestic market in the countries that also want to make it, which lets local producers gain scale before exporting. And the products, panels, batteries, inverters, chargers, meters and cables, span a range of complexity, so a country can enter at the assembly end and climb. None of these advantages is automatic, and the crisis environment makes each harder to exploit.

9.2 The value-chain ladder and the India test

The value chain for solar begins with polysilicon and wafers, proceeds through cells and modules, and ends with balance-of-system equipment, installation and operation. Value and technological learning are concentrated upstream; the downstream is closer to services. A country that imports modules and installs them captures the installation margin. A country that assembles modules from imported cells captures a little more. A country that makes cells and wafers captures a large share of the learning, and also of the risk.

India provides the most instructive current test because it has moved furthest and fastest. Its approved module-manufacturing capacity, as listed under the government's Approved List of Models and Manufacturers, has grown from under 20 GW in 2022 to about 217 GW in August 2026, while cell capacity stood at about 35 GW, up from 13 GW a year earlier, with a target of 100 GW by the end of 2027. Cells came under the list from 1 June 2026. Annual solar installations are projected at only 55 to 60 GW. As pv magazine reported in September 2026, India now faces module overcapacity and an underdeveloped upstream: the part of the chain that is easiest to build has been built well beyond domestic demand, and the part that carries the learning and the strategic value has not.

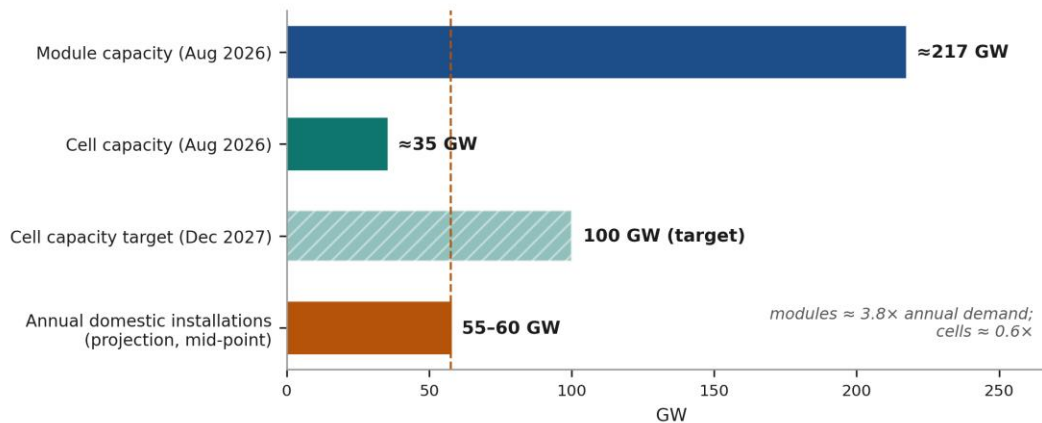


Figure 8. India's solar value-chain ladder: capacity by stage against annual domestic demand (GW).

Energetica India (ALMM lists, August 2026); pv magazine (16 September 2026) and ICRA commentary for the 55–60 GWdc annual installation projection (mid-point shown). Cell capacity of 100 GW is a target for December 2027. Wafer and polysilicon capacity is not shown because reported figures are incomplete.

Three lessons follow. First, capacity is not capability: a module line that runs at partial utilisation transfers little tacit knowledge. Second, the sequencing of the policy matters. India first protected the module stage and then extended the same instrument, a mandatory approved-manufacturer list, to cells, which is the right direction but leaves a period in which module makers depend on imported cells. Third, even the largest emerging economy with a large domestic market and strong industrial policy has found that trade-offs between protection, cost and speed are unavoidable. A smaller, more indebted country cannot afford to replicate the strategy without adaptation.

9.3 Processing, batteries and the mineral route

A second route runs through minerals. Indonesia's ban on raw nickel ore exports, introduced in 2014, is the best-known attempt to capture value in the battery chain: the country holds a large share of global nickel reserves and has built a processing industry, and in 2024 Hyundai and LG opened its first electric-vehicle battery-cell plant. The [Center for Strategic and International Studies](#) documents the approach and its dependence on foreign capital and foreign technology. The IEA's finding that Indonesia accounted, with China, for over three-quarters of the growth in refined mineral supply in the last two years shows how successful this route has been in volume terms. It also shows the risk: a country that becomes the world's dominant processor of a single mineral is exposed to a battery-chemistry shift, and to the political economy of the firms that hold the technology.

Morocco's route is different: rather than processing a domestic mineral, it has used a stable investment environment, proximity to Europe and a long-run commitment to renewables to attract downstream manufacturing. The [African Development Bank approved a €100 million loan](#) in July 2026 to Gotion Power Morocco for what will be Africa's first integrated lithium iron phosphate battery gigafactory, starting at 10 GWh a year and planned to scale to 100 GWh, part of a US\$5.6 billion investment announced in 2025. The project shows that the production layer can be financed in the crisis environment, but on one condition: a foreign investor and a multilateral lender are both carrying the risk, and the project has been accompanied by scrutiny of whether Morocco's grid, still heavily reliant on coal, can power it cleanly.

9.4 What the production layer needs from the network layer

The connection between layers B and C is the least appreciated feature of the transformation problem. A factory needs reliable, competitively priced, increasingly low-carbon electricity, because buyers in export markets, notably the European Union's carbon border adjustment, increasingly price the carbon content of imports. A manufacturing strategy that ignores the grid will produce plants that run at part-capacity, pay for diesel back-up, and face a carbon penalty on their exports. This is why the balance-sheet sort matters for structural transformation: the layer that starves is the one on which the layer that industrialises depends.

10. Country Cases: Five Configurations of the Same Problem

The framework predicts different outcomes depending on where a country stands on two dimensions: how severe its fiscal and debt stress is, and how much industrial and institutional capability it can bring to bear. The following cases illustrate five configurations.

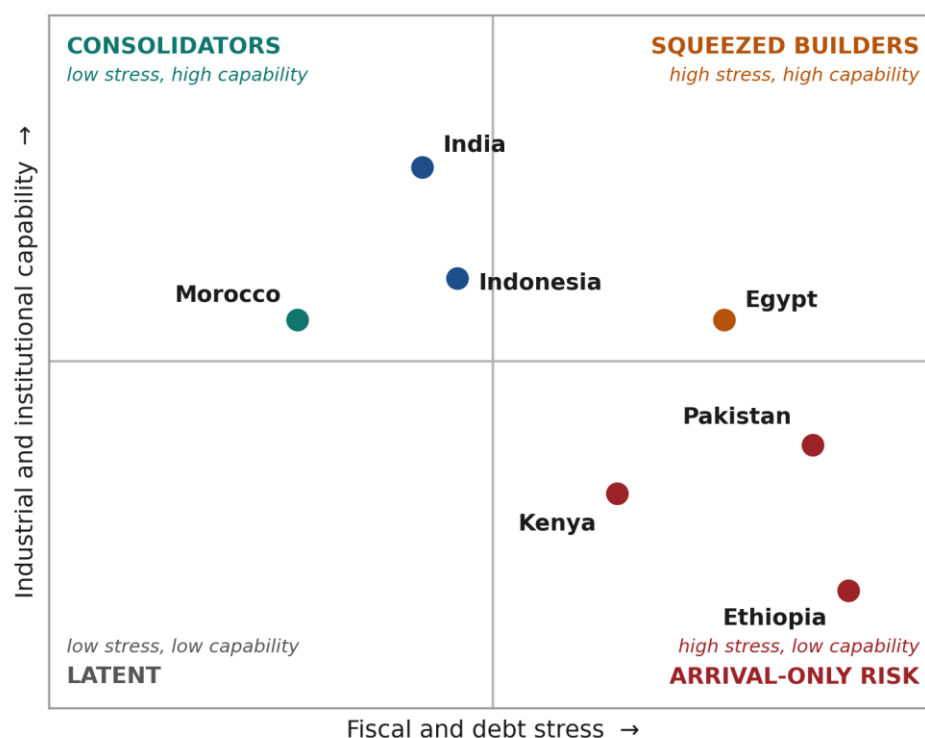


Figure 9. Country configurations by fiscal stress and industrial capability (illustrative placement).

H Heuristics qualitative placement based on the evidence in Section 10; positions are illustrative and are not the output of an index. Quadrant labels are the report's.

Table 4. Five country configurations

Case	What diffused	What is missing	Lesson
Pakistan	Net-metered solar from 190 MW (FY2020) to about 6,978 MW (FY2026); about 27 GW of distributed solar in two years	A financially sound grid: power-and-gas circular debt of about PKR 5.2tn; net billing introduced February 2026	Arrival without embedding: private balance sheets moved faster than the sovereign's
Ethiopia	Import ban on new internal-combustion cars (2024); about 100,000 EVs; grid >95% hydropower	Fiscal space: 2023 default, IMF programme; US\$7bn a year of fuel imports being displaced	Debt stress can motivate leapfrogging when clean technology saves foreign exchange
India	217 GW module capacity; solar at scale; UPI and digital public infrastructure	Upstream cells and wafers; demand for 217 GW of modules	Capacity is not capability; overcapacity is a risk of industrial policy
Indonesia	Nickel processing and first battery-cell plant (2024)	Diversification beyond a single mineral and a single buyer	Capturing processing value exposes a country to chemistry and geopolitical shifts

Case	What diffused	What is missing	Lesson
Morocco	First African LFP gigafactory (AfDB-backed); long-run renewables planning	Clean grid for the factory; domestic supplier base	Production-layer finance is available when risk is shared with multilaterals and a foreign anchor

Sources: Ember; ProPakistani and Arab News on net metering; IMF-related reporting on circular debt; Bloomberg and Energy Connects on Ethiopia; Energetica India; ESS News; CSIS.

10.1 Pakistan: arrival without embedding

Pakistan is the emblematic case. Net-metered solar capacity rose from 190 MW in fiscal 2020 to about 7 GW by mid-2026, driven, on reported analysis, by grid tariffs that had risen by around 140 per cent, a depreciating rupee and falling panel prices. Ember has estimated that about 27 GW of distributed solar was installed in two years, with a household solar-plus-battery system producing power at around PKR 20 per kilowatt-hour against PKR 40 from the grid. This is real diffusion, and it happened without a sovereign programme.

The consequence is on the other balance sheet. As paying customers left the grid, the utility's fixed costs were spread over fewer users. The energy-sector circular debt reached a record PKR 5.2 trillion in 2026, and the power sector missed its IMF-agreed target, with a stock of about PKR 1.84 trillion against a target of PKR 1.61 trillion. In February 2026 the regulator replaced net metering with net billing, paying a lower reference price for exported power. The policy is defensible, but it shows how the sort operates: the distributed layer's success creates a fiscal problem for the network layer, which the state then addresses by reducing the incentives that made the distributed layer succeed.

10.2 Ethiopia: debt stress as a spur to leapfrogging

Ethiopia shows the opposite side of the debt channel. The country defaulted on its sovereign bonds in 2023 and entered an IMF programme in 2024 while spending about US\$7 billion a year on fuel imports. In January 2024 it banned imports of petrol and diesel cars, later extended to trucks, and press reports based on government data now put the electric fleet at around 100,000 vehicles, with a target of 440,000 by 2030. The logic is one of balance of payments rather than climate: the electricity comes from more than 95 per cent hydropower, including the 5,150 MW Grand Ethiopian Renaissance Dam completed in 2025, so each electric vehicle displaces imported fuel. The case shows that debt stress does not only suppress diffusion; where clean technology saves scarce foreign exchange it can accelerate it. It also shows the network-layer risk: a fleet that grows faster than charging infrastructure and grid capacity will run into the same absorption limit as Pakistan's solar.

10.3 India, Indonesia and Morocco: three routes into production

India, Indonesia and Morocco illustrate three ways of trying to enter the production layer, described in Section 9: domestic-market scale, mineral processing and foreign-anchored assembly. Each has a different risk. India's risk is overcapacity relative to its own demand and the absence of upstream depth. Indonesia's is dependence on one mineral, one downstream technology and a small number of foreign firms. Morocco's is that a single anchor investment, however large, does not by itself create a supplier ecosystem. Common to all three is that the production layer is being financed in ways that share risk with someone: a domestic

government that guarantees demand in India's case, foreign firms in Indonesia's, a multilateral lender in Morocco's.

10.4 Kenya, Senegal and Egypt: the middle of the distribution

The IEA's finding that solar financing costs in Kenya and Senegal are 8.5 to 9 per cent, lower than in South Africa and many other emerging economies but still well above European levels, is representative of a large group of countries that are neither insolvent nor unencumbered. Kenya already generates roughly 93 per cent of its electricity from renewables, so its issue is less the volume of clean supply than the cost of extending and reinforcing the grid. Egypt is a different case: solar panel imports more than doubled in 2025 to 2.3 GW, and the government has raised its target to 42 per cent renewable electricity by 2030, but Egypt carries substantial external debt and its exposure to fuel-import prices is high. For these countries the priority is neither to wait for a fiscal recovery nor to attempt industrial leaps, but to lower the cost of capital for the network layer in ways that do not add to the debt stock.

11. A Strategy for Sustaining Transformation

The analysis implies a strategy with three tasks that need to be pursued in parallel but sequenced differently: protect the diffusion that is already happening, repair the balance sheet of the network layer, and build production capacity selectively. This section sets out seven principles and a roadmap.

11.1 Seven principles

- **Do not tax the layer that works.** Import duties and tax changes that raise the price of panels, inverters and batteries hit the layer that is carrying diffusion through the crisis. Where revenue or industrial reasons require measures, they should be phased and predictable; a proposal such as Pakistan's 2025 plan for an 18 per cent tax on imported panels is exactly the kind of instrument to avoid or delay.
- **Treat grid finance as the priority use of concessional money.** Because the network layer is the one starved by the debt channel, it should receive first call on scarce concessional finance, guarantees and multilateral lending, including the resources the World Bank has said it can scale up. The measure of success is a utility that collects revenue and can invest, not a headline count of gigawatts connected.
- **Reform tariffs in ways that keep the distributed layer whole.** Net billing, time-of-use tariffs and grid-access charges are legitimate tools, but if they are introduced abruptly they penalise the households and firms that have already invested, and discourage storage. Reform should be paired with incentives for batteries and with targeted rather than universal subsidies.
- **Break the debt-climate loop with pre-arranged instruments.** Climate-resilient debt clauses, contingent credit lines and disaster-linked insurance turn the loop from a spiral into a bounded shock. They cost little in present-value terms and should be built into new borrowing, particularly for climate-exposed and small-island economies.
- **Diversify dependence without pursuing autarky.** The aim is not to replace one supplier with domestic production but to avoid a single point of failure: multiple sourcing, common technical standards, strategic reserves of critical spares, recycling, and regional pooling for smaller economies.
- **Build production where there is demand and capability, and in stages.** Follow the demand: begin with the balance-of-system equipment, cabling, transformers, mounting structures, pack assembly and installation services that local markets need, and move upstream only as utilisation and skills justify it. India's module overcapacity is a warning against building capacity ahead of demand.
- **Measure embedding, not arrival.** Governments and lenders should track a small dashboard of embedding indicators: utility collection rates and circular debt, curtailment and the share of clean power the grid can absorb, the spread between local and benchmark financing costs, local value-added in installed systems, and the number of certified technicians.

11.2 A three-horizon roadmap

The seven principles fall into three horizons. In the first, the immediate response to the energy shock, the task is to keep distributed diffusion running, avoid harmful import measures, and stabilise the utility's finances. In the second, over one to four years, attention shifts to the network layer: grid investment, storage,

tariff reform and debt-instrument design. In the third, over three to ten years, production capacity is built in stages, with support conditional on demand and utilisation. The horizons overlap, and preparation for a later horizon has to begin before its deployment: the workforce and standards for a factory need to exist years before the factory opens.

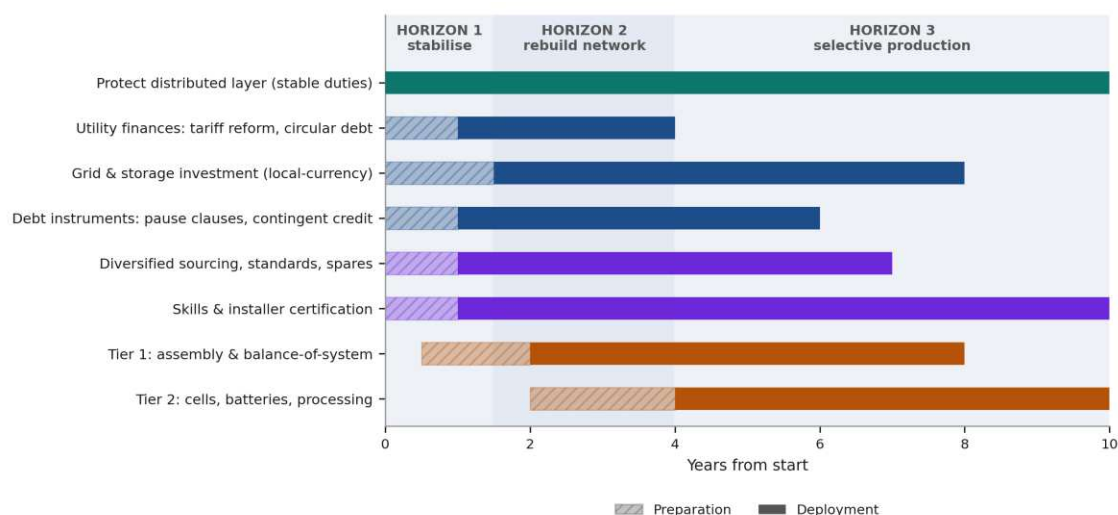


Figure 10. A three-horizon roadmap: preparation (hatched) and deployment (solid) across eight workstreams.
H Heuristics. Illustrative sequencing; timing will vary by country.

Table 5. Policy portfolio mapped to layers and links

Instrument	Layer	Links weakened	Lead actor
Utility tariff reform with targeted subsidies; circular-debt resolution	B	Debt → climate; geopolitics → debt	Finance ministry and regulator
Local-currency and guarantee-backed lending for grids and storage	B, C	Debt → climate; debt → geopolitics	MDBs, development banks
Climate-resilient debt clauses and contingent credit	B	Climate → debt	Debt office; creditors
Stable, predictable treatment of imported solar, storage and EV equipment	A	Geopolitics → debt	Trade and revenue authorities
Approved-supplier standards and staged local-content schedules tied to utilisation	C	Debt → geopolitics; geopolitics → climate	Industry ministry
Diversified sourcing, regional pooling and critical-spares reserves	A, C	Climate → geopolitics	Energy ministry; regional bodies
Skills and installer certification programmes	A, B	All (raise absorptive capacity)	Education and labour ministries

Layers: A = consumption and distributed; B = network and system; C = production and industrial.

11.3 The role of international finance and creditors

The national strategy depends on an international one. The Sevilla Commitment placed debt-pause clauses, expanded concessional lending and reform of credit-rating methodologies on the agenda of the 2025

Financing for Development conference, and the April 2026 review process has begun to track implementation. The most useful contribution creditors and multilaterals can make in the current environment is to lower the cost of capital for the network layer, where the IEA's analysis shows the largest cumulative saving, rather than to add new programme labels. Where aid is contracting, as the OECD data show it is, it is all the more important that concessional resources are spent where they can unlock commercial capital.

12. Limits and What Would Change the Argument

A framework that explains everything explains nothing. This section lists the most important limits of the argument and the observations that would count against it.

- **The sort is a qualitative judgement.** The scores in Figure 7 are informed by evidence but are not estimated parameters. A more formal test would require country-level data on financing source by technology, which does not yet exist in a consistent form.
- **The distributed layer is less insulated than it appears.** It depends on imported hardware paid for in foreign exchange, on inverter and battery supply chains subject to the same controls as other technology, and on grid connection or tariff rules that governments can change, as Pakistan has shown.
- **The 2026 shock may prove temporary.** If the energy-price spike reverses quickly, part of the geopolitical accelerant will fade, and some of the record 2026 imports may prove to have been front-loaded. The argument is about structure, not about the level of any 2026 number.
- **Overcapacity can help arrival.** Module oversupply in India and China lowers panel prices for importers elsewhere. What is a problem for a manufacturer's balance sheet is a benefit for a buyer's.
- **Case selection.** The five cases are chosen to illustrate configurations, not sampled at random. Some countries with severe debt stress have made progress on network investment, and some with strong institutions have struggled.
- **China's role is not modelled.** The report treats Chinese supply and finance as part of the environment. A deeper analysis would examine how Chinese lending, investment and export policy interact with each of the three crises.

Three observations would count against the central thesis. First, if by 2028 countries with rapid distributed diffusion also show rising local value-added and rising utility collection rates without any deliberate repair of the network layer's balance sheet, the claim that diffusion without embedding is the default outcome would be weakened. Second, if network-layer investment recovers in heavily indebted countries without a fall in the cost of capital, the claim about the debt channel's primacy would need revision. Third, if countries that build production capacity without domestic demand or grid reliability nonetheless become competitive exporters, the argument for staging would be weaker than claimed.

13. Conclusion: Two Trajectories

Clean technology is arriving. Whether it transforms economies depends on what happens to the balance sheets that must carry the layers of diffusion that arrival alone cannot provide.

The report has argued that debt, climate and geopolitical pressures are not three problems but one interlocking system, and that the way that system acts on clean-technology diffusion is best understood through the balance sheets that fund each layer. The distributed layer, financed by households and firms, is accelerated by energy insecurity and resilient to fiscal stress. The network layer, financed by the sovereign and the utility, is throttled by debt and exposed to climate damage. The production layer, financed by foreign capital and constrained by trade, is caught in a geopolitical vice. Left alone, the result is a diffusion process that is fast, visible and shallow.

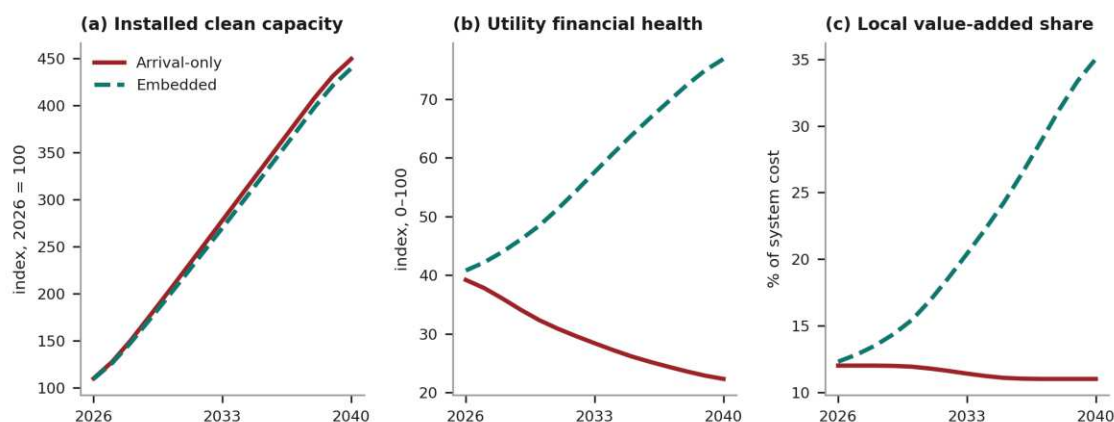


Figure 11. Two illustrative trajectories: arrival-only diffusion versus diffusion that is embedded in the network and production layers.

H Heuristics. Illustrative schematic constructed to show the argument; not a projection for any country.

The two trajectories in Figure 11 begin identically. Installed clean-technology capacity rises in both because prices are falling and energy security is a strong motive. They diverge in what surrounds the capacity. In the arrival-only path, the utility's finances deteriorate, the grid struggles to absorb variable supply, local firms remain installers rather than manufacturers, and the value added captured at home stays flat while the import bill for hardware and the dependence on a single supplier rise. In the embedded path, the network layer is refinanced, tariff reform keeps the distributed layer whole, production capacity grows in stages behind real demand, and local value-added rises.

Nothing in the current environment guarantees the second path. But nothing prevents it either, and the choices that separate the paths are specific: which balance sheet receives scarce concessional finance, how tariff reform is sequenced, whether debt instruments are built to bend rather than break under a climate shock, and whether production policy follows demand. The 2026 crisis has made the arrival of clean technology more urgent and its embedding more difficult at the same time. The task for governments, lenders and the multilateral system is to ensure that the record year for solar is followed by something more durable than a record number of imported panels.

References and Further Reading

Macroeconomic outlook, debt and aid

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