Policy Brief

2026 NO. 2

ISETS
INTERNATIONAL SOCIETY FOR ENERGY TRANSITION STUDIES

The Open-League Model for Resilient, Efficient, and Sustainable (REES) Clean-Tech Supply Chains

Xunpeng Shi

University of Technology Sydney

April 2026

ABOUT ISETS

The International Society for Energy Transition Studies (ISETS) is an independent, non-profit global organization headquartered in Sydney, Australia. We are open to anyone who is interested in contributing to the advancement of sustainable energy transitions. Membership registration as an Associate Member is permanently free and can be completed at www.isets.org . Currently, ISETS boasts a diverse community of nearly 2,500 members hailing from more than 100 countries worldwide.

At ISETS, our mission is dedicated to facilitating a just, equitable, and inclusive transition of energy and relevant sectors toward a sustainable low-carbon future. We do so while considering the critical pillars of economic development, social equity, and environmental stewardship through international partnerships.

COPYRIGHT

Printed and bound in Australia.
Published by International Society for Energy Transition Studies.

CITATION

Shi, X., 2026. The Open-League Model for Resilient, Efficient, and Sustainable (REES) Clean-Tech Supply Chains. Sydney, International Society for Energy Transition Studies, Policy Brief, 2026, NO.2.

International Society for Energy Transition Studies
Barraba Place, Bella Vista, NSW 2153 Australia
Email: isets@isets.org
Website: www.isets.org

Official Website LinkedIn YouTube WeChat Twitter

Introduction

Clean-technology supply chains have achieved historic cost declines through concentrated production, yet this same concentration has increased fragility and widened inequalities. To meet climate timelines without sacrificing social legitimacy, we argue for REES supply chains—Resilient, Efficient, Equitable, and Sustainable—where equity (fair sharing of opportunities, risks, and benefits across countries, industries, and communities) is embedded alongside efficiency, resilience, and sustainability. We first diagnose why today's governance is failing; we then motivate why REES supply chains—explicitly embedding equity—are needed; finally, we propose the Open League model as a practical governance architecture to deliver REES global clean-tech supply chains.

Why supply-chain governance must change-now

Clean-technology supply chains—shifting energy security from fuels to access to technologies and manufacturing—are monocentric, having coalesced around China through agglomeration, scale and learning-by-doing effects. In the low carbon energy system, instead of securing barrels or tonnes, countries must secure access to technologies, mid-stream processing and end-use manufacturing (Yao et al., 2025). Supply chains in solar, wind, batteries and electric vehicles are long, specialized and capital-intensive. Because these industries combine steep learning curves, high fixed costs, dense supplier ecosystems and process know-how that compounds with scale, production naturally agglomerates into a few clusters where cost and quality advantages reinforce themselves (Energy Transitions Commission, 2023; Helveston et al., 2022), leading to the "winner-take-most" outcome.

China exemplifies these dynamics. By 2023, it accounted for over two-thirds—and in some sectors more than 90%—of global manufacturing capacity in solar photovoltaics, batteries, electric vehicles, electrolysers and heat pumps (IEA, 2024). In 2024, China produced around 70% of the world's electric vehicles and over 80% of global battery cells (IEA, 2025), more than 95% of solar wafers and over half of cumulative global photovoltaic installations (Fraunhofer ISE, 2025).

The result is efficiency with fragility and inequality. Concentration has lowered costs via scale and learning-by-doing (Helveston et al., 2022; IEA, 2024), yet it also exposes the system to correlated shocks—from export controls and natural disasters to shipping disruptions and cyber incidents (IRENA, 2024; Shi et al., 2025) . Manufacturing leaders capture outsized value-added and innovation rents; resource-rich exporters without mid-stream capacity risk remaining in low-value positions; late-industrializing economies face steep entry barriers; and incumbent fossil-fuel communities confront job losses and stranded assets (Fernández Intriago et al., 2025; Hodok and Kozluk, 2024; IEA, 2024). The clean-technology transition is also a redistribution of economic power: while global scale and learning have lowered costs, heavy reliance on a few dominant producers has created vulnerabilities (IEA, 2021). These dynamics have intensified political frictions; for example, traditional automakers in Germany, Japan and the United States have lost ground to Chinese competitors, intensifying pressure on their governments to respond (Steiber and Teece, 2025).

Mounting supply-chain security concerns, amplified by geopolitical and geoeconomic pressures, are steering diversification down a path that effectively excludes China and splits supply chains into rival blocs and provoke reciprocal measures (Helveston et al., 2022; Meckling, 2025; OECD, 2025). Strategic competition, subsidy races, export controls on critical minerals and equipment, screening of foreign investment, and disruptions at maritime chokepoints have turned clean-technology supply chains into

instruments of statecraft (IRENA, 2024; Meckling, 2025). These measures can reduce single-point exposure for individual economies, but when pursued without coordination they fragment markets, raise compliance and financing costs, and slow diffusion of low-carbon technologies (European Commission, 2023; Meckling, 2025; OECD, 2025). Such exclusion heightens the risk of retaliatory responses from China—illustrated by recent export restrictions on rare earths and other strategic battery inputs—which tighten chokepoints and magnify volatility (Reuters, 2025). Exclusion tends to spiral into tit-for-tat measures—tariffs, export controls and market-access curbs—that spread across partner economies and amplify uncertainty (Benguria et al., 2022).

The increasingly bifurcating supply chains drive the duplication of fixed investment, shrink effective market size and undermine scale economies. These bifurcation efforts raise unit costs, slows learning-by-doing and lengthens lead times, while re-routing production to less efficient nodes increase life-cycle emissions and environmental footprints (Helveston et al., 2022; IRENA, 2024). Policy races risk locking-in protectionist measures that fragment standards and data regimes, further raising compliance costs, investment risk premia and supply risk (European Commission, 2023; Meckling, 2025; OECD, 2025). Yet this decade demands rapid scale-up; any delay, cost uplift or uncertainty risks missed deployment and higher cumulative emissions (Barbier, 2025; IEA, 2024; IRENA, 2024). Therefore, there is an increasingly prominent paradox between concentrated efficiency from and diversity security. The policy challenge is to manage rivalry while maintaining a common playing field that preserves efficiency and legitimacy.

Security Without Splintering: A REES Path Forward

Neither ignoring legitimate security concerns nor pushing toward hard bifurcation is a viable path. Excluding China from emerging global supply-chain frameworks would be costly, counterproductive and potentially destabilising (Goldthau and Hughes, 2020; Helveston and Nahm, 2019; Helveston et al., 2022). No other economy matches China's manufacturing scale, its dominance in critical-mineral processing or its ability to deliver continuous cost reductions across photovoltaics, batteries, electric vehicles and key intermediates(IEA, 2024). Parallel systems developed without China's participation are unlikely to achieve comparable cost competitiveness given China's deeply embedded production ecosystems; to remain viable they would need sustained tariffs or non-tariff protection, driving inefficiency and fragmentation (Helveston and Nahm, 2019; Meckling, 2025). Substituting away from China's advanced technologies and resources would also divert the world toward less cost-effective—and potentially more pollutive—alternatives (Helveston and Nahm, 2019), undermining both sustainability and equity.

Cooperation with China is therefore the pragmatic path: enabling participation under shared rules and standards, transparent governance and reciprocal access that channels competition into innovation and sustainability rather than bifurcation, while diversified hubs hedge single-point dependence on any one producer (Helveston and Nahm, 2019). China's inclusion offers gains for all: it lowers geopolitical frictions including China's retaliatory responses, enhances supply-chain resilience and speeds collective progress toward net-zero; for major producers it preserves efficiency gains while spreading risk; and for emerging hubs it opens higher-value entry points through common rules rather than exclusive blocs.

What is needed is re-governance: rules that preserve efficiency gains while reducing fragility and embedding fairness (Geels et al., 2017a, 2017b). To build truly resilient systems, supply chains must diversify both geographically and institutionally while keeping markets connected through common standards and transparent product information (OECD, 2025); aligning access with responsibility via

reciprocal market access conditioned on verifiable due diligence and traceability (OECD, 2016); and strengthening preparedness and transparency so supply can be re-routed during shocks without resorting to market-fragmenting interventions(Goldthau and Hughes, 2020; OECD, 2025).

Equity must be embedded alongside efficiency, resilience, and sustainability to sustain diffusion, legitimacy, and risk-sharing at global scale. Equity is not a moral add-on; it is the political-economy glue that holds coalitions together and supports durable climate policy. Evidence from the IPCC indicates that equity and just-transition approaches increase social acceptance and policy durability, enabling higher ambition, and the UNFCCC's first Global Stocktake formalized "just transition pathways," elevating equity from rhetoric to implementation.(IPCC, 2023; UNFCCC, 2023) Without perceived fairness, governments face mounting pressure to slow or reverse climate policies(UNFCCC, 2025). In short, adopting **REES**—Resilience, Efficiency, Equity, and Sustainability—as co-equal design principles provides the practical rulebook to turn clean-tech supply chains from zero-sum arenas into shared, shock-tolerant systems that accelerate decarbonization at lower political cost.

Within such a REES framework, the role of major producers—including China—can be recast: not dominant but constructively engaged under shared rules, with legitimate interests respected and matched by clear co-leadership responsibilities for standards, transparency and resilience (Goldthau and Hughes, 2020; Helveston and Nahm, 2019). To align resilience with efficiency, alternative supply chains outside China should allow Chinese participation as an investor, component supplier, or technical/supporting partner—without a dominant role. This approach diversifies geography, leverages China's technical capacity, and builds shared stakes in success, while preserving efficiency gains from specialization and adding redundancy against shocks.

Policymakers should convene key partners (China, EU, US, others) to endorse globally integrated—not bifurcated—supply chains, and jointly map diversification and co-location options. Done well, this retains scale economies and learning-by-doing while lowering systemic risk and political friction—avoiding the false choice between unmanaged concentration and costly bifurcation.

From Concept to Practice: The Open-League Model to Deliver REES

To put those measures into practice—aligning security with openness and enabling participation by all major producers—we propose the Open League Model to deliver the REES clean-technology supply chains. The traditional flying-geese model of gradual transfer and progressive upgrading is ill-suited to the innovation and diffusion of clean technologies. First, as technologies such as solar photovoltaics, batteries and electric vehicles matured at extraordinary speed, production naturally clustered where innovation capacity, cost advantages and quality control were strongest. Second, the energy transition needs rapid diffusion and adoption of clean technologies and thus gradual transfer is too slow to be accepted. Moreover, clean-tech innovation could be disruptive and diminish the value of old industrial resources to be relocated.

Under this model, clean-technology supply chains are governed like a football league: many strong "teams" (regional hubs) that compete to innovate and reduce costs, while depending on shared rules that ensure fair play, interoperability and reciprocal access. Under this model, supply chains diversify for resilience and equity while retaining efficiency and learning-by-doing through shared rules, common standards and reciprocal access. In short, many hubs, fair shares: a plural, rule-based system where each actor contributes comparative strengths and no single actor dominates.

The Open League Model operationalises the four REES principles through shared rules and standards, and competitive, transparent markets. It is Resilient, diversifying geography and creating options at critical nodes while coordinating pooled inventories, surge capacity—temporarily deployable output during shocks—and cyber-physical risk management for rapid re-routing across hubs; together these measures turn local efficiencies into system-level resilience without duplicating entire value chains. It is Efficient, because hubs compete on cost, quality and innovation without fragmenting markets, preserving scale economies and learning-by-doing. It is Equitable, diversifying supply chains geographically and institutionally to ensure a fairer distribution of value-added across regions, and embedding labour standards, community benefits and just-transition measures that safeguard social legitimacy. And it is Sustainable, with circular design, recycled-content targets and low-carbon production reducing environmental footprints and mineral pressure along the chain.

Shared leadership

The Open League can harness comparative strengths without over-privileging any actor. The central question is not who dominates, but how we steward a system on which climate goals, industrial renewal and social legitimacy increasingly depend. As in successful sports leagues, no team prospers by eliminating the others; a league's value arises from robust competition within a common framework. Like football leagues, the system thrives because teams co-exist under shared rules, common standards, transparent supply chain and competitive market and no team truly "wins" by removing its rivals; revenues, talent pipelines, and prestige depend on the collective ecosystem. Likewise, interdependent regional hubs in the clean-technology system innovate and compete while relying on diversified inputs, shared standards and reciprocal market access, so that many strong teams raise the quality of the whole league and deliver competitive excellence without systemic fragility or inequality. Unlike a football league, however, this is an open architecture—any regional hub that meets the common rulebook can participate.

A league thrives when participants contribute distinct public goods. The European Union and partners can lead on rule-setting for product passports, lifecycle carbon accounting, eco-design and due-diligence, using consumer-side market power and finance to drive adoption. The United States can contribute technology innovation, open procurement that scales markets, and deep venture ecosystems, with strengths in advanced equipment, software, innovation and investment. Japan and the Republic of Korea bring quality-first manufacturing, process engineering and SME integration, including leadership in battery materials, electrolyzers and power electronics. Emerging and developing economies such as India, Vietnam, Indonesia, Thailand, Brazil and Mexico offer competitive labour costs, expanding markets and industrial parks suited to mid-stream processing and final assembly, provided co-investment and technology partnerships are in place. Resource-rich producers—Australia, Chile, Argentina, the DRC and Indonesia—can supply critical minerals with clean, traceable extraction and beneficiation powered by renewables, opening minerals-to-manufacturing corridors.

Diversification need not imply exclusion.

The model is inclusive by design: it brings China and other major producers into a rules-based, interoperable architecture in which multiple hubs—across the Americas, Europe, East Asia, South Asia, Africa and Latin America—operate in parallel and interconnect, with overlapping capabilities and shared component supply chains that can cross-source from one another. It preserves existing strengths while reducing vulnerability from over-concentration by building parallel, interoperable regional chains able to backstop one another during shocks. Leading producers remain central, but the emphasis shifts from dominance to stewardship, with fair competition under shared rules and

transparent reporting delivering the REES principles—Resilience, Efficiency, Equity and Sustainability.

China's shift from capacity to legitimacy:

Attempting to preserve a Monocentric—and increasingly bifurcating—supply chains risk higher compliance costs, market bifurcation and shrinking access. As the largest producer of clean-technology, it has underpinned global decarbonization through scale, innovation and cost reductions, yet continued dominance also brings political and economic costs —political backlash, diversification drives and diplomatic frictions (Meckling, 2025; OECD, 2025). The "whale-fall" dynamic underscores the unsustainability of over-concentration: when a dominant actor weakens, others rush to capture redistributed value and influence and benefits from the fall of the dominant player.

Additionally, the Open League Model can align with China's long-term strategic interests. China has a clear interest in sharing and internationalizing its clean-technology supply chains: a 2024 ministerial guidance document explicitly promotes overseas investment and cooperation in R&D, standards, and supply chains, and encourages Chinese EV firms to build factories abroad to diffuse advanced technologies, expand global influence, and foster resilient, diversified production.(Government of China, 2024) The Central Committee of the Communist Party of China recommends that the 15th Five-Year Plan should guide the overseas distribution of industrial and supply chains in a rational and orderly manner to enhance global coordination and resilience in China's economic development strategy.(Xinhua, 2025)

In contrast, China will remain one of the strongest teams—an anchor investor, component supplier and partner across other parallel hubs in the Open League model. This co-development gives China a direct economic stake in multiple, parallel systems—partnering and investing in hubs outside China to compensate for diminished monopoly rents with stable returns, diversified markets and reputational gains—rather than relying on a single, monopolised chain.

China needs to set out a clear vision for shared clean-tech supply chains overseas and take the lead in coordinating the siting and planning of global supply-chain hubs. China should progressively disperse selected parts of its supply chains across parallel, rule-compliant hubs while embedding shared stewardship. That means moving from leadership in scale to leadership in legitimacy by providing public goods: co-developing shared rules and standards and transparent traceability systems, co-investing in parallel hubs, and advancing circularity. Such a pivot consolidates influence while easing external pressures and strengthening global trust. A strategic shift to the Open League Model therefore serves both global goals and China's long-term interests.

Licensing-based manufacturing

Recent tightening of Chinese export controls on rare earths and related processing technologies has amplified concerns about chokepoints in clean-technology inputs (Reuters, 2025). Rather than attempting full decoupling—which would be costly and slow—the League can encourage licensed manufacturing models that allow overseas hubs to produce with access to Chinese intellectual property under strict governance. The analogy is the "TikTok model" in the United States: core algorithms and sensitive IP remain under controlled ownership and update rights, while localised operations comply with host-country oversight.

Applied to clean-technology supply chains, companies could retain control of process IP and key equipment while licensing production to qualified partners within League-compliant hubs. Governance would combine escrowed source files, audited firmware and tooling updates, data-residency where relevant, and joint-venture or trust structures that ring-fence sensitive know-how. This approach builds parallel capacity that improves resilience without sacrificing efficiency: hubs gain scale and learning by using proven processes and

supplier networks; IP owners maintain control and monetise technology rather than losing markets to protectionism; and regulators gain visibility through League standards for traceability, cybersecurity and reciprocal access. Export-control compliance is preserved because the IP holder dictates update cadence and scope, while host hubs meet common rules for verification and reporting. Over time, such licensed hubs can specialise in specific stages—cathode precursors, wafering, magnet fabrication—expanding geographic diversification without fragmenting standards or duplicating R&D (Goldthau and Hughes, 2020).

Conclusion

Clean-technology supply chains are the new arteries of the global economy. Concentration has propelled learning and scale, but fragility and inequity now threaten momentum. Clean-tech supply chains must evolve from monocentric efficiency toward REES performance—with equity embedded by design. By embedding REES and aligning on a lean, shared rulebook and competitive, transparent markets, governments and firms can convert today's zero-sum dynamics into a resilient, efficient, and fair system that endures political cycles and withstands shocks. The Open League model—transparent competition under shared rules— offers a practical, rules-based way to reconcile security with openness, retain learning-by-doing, broaden participation, and thus achieving the REES globally harden the system against shocks. By adopting shared standards, transparent product passports, reciprocal access, and pilot compacts across multiple regional hubs (including China), policymakers and firms can deliver supply chains that are resilient to shocks, efficient in cost and scale, equitable in value sharing, and sustainable in their environmental footprint.

References

1. Yao, B. *et al.* Understanding supply chain constraints for the US clean energy transition. *npj Clean Energy 2025 1:1* **1**, 1–16 (2025).
2. Helveston, J. P., He, G. & Davidson, M. R. Quantifying the cost savings of global solar photovoltaic supply chains. *Nature* **612**, 83–87 (2022).
3. Energy Transitions Commission. *Better, Faster, Cleaner: Securing Clean Energy Technology Supply Chains*. www.twitter.com/ETC_energy (2023).
4. IEA. *Energy Technology Perspectives 2024*. https://www.iea.org/reports/energy-technology-perspectives-2024 (2024).
5. IEA. *Global EV Outlook 2025*. https://www.iea.org/reports/global-ev-outlook-2025 (2025).
6. Fraunhofer ISE. Photovoltaics Report - Fraunhofer ISE. https://www.ise.fraunhofer.de/en/publications/studies/photovoltaics-report.html (2025).
7. IRENA. Geopolitics of the energy transition: Energy security. www.irena.org (2024).
8. Shi, H. *et al.* Critical mineral constraints pressure energy transition and trade toward the Paris Agreement climate goals. *Nature Communications* **16**, 1–13 (2025).
9. Hodok, J. & Kozluk, T. *Distributional Impacts of Energy Transition Pathways and Climate Change*. https://dx.doi.org/10.1787/56e93f3e-en (2024) doi:10.1787/56e93f3e-en.
10. Fernández Intriago, L. *et al.* Overcoming five key challenges to make the energy transition a just labor transition. *Nature Communications 2025 16:1* **16**, 1–3 (2025).
11. IEA. *The Role of Critical Minerals in Clean Energy Transitions*. https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions (2021).
12. Steiber, A. & Teece, D. J. Shifting Gears: How China is Outpacing the Global Automotive Competition | California Management Review. *California management review* https://cmr.berkeley.edu/2025/05/shifting-gears-how-china-is-accelerating-past-the-global-

automotive-competition/ (2025).
13. Meckling, J. The geoeconomic turn in decarbonization. *Nature* **645**, 869–876 (2025).
14. OECD. *OECD Supply Chain Resilience Review NAVIGATING RISKS*. https://doi.org/10.1787/94e3a8ea-en. (2025) doi:10.1787/94e3a8ea-en.
15. European Commission. European Critical Raw Materials Act. https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1661 (2023).
16. Reuters. China expands rare earths restrictions, targets defense and chips users. https://www.reuters.com/world/china/china-tightens-rare-earth-export-controls-2025-10-09/ (2025).
17. Benguria, F., Choi, J., Swenson, D. L. & Xu, M. (Jimmy). Anxiety or pain? The impact of tariffs and uncertainty on Chinese firms in the trade war. *J Int Econ* **137**, 103608 (2022).
18. Barbier, E. Why the green-technology race might not save the planet. *Nature 2025 641:8062* **641**, 305–308 (2025).
19. Helveston, J. & Nahm, J. China's key role in scaling low-carbon energy technologies. *Science (1979)* **366**, 794–796 (2019).
20. Goldthau, A. & Hughes, L. Protect global supply chains for low-carbon technologies. *Nature* **585**, 28–30 (2020).
21. Geels, F. W., Sovacool, B. K., Schwanen, T. & Sorrell, S. The Socio-Technical Dynamics of Low-Carbon Transitions. *Joule* **1**, 463–479 (2017).
22. Geels, F. W., Sovacool, B. K., Schwanen, T. & Sorrell, S. Sociotechnical transitions for deep decarbonization. *Science (1979)* **357**, 1242–1244 (2017).
23. OECD. OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas. Preprint at https://www.oecd.org/corporate/mne/mining.htm (2016).
24. IPCC. *Summary for Policymakers*. *Climate Change 2022 – Impacts, Adaptation and Vulnerability* https://www.cambridge.org/core/product/identifier/9781009325844%23pre2/type/book_part (2023) doi:10.1017/9781009325844.001.
25. UNFCCC. *Outcome of the First Global Stocktake*. (2023).
26. UNFCCC. *Just Transitions in National Climate Frameworks and Climate Policies: Experiences in Alignment, Planning and Progress Tracking* . https://unfccc.int/documents/645834 (2025).
27. Government of China. Guiding Opinion on the Healthy Development of Trade and Cooperation on New Electric Vehicles "关于支持新能源汽车贸易合作健康发展的意见". https://www.gov.cn/zhengce/zhengceku/202402/content_6931276.htm (2024).
28. Xinhua. Recommendations of the Central Committee of the Communist Party of China for Formulating the 15th Five-Year Plan for National Economic and Social Development-Xinhua. *Xinhua News* https://english.news.cn/20251028/efbfd0c774fd4b1c8daeb741c0351431/c.html (2025).

Author Biographies

Xunpeng Shi is a Professor at the University of Technology Sydney and the President of the International Society for Energy Transition Studies. Email: xunpeng.shi@uts.edu.au.