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Green Transition, Energy and Economic Security: An Avoidable Dilemma

Geopolitical fragmentation appears to pit climate goals against energy and economic security. Economies fear that the acceleration of the net-zero transition will shift their dependence from “brown” (on fossil fuel suppliers) to “green” (on those who currently dominate key green supply chains). Governments tend to respond either by weakening climate ambition or by pursuing broad import substitution strategies. Framing this issue as a policy dilemma can be misleading. The relevant question is not whether Europe should choose between decarbonisation and autonomy, but rather which dependencies are strategically consequential and in which areas capability building is feasible. Drawing on evidence from photovoltaic and lithium-ion battery supply chains, this analysis combines granular supply chain mapping with indicators of import dependency, technological specialisation and policy orientation. The evidence points to a marked reshuffling in favour of China, growing vulnerabilities for the EU and the US, and substantial heterogeneity across products and stages. These patterns imply that reducing vulnerability does not automatically require self-sufficiency across entire sectors. It requires product-level intelligence and selective interventions: capability building where upgrading is plausible, and diversification, partnerships or stockpiling where it is not.

Over recent decades, climate policies and technological developments have pushed economies towards more sustainable growth. CO₂ emission targets reshaped investment and policy strategies, while subsidies, conditional R&D incentives and public procurement accelerated environmental innovations by making low-carbon technologies more competitive and reducing uncertainty (Tchorzewska et al., 2022; Costantini & Crespi, 2008; Cheng et al., 2018; OECD, 2024; Zoboli et al., 2024).

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As globalisation expanded, decarbonisation-related production, sourcing and make-or-buy decisions, including those concerning green technologies, were largely shaped by cost minimisation. This delivered efficiency gains and accelerated the diffusion of solar panels, lithium-ion batteries and electric vehicles. Yet it also re-configured technological and production hierarchies, strengthening Asian economies, especially China, in most green industries (Crespi et al., 2026).

As geopolitical tensions intensified, interdependence among unequally endowed economies increasingly turned into trade coercion and weaponised choke points, exposing economies reliant on external sources for raw materials, technology and strategic goods. Economic policy has consequently shifted from trade liberalisation, offshoring and the search for the cheapest suppliers towards strategic industry protection, rebuilding production capacity and technological sovereignty (Crespi et al., 2021; Edler et al., 2023; Rodrik & Walt, 2022; European Commission, 2024, 2026).

Offshoring reduced the cost of green goods and helped speed the net-zero transition, but it now sits uneasily with the need to avoid excessive dependence on foreign suppliers when political relations are unstable (Johnstone & Schot, 2023). Recent tensions affecting strategic energy

routes, including the Strait of Hormuz, again show how localised geopolitical crises can generate systemic effects. For energy-importing economies such as the EU, decarbonisation is therefore also a way to reduce exposure to traditional energy shocks and the risk that growth, prices and macroeconomic stability are tied to on geopolitical disruptions (Guarascio et al., 2025).

Decarbonisation is thus shaped by a policy dilemma. Access to international markets can accelerate the transition by lowering the cost of raw materials, components and technologies. Yet the international division of labour increasingly clashes with the concentration of manufacturing and technological capabilities in a few firms and countries. Recent evidence shows that many key green technologies are geographically concentrated, with China dominant in several sectors (International Energy Agency, 2024). Climate policies relying mainly on demand incentives and regulation may therefore accelerate adoption while increasing strategic dependency (Baldwin & Freeman, 2022; Caravella et al., 2024).

In asymmetric green value chains such as photovoltaics and lithium-ion batteries, trade can widen the gap between dominant players and lagging countries. Ambitious environmental targets may reduce fossil fuel dependence, but they can also create new vulnerabilities linked to imported technologies, intermediate inputs and critical raw materials: a shift from “fossil dependency” to “green dependency” (Caravella et al., 2021, 2024).

We argue that this “climate policy versus strategic autonomy” trade-off is not inevitable but a policy dilemma that can be addressed through an appropriate policy mix. Whether the transition generates new vulnerabilities depends on the combination of policies and on where intervention is directed along the value chain (Flanagan et al., 2011; Costantini et al., 2017; Rogge & Song, 2025). The issue is whether governments can identify nodes where dependency is consequential and domestic capability building is both strategically relevant and realistically attainable.

To frame this argument, we introduce a conceptual framework in which the private value added generated by a stage may diverge from its broader strategic importance. Market signals may therefore understate the value of preserving or developing capabilities in critical nodes.

Granular supply chain mapping and product-level intelligence are therefore crucial. Strategic importance cannot be measured directly, but three related dimensions can be tracked: dependency on external suppliers, systemic relevance for the chain and the plausibility of upgrading

domestic capabilities through innovation. We measure import dependency through trade indicators and use patent-based technological specialisation as a proxy for local capability and upgrading potential. Systemic relevance instead requires broader technological and policy judgement. The framework helps distinguish nodes where capability building may be realistic and strategically meaningful from those where diversification, long-term partnerships or stockpiling may be more appropriate (Edler et al., 2023; Caravella et al., 2024; Crespi et al., 2026).

We focus on the photovoltaic and lithium-ion battery supply chains, both central to decarbonisation but different in technology, stage composition and market concentration. Building on Caravella et al. (2024) and Crespi et al. (2026), we combine trade and patent data to analyse strategic dependency and technological capabilities across countries and stages, and relate this evidence to environmental and industrial policy approaches (Guarascio et al., 2025, 2026).

Our main conclusion is that the climate–autonomy dilemma is avoidable when policy targets strategically relevant and tractable nodes. Environmental policies can create demand and accelerate diffusion, but without productive and technological strengthening they may increase import dependence. Conversely, broad or poorly targeted industrial interventions may be costly and ineffective. The policy problem is therefore how to pursue strategic autonomy selectively, pragmatically and consistently with the green transition.

The acceleration–autonomy trade-off

Climate policy can clash with energy and economic security when it relies mainly on demand-side and regulatory instruments. Consumption subsidies, green public procurement and standards can accelerate low-carbon diffusion by expanding demand and reducing uncertainty. Yet if productive and technological capabilities are concentrated abroad, they may raise imports rather than strengthen domestic industry, increasing dependence on foreign suppliers of critical inputs, components and technologies (Baldwin & Freeman, 2022; Crespi et al., 2026).

Reducing external dependency can also create tensions with acceleration. Governments may respond to vulnerabilities through broad protectionism, local content requirements or poorly targeted import substitution. These measures can raise costs and may not stimulate domestic production or innovation where capabilities are weak. If autonomy is pursued too rapidly or broadly, it may slow the transition or strengthen coalitions favouring delayed decarbonisation (Meckling & Nahm, 2018).

These tensions do not mean that climate policy and strategic autonomy necessarily conflict. Their relationship depends on the value chain and the policy mix. Decarbonisation is a global objective, while strategic autonomy is context specific: it depends on countries' positions, the geopolitical environment and the characteristics of particular inputs, products and technologies. This suggests that autonomy should be pursued by identifying concrete vulnerabilities and targeted interventions, not through broad sectoral measures (European Commission, 2026).

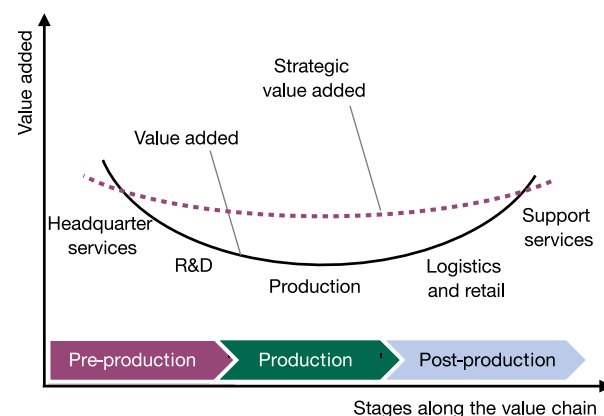
Conceptually, this can be framed as a wedge between the private and social value of maintaining domestic productive and technological capabilities in specific nodes of green value chains. In the standard smile-curve representation, private value added tends to be higher in pre-production and post-production activities and lower in manufacturing (Mudambi, 2008). In a geopolitically fragmented context, however, the private value added of a stage may diverge from its strategic relevance. Activities that are not especially profitable for firms may still matter because they reduce dependency, preserve technological control and prevent downstream vulnerabilities. Production-related knowledge, generated through new processes, learning by doing and organisational learning, can also enhance efficiency, strengthen competitiveness, and foster spillovers across the supply chain and the wider economy (Chang & Andreoni, 2020).

The “modified smile curve” illustrates this idea. It suggests that, at each stage of a value chain, firms' private value added may differ from “strategic value added”: the net social value generated in terms of resilience, security of supply, idiosyncratic knowledge and capacity to reduce vulnerabilities. Some stages, products and technologies may therefore deserve policy attention even when market signals alone do not identify them as especially valuable (Figure 1).

Strategic value added is a conceptual rather than directly observable object. Still, three dimensions help identify where policy intervention may be justified: dependency on external suppliers, systemic relevance for the chain and the plausibility of upgrading domestic capabilities. In our empirical set-up, import dependency is captured through trade indicators, while technological specialisation provides a partial proxy for the local capability base and upgrading potential (Caravella et al., 2024; Crespi et al., 2026). Systemic relevance cannot be inferred mechanically from these indicators and requires broader technological and policy judgement.

This distinction matters because not all dependencies require the same response (Table 1). Highly strategic but

Figure 1
A modified smile curve



Source: Authors' own elaborations on Mudambi (2008).

hard-to-upgrade stages may call for diversification, long-term partnerships, stockpiling or other risk-management strategies. Other nodes may combine high dependency with a non-negligible capability base, making selective capability building more realistic. The objective is not self-sufficiency along the entire chain, but rather reducing excessive unilateral dependencies where policy can affect domestic capabilities, while anticipating emerging vulnerabilities (Edler et al., 2023). Even low-dependency areas may need monitoring, since specific raw materials or inputs can become critical after disruptive technological change.

Strategic dependencies are uneven across green value chains

Our analysis starts from a clear stylised fact: in less than two decades, the US and the EU have lost ground in key green value chains, while China has become dominant in several crucial nodes. This applies to both the lithium-ion battery and the photovoltaic supply chains, with differences across sectors and stages. Export shares over the 2007-2022 period show a marked reshuffling: China reached roughly 30%-32%

Table 1
Types of policy response

Dependency	Upgrading potential	Policy response
High	High	Targeted capability building
High	Low	Diversification, partnerships, stockpiling
Low	High	Preserve existing strength
Low	Low	No strong case for intervention (need to monitor dependencies that may emerge in the future)

Source: Authors' elaboration.

of world exports in both chains in 2022, up from about 9% in batteries and 19% in photovoltaics. By 2022, the EU's shares were around 12%-13%, Japan's around 6%-13%, the US's around 6%-10% and South Korea's around 4%-7%. The issue is therefore not only trade performance, but changing global control over strategically relevant production segments.

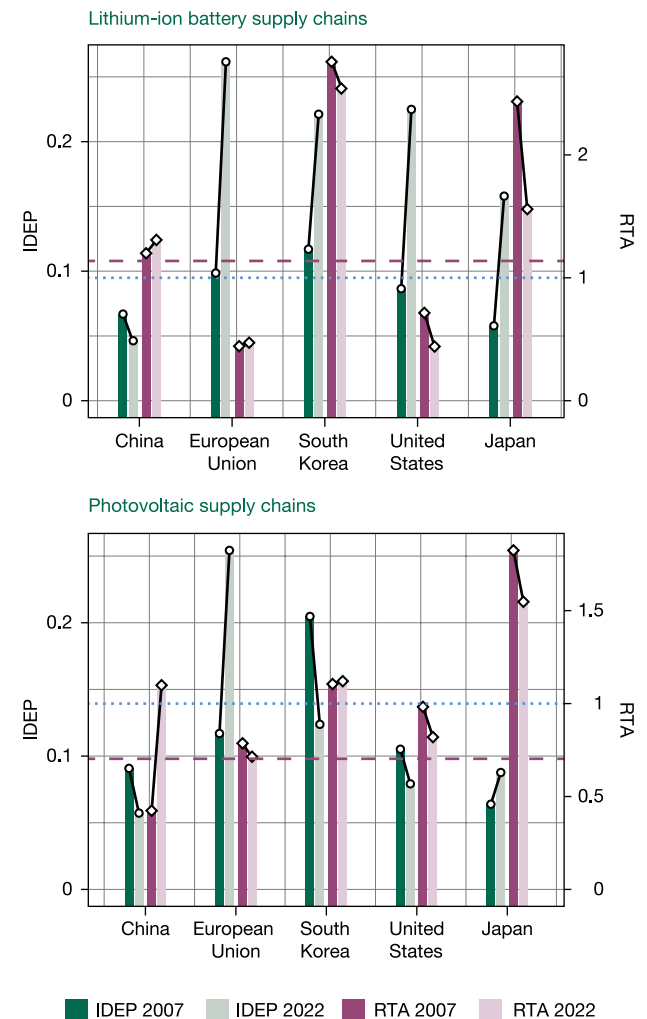
Manufacturing capacity data and announced projects confirm these patterns. The International Energy Agency (2024) shows that China controlled more than 80% of global photovoltaic production in 2023 and that high concentration is expected to persist until 2030. China also accounts for about 80% of global battery cell manufacturing capacity, although this share is projected to decline to 60% by 2030 as industrial policies such as the Inflation Reduction Act and the Net-Zero Industry Act support new investment. Yet battery capacity built in the EU is largely driven by foreign-headquartered firms, mainly from South Korea (International Energy Agency, 2026). Thus, even when strategic autonomy concerns push Europe to expand domestic production, current policy may still increase dependence on foreign actors.

Global hierarchies have also shifted in technological capabilities. China's share of patent stock increased from a very low level in 2007 to 26.2% in lithium-ion battery supply and 22.0% in photovoltaic supply chain by 2022. In batteries, Japan remained the largest holder despite its share falling from 39.2% to 30.7%, while South Korea's share rose from 9.2% to 18.4% and the EU's declined from 13.1% to 9.5%. In photovoltaics, Japan's share remained around 30%, the EU's share fell from 23.2% to 14.2% and South Korea's rose from 3.7% to 8.1%. The joint consideration of trade and technology is crucial: strategic dependency is revealed in imports or exports, but shaped by production and technological capabilities, which affect upgrading, diversification and vulnerability over time.

Starting from this evidence, we use two indicators to identify vulnerable nodes and the capability base available to address them. The first is import dependency (IDEP),¹ which combines the normalised trade balance, the import share from the main supplier and that supplier's global export share (higher values indicate stronger dependency). The second is revealed technological advantage (RTA), a patent-based Balassa-type index measuring technological specialisation in each input (values above one indicate relative specialisation). Together, these indicators show how dependency and capabilities evolve and, up to the six-digit product level, where vulnerabilities are more severe and upgrading more plausible.

1 Formally, the IDEP is computed as follows (Gehring, 2023): $IDEP_{i,k,t} = NTB_{i,k,t} * ((IMPMS_{i,k,t} + EXPSH_{k,t})/2)$. Where, for each product included in the supply chain, NTB represents the normalised trade balance, IMPMS the import share from the main supplier j , while EXPSH the main supplier's global export share.

Figure 2
Import dependency (IDEP) and technological specialisation (RTA) in 2007 and 2022



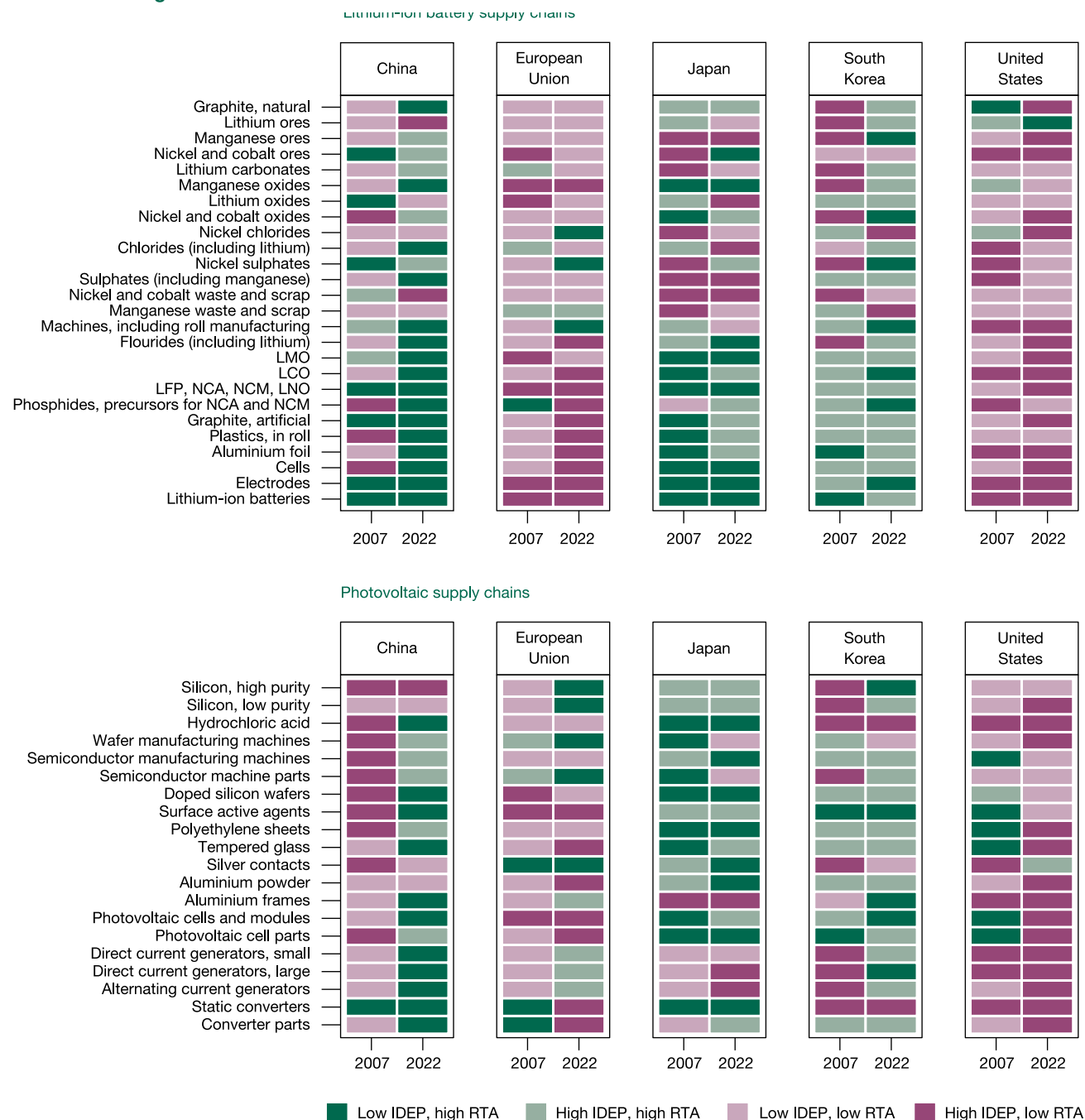
Notes: Diamonds represent RTA values, while dots represent IDEP values. The figures refer to the totality of the supply chain. The purple dashed line represents the median of IDEP. The blue dotted line, equal to one for the RTA indicator, represents the threshold of over/under-specialisation.

Source: Authors' elaboration based on BACI and OECD Regpat data.

The aggregate picture conveys a clear message (Figure 2). China moves from relative weakness to significant strength, combining lower dependency with stronger technological specialisation. The EU and the US follow the opposite trajectory: increasing dependency is associated with technological weakening, or with technological strengthening that is too slow to offset productive decline. Japan also loses ground, while South Korea remains dependent in several cases but shows signs of upgrading. Overall, countries that strengthen their technological position are more likely to reduce dependency, while those that lose technological ground tend to become more exposed.

Figure 3

Countries' positioning relative to the import dependency (IDEF) and technological specialisation (RTA) indicators along the value chain



Note: High IDEF: IDEF > median (IDEF). High RTA: RTA ≥ 1.

Source: Authors' elaboration based on BACI and OECD Regpat data.

This relationship should not be overstated. It is neither mechanical nor uniform across sectors and stages. Aggregate indicators can hide significant product-level heterogeneity: in both batteries and photovoltaics, competitive positions in one part of the chain may coexist with vulnerabilities in another.

Strengthening selected nodes can therefore reduce some dependencies while new exposures emerge elsewhere.

Disaggregation by stage and product makes the picture more useful for policy (Figure 3). China dominates impor-

tant downstream segments of both the lithium-ion battery and the photovoltaic supply chains, such as battery chemistries (LFP, NCA, NCM, LNO) and static converters, but remains more dependent on some upstream inputs, including lithium ores and high-purity silicon. The EU is weak in several upstream and downstream stages, while preserving advantages in specific segments such as manufacturing machines for battery and panel production. The US faces similar problems, with some supplier diversification in photovoltaics. South Korea shows a stronger upgrading trajectory in batteries, while Japan combines remaining technological capabilities with a declining role in several market segments.

Strategic dependencies are therefore not uniform. A country may be highly exposed in one stage, well positioned in another and marginal in a third. Granular supply chain intelligence is needed to distinguish more and less critical nodes and identify realistic margins for selective industrial policy.

This also clarifies the link with the conceptual framework. The empirical exercise does not measure strategic value added directly, but it identifies characteristics plausibly related to it: high import dependency signals vulnerability, technological specialisation indicates part of the domestic capability base, and systemic relevance requires technological and policy judgement about the role of each product or stage.

The role of industrial and environmental policies

Strategic dependencies cannot be understood independently of policy. The evidence above identifies where vulnerabilities arise, while the policy mix helps assess whether climate policy can coexist with domestic production and technological upgrading or instead increases import dependence. In the European debate, environmental policies are often portrayed as a threat to competitiveness, but the relationship is more complex. Environmental stringency, green public procurement and consumer subsidies can expand domestic markets for green goods. However, if domestic production and technological capacity are weak, rising demand is likely to be met by foreign producers, increasing external dependence.

This is especially relevant for photovoltaics and lithium-ion batteries. In both cases, climate policy-induced demand does not automatically translate into domestic production, innovation capabilities or learning. Demand-side support may accelerate adoption, but without supply-side strengthening it may reinforce dominant foreign producers. The problem is not environmental targets as such, but their disconnection from the productive side of

the transition (Costantini et al., 2015; Crespi, 2016; Nunez-Jimenez et al., 2022).

The divergent trajectories of key players become evident when comparing the Environmental Policy Stringency indicator with industrial policy initiatives targeting lithium-ion battery and photovoltaic products (Figure 4). This evidence should be read cautiously, but it suggests broad policy orientation and sequencing.² China has combined an active industrial policy stance with gradually stronger environmental stringency, alongside declining import dependencies in both chains (Figures 2 and 3). By contrast, the EU and the US long focused mainly on environmental stringency and only recently intensified industrial policy to reduce accumulated external dependence. This is consistent with the idea that the interaction between environmental, industrial and innovation policies matters for external dependency.

The comparison also points to sequencing. In China, industrial and innovation policies appear to have built productive and technological capabilities before or alongside stronger environmental regulation. In the EU and the US, the policy profile was more unbalanced: for a long time, acceleration occurred while too little attention was paid to production and technological capacities along the supply chain. Under these conditions, green demand may have accelerated adoption but also increased import dependency. This supports the broader argument that the climate-autonomy dilemma depends on how climate, industrial and innovation policies are combined.

Where domestic capabilities are weak, demand expansion may reinforce countries that already dominate the chain. Selective industrial and innovation policies are therefore needed to address coordination failures, capability gaps and dependency risks in strategic nodes. Policy should focus where dependency is significant, capability development is plausible and resilience gains do not undermine the pace of transition.

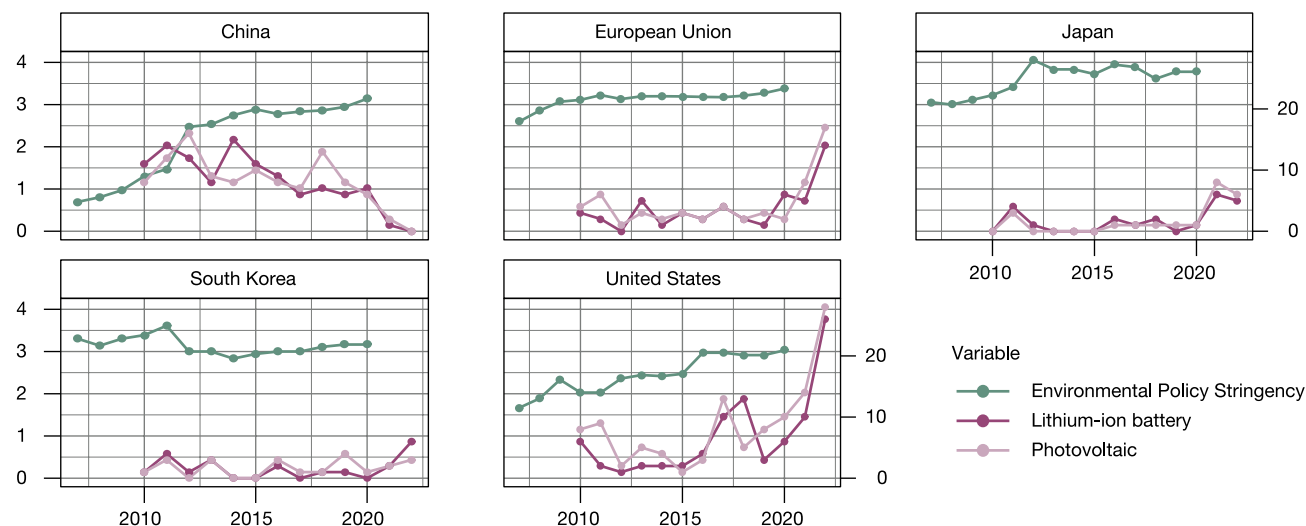
Implications for European policymaking

This analysis yields three implications for European policymaking. First, strategic dependency is not binary. Some external dependence is less risky, especially when diversified, and openness can still lower costs, create scale economies and diffuse technology. The objective is not self-sufficiency, but reducing excessive dependence

² A simple count of industrial policy measures does not capture their scale, fiscal intensity, quality, implementation capacity or effectiveness. Nor does it fully account for institutional differences across China, the United States and the European Union. Moreover, the Global Trade Alert database on which the policy count rests is limited to trade-related policies.

Figure 4

Number of industrial policies targeting photovoltaic and lithium-ion battery supply chains (right-axis) and Environmental Policy Stringency indicator (left-axis)



Notes: Industrial policies are selected if they target at least one product included in the value chains of interest. Only national-level and non-firm-specific policies are considered. According to the data employed, China is overrepresented in firm-specific policies. This further supports the idea that vertical and mission-oriented industrial policies have played a crucial role in Chinese establishment as a leader in these value chains. However, to keep comparability with the Environmental Policy Stringency indicator, we consider only national-level and non-firm-specific policies, providing an intuition of the broader attitude of the country towards industrial policy.

Source: Authors' elaboration based on Juhász et al. (2025) and OECD.

in strategically important nodes. The key question is under what conditions openness generates vulnerabilities beyond standard efficiency concerns.

Second, industrial policy must be selective. The appropriate response depends on the combination of dependency, strategic relevance and plausible upgrading potential. Some cases justify targeted support to innovation, scale-up and production; others call for supplier diversification, long-term partnerships, stockpiling or risk management. Intervention should follow granular supply chain mapping rather than broad sectoral narratives.

Third, timing and sequencing matter. Ambitious environmental targets can expand green markets and accelerate adoption, but they do not automatically create domestic productive capabilities. If demand-side measures precede attention to supply-side constraints, stronger demand may mainly raise imports and make later upgrading more difficult and costly. Environmental policy should therefore be accompanied early by measures strengthening capabilities where domestic upgrading is strategically relevant and feasible.

The evidence from solar and lithium-ion battery supply chains points in the same direction. Environmental poli-

cies can enlarge domestic markets while also creating strategic vulnerability, but this outcome is not inevitable. Where capabilities are concentrated abroad, demand expansion alone may reinforce foreign suppliers. A balanced supply-push and demand-pull policy mix can instead support the green transition without compromising energy and economic security. Industrial policy will be ineffective if it is too broad, poorly targeted or disconnected from the value chain. The challenge is to align climate policy and strategic autonomy through a pragmatic and selective policy mix.

European policy should distinguish among dependencies. Where dependency, systemic relevance and capabilities are high, policy should support innovation, scale-up and production. Where dependency is high but upgrading unrealistic, priorities should be diversification, partnerships, recycling, stockpiling or demand flexibility. Where Europe has capabilities, policy should prevent erosion; where dependency is limited but systemic relevance high, it should prevent future vulnerabilities.

We conclude that the climate-autonomy dilemma is not inescapable. Its severity depends on how green value chains are structured and how environmental, industrial and innovation policies are combined. The transition is

unlikely to be delivered by market incentives alone. It requires public policy capacity to identify strategic nodes, coordinate interventions and mobilise resources where price signals and firm-level incentives understate broader resilience, security and capability-building benefits.

For the EU, this means moving beyond both unrealistic self-sufficiency ambitions and the belief that market openness alone will solve the problem. A realistic objective is to preserve openness while reducing dependence in strategically relevant and tractable nodes. Guided by granular evidence, decarbonisation and strategic autonomy can become mutually reinforcing objectives of a more resilient European growth strategy.

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