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Research Article

SPECIAL ISSUE: The Wicked Problems in the Governance of the Just Green Transitions: between Territorial Resilience and Foresight

Reframing Just Green Transitions through Energy Geopolitics: Actors, Inequalities, and Territorial Vulnerabilities

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Abstract

This paper addresses the Just Green Transitions (JGTs) as a wicked, multiscalar problem at the intersection of energy geopolitics, territorial justice, and anticipatory governance. The analysis adopts an integrated foresight methodology combining cross-impact analysis, horizon scanning, and scenario planning to explore the geopolitical complexity of the JGTs. Drawing on a meta-geopolitical framework, the study examines the interplay between critical raw material dependencies, spatial inequalities, and global power shifts. Foresight tools are applied to construct alternative transition trajectories, namely competitive and co-operative pathways, and to assess the strategic role of territorial resilience and anticipatory governance mechanisms in managing uncertainty and fostering equitable policy innovation across scales. Through comparative case studies of the European Green Deal (EGD) and the U.S. Inflation Reduction Act (IRA), the paper highlights paradoxes in just transition strategies in which efforts to decarbonise risk deepening inequalities and fuelling forms of energy neo-colonialism, particularly across North–South divides. By repositioning territorial resilience not merely as a technical goal but as a normative foundation for equitable transitions, this contribution advances a critical lens on the governance of sustainability transformations.

Keywords

Just Green Transitions, energy geopolitics, meta-governance, territorial justice

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Introduction

The Just Green Transitions (JGTs) are not a linear technological shift but a set of contested, multi-scalar transformations in which decarbonisation imperatives intersect with energy geopolitics, territorial justice and anticipatory governance (Blondeel et al., 2021; Kuzemko et al., 2024; Epasto, 2025). Building on recent debates, this article reads the JGTs through a meta-geopolitical lens that foregrounds how power, space and institutions co-evolve across scales. In doing so, it distinguishes between territorial resilience as a normative principle, concerned with justice, inclusion, and long-term territorial cohesion, and resilience as a technical capability, referring to the capacity of infrastructures, institutions, and communities to absorb, adapt to, and recover from shocks (Brunetta et al., 2020; Epasto, 2024; Epasto, 2025).

From this geopolitical standpoint, JGTs are understood not only as a climate-policy or technological process, but also as a reconfiguration of power, dependency, security, and territorial vulnerability. Current geopolitical developments, including strategic competition over critical raw materials, the securitisation of energy infrastructures, industrial-policy rivalry, and the political reversibility of transition commitments, show that decarbonisation is increasingly embedded in unstable global and regional orders. A geopolitical framing is therefore necessary to understand where new dependencies emerge, which territories are exposed to transition risks, and how justice, resilience, and security become mutually constitutive dimensions of transition governance (Blondeel et al., 2021; IRENA, 2023; Kuzemko et al., 2024; Herranz-Surrallés, 2024).

Over the past decade, the centre of gravity in energy geopolitics has shifted from scarcity narratives to a "twofold" transformation: phasing down fossil-fuel infrastructures while scaling low-carbon systems. This reconfiguration relocates influence from hydrocarbons to technologies, grids, standards, data and critical minerals, and it generates uneven spatial outcomes across regions and sectors (Blondeel et al., 2021). A whole-systems perspective is therefore essential to grasp the interdependence of "high-carbon" and "low-carbon" transitions and their differentiated territorial effects (Blondeel et al., 2021).

At the same time, the race for clean-tech value chains and critical raw materials introduces new dependencies and potential forms of energy neo-colonialism along North–South fault lines. International agencies emphasise that supply security for lithium, nickel, cobalt and rare earths—and the standards that govern their extraction, processing and recycling—now conditions both national strategies and regional cohesion (IRENA, 2023, 2024). Political narratives and media ecologies further mediate these conflicts, shaping coalitions and public consent, sometimes amplifying asymmetries rather than reducing them (Lizza, 2024).

Flagship policy packages crystallise these tensions. In the European Union (EU), the European Green Deal (EGD) couples climate ambition with industrial policy and place-based instruments, while reviving debates on strategic dependencies and distributive outcomes; in the United States, the U.S. Inflation Reduction Act (IRA) mobilises unprecedented incentives for clean energy and advanced manufacturing but raises questions about residual fossil support and equity (European Commission, 2019; U.S. Congress, 2022; Epasto, 2024). Together, these trajectories illuminate the stakes of competitive versus co-operative transition logics and the need to embed justice, understood as distributional, procedural and recognitional, into governance architectures from the outset (Epasto, 2025; Blondeel et al., 2021).

The article advances an integrated foresight approach, including horizon scanning, cross-impact analysis and scenario planning, to map how policies and value chains reconfigure power and vulnerability across scales, and to stress-test policy options under uncertainty with territorial resilience as a guiding value (Epasto, 2024, 2025).

1 Theoretical framework and critical approach

This article adopts a meta-geopolitical lens that reframes energy geopolitics around the global energy system transformation (GEST) as a contested, path-dependent and socially produced process, rather than a static shift from a fossil to a renewable world (Kuzemko et al., 2024). This implies analysing co-evolving high- and low-emissions sub-systems, their materialities (fuels, technologies, infrastructures, standards, critical minerals) and the political economies that assemble them over time.

This transformation should also be situated within the longer-standing literature on rentier states and petrostates. Classical contributions demonstrated how dependence on hydrocarbon rents shapes state capacity, fiscal structures, political coalitions, and relations between governments and society (Beblawi & Luciani, 1987; Karl, 1997; Mitchell, 2011). The transition from fuels to grids does not simply dissolve these political-economic configurations; rather, it redistributes strategic leverage towards states able to control clean-technology manufacturing, electricity networks, storage systems, standards, and critical-material processing. The more recent notion of the “electrostate” captures this emerging configuration of power, which rests less on the extraction and export of fuels than on technological, infrastructural, and industrial capabilities (Mitrova & Corbeau, 2025; Kuzemko et al., 2024). Petrostates and electrostates should not, however, be understood as mutually exclusive or sequential ideal types, since fossil and electrified systems continue to coexist and remain materially and geopolitically entangled.

First, the analysis moves beyond neo-classical energy geopolitics—focused on state-centric security and fossil chokepoints (Bradshaw, 2009)—and beyond ‘renewable geopolitics’ that often presumes a ready-made low-carbon order. Instead, it centres the process of transformation: changes in one attribute (e.g., phasing down extraction or scaling storage) cascade across supply chains, spaces and institutions (Kuzemko et al., 2024; Blondeel et al., 2021).

Within this broader understanding, security is not treated solely in negative terms, as protection against supply disruptions, geopolitical coercion, price volatility, cyberattacks, and infrastructural breakdown. It also has a positive dimension, referring to the institutional, social, and territorial conditions that enable individuals and communities to experience stability, participate in decision-making, access energy equitably, and develop the capacity to shape their own futures. Negative and positive security are therefore understood as complementary rather than mutually exclusive dimensions. Renewable-energy systems may reduce certain forms of negative insecurity through diversification and decentralisation, while simultaneously producing new vulnerabilities associated with critical-material dependencies, grid instability, cyber risks, land-use conflicts, and unevenly distributed transition costs. Their contribution to positive security consequently depends on governance arrangements capable of fostering trust, inclusion, justice, and long-term territorial capabilities (Turnheim et al., 2018; Kivimaa, 2024).

Second, the analysis foregrounds space as produced and uneven. Energy transitions (re)make places—winding down carbon-intensive landscapes while creating new ones for renewables, storage and e-materials processing—and thus redistribute winners and losers across scales. The energy-geographies canon helps explain why electrification and renewables multiply and disperse energy sites, intensifying land-use politics and coordination challenges (Bridge et al., 2013; Kuzemko et al., 2024).

Third, politics is treated as political economy. Transitions are shaped by conflicts among incumbents and challengers, policy arenas that (re)allocate authority and resources, and coalitions that steer the pace and form of decarbonisation. Scenario-based work underscores that geopolitical outcomes hinge on how industrial policy, standards and finance interact with system change, yielding more competitive or more co-operative trajectories (Bazilian et al., 2019; Kuzemko et al., 2024; Epasto, 2024).

Fourth, justice is embedded as a governance principle. Distributional fairness, procedural inclusion and recognition of place-based vulnerabilities are constitutive of feasible transition pathways (Healy & Barry, 2017). The EU's territorial operationalisation via the Just Transition Mechanism (JTM) illustrates how rescaling to sub-national carbon-intensive regions can enable agency but also reveals monitoring gaps for vulnerable groups and risks of instrumentalisation (Strambo, 2020).

In sum, the analytical stance is a whole-systems, place-aware geopolitical economy of the GEST: it links materials and infrastructures to space and scale, and ties both to conflictual political economies and just-transition governance. This lens underpins the methodological choices that follow and structures the subsequent empirical analysis (Kuzemko et al., 2024; Blondeel et al., 2021; Bradshaw, 2009; Bridge et al., 2013).

2 Methodology: an integrated foresight approach

This article adopts an integrated foresight design that combines horizon scanning, cross-impact analysis, and scenario building, grounded in a relational reading of energy geopolitics and in anticipatory governance for territorial resilience (Epasto, 2024, 2025). This responds to recent calls to treat the global energy system transformation (GEST) as a contested, path-dependent process unfolding across co-evolving high- and low-emissions sub-systems rather than as a static shift from fossil to renewable orders (Kuzemko et al., 2024; Blondeel et al., 2021).

2.1 Design principles and rationale

The design follows three principles. Relationality: actors, infrastructures, standards and narratives are treated as interdependent, multi-scalar assemblages across which power is produced and contested (Jean, 2003; Antonsich, 1995; Kuzemko et al., 2024). Cross-impact consistency: pairwise relations among drivers are made explicit to avoid internally inconsistent futures and to surface tensions among policy goals (Jean, 2003; Epasto, 2024; Epasto, 2025). Anticipatory governance: scenarios are used to stress-test options under uncertainty with territorial resilience as a normative anchor for distributional, procedural and recognitional justice. Technical resilience is operationalised separately through indicators concerning grid adequacy, flexibility, interconnection, storage capacity, and cyber-physical security (Brunetta et al., 2020; Strambo, 2020; Epasto, 2025).

2.2 Horizon scanning and factor elicitation

A structured horizon scan across academic, policy and industry sources identified a long-list of drivers (e.g., technologies, critical-materials chains, grid integration, finance and standards) and uncertainties (e.g., trade regimes, supply security, social consent). Items were coded under social, technological, economic, environmental, political and governance (STEEP+G) categories and mapped to scales (local–regional–national–EU/global) to preserve spatial specificity and enable a place-aware comparison of vulnerabilities (Epasto, 2025; Kuzemko et al., 2024). Technology foresight is employed here not as an attempt to predict a single technological future, but as a structured process for identifying alternative trajectories, emerging technologies, systemic interdependencies, and potential bottlenecks (Martin, 1996). From the perspective of large technological systems, such bottlenecks can be interpreted as “reverse salients”: components, infrastructures, or institutional arrangements whose comparatively slower development constrains the performance and expansion of the system as a whole (Hughes, 1987). In the context of JGTs, critical-mineral processing, grid expansion, storage capacity, permitting procedures, recycling systems, and specialised skills may operate as reverse salients. Their identification through horizon scanning is therefore essential to assess where geopolitical dependencies and territorial vulnerabilities may persist even when the deployment of low-carbon technologies accelerates.

2.3 Variables and indicators

From the long-list, a compact set of state variables was derived with observable indicators (e.g., diversification of critical-materials supply; interconnection capacity; storage penetration; participation safeguards; labour transition support; cost of capital; innovation capacity). Operationalisation follows a whole-systems logic so that variables can be measured consistently and compared across territories (Blondeel et al., 2021; Epasto, 2024; Jean, 2003; Epasto, 2025). The operationalisation of the variables, including definitions, indicators, thresholds, the cross-impact matrix, and uncertainty-tagging rules, is detailed in Appendix A1–A3. The scenario logic is explained in Section 2.5 and summarised in Table 1.

2.4 Cross-impact analysis

The cross-impact analysis was operationalised through a 6 × 6 matrix comprising the six variables defined in Appendix A1. Each off-diagonal cell records the direction and intensity of the influence exerted by variable *i* on variable *j* over a three-to-five-year horizon, using a five-point scale ranging from –2, indicating a strong negative influence, to +2, indicating a strong positive influence (Jean, 2003; Epasto, 2024; Epasto, 2025).

The scoring procedure followed three sequential steps. First, the direction of each relationship was established on the basis of the causal mechanisms identified through the literature review, policy documents, and horizon-scanning sources. Second, its magnitude was assessed by considering the expected breadth of the effect, its temporal proximity, and its relevance across territorial scales. Third, each score was accompanied by an evidence tag—empirical (E), expert-based (X), or conjectural (C)—and by a confidence level ranging from 1 to 3. Where sufficiently robust empirical evidence was unavailable, assessments were triangulated through expert judgement and coherent signals emerging from the horizon-scanning process (Jean, 2003; Epasto, 2024; Epasto, 2025).

Directional asymmetries were retained whenever the causal mechanism differed according to the direction of influence. For example, greater system flexibility may strongly improve industrial competitiveness, whereas short-term competitiveness pressures may delay investment in flexibility infrastructure. Row and column totals were subsequently used to distinguish variables primarily operating as drivers, outcomes, levers, or buffers. The complete matrix is reported in Appendix A2, while Appendix A3 sets out the uncertainty-tagging rules and provides illustrative examples of their application.

2.5 Morphological analysis and scenario logic

The cross-impact results were subsequently translated into a morphological scenario space structured around three axes. These axes were selected because they capture analytically distinct but mutually interacting dimensions of the transition. Axis A1, transition geopolitics, represents the external geopolitical environment and distinguishes competitive from co-operative configurations. Axis A2, system architecture, captures the techno-spatial organisation of the energy system, ranging from centralised, large-scale infrastructures to distributed and meshed configurations. Axis A3, governance norm, expresses the prevailing institutional orientation, contrasting efficiency- and security-first approaches with justice- and resilience-first approaches.

The selection of the axes was guided by four criteria: conceptual independence, policy relevance, territorial discriminability, and consistency with the strongest relationships emerging from the cross-impact matrix. Taken together, the axes connect the international geopolitical context, the material and spatial configuration of energy systems, and the normative orientation of transition governance.

A complete 2 × 2 × 2 morphological field would generate eight possible combinations. Rather than treating all combinations as equally plausible or analytically useful, the study retains four policy-relevant archetypes: S1, competitive–centralised–efficiency-first; S2, competitive–distributed–justice-first; S3, co-operative–centralised–efficiency-first; and S4, co-operative–distributed–justice-first. S1 and S4 represent the two polar configurations, while S2 and S3 serve as mixed scenarios through which the independent effects of system architecture, geopolitical co-operation, and governance orientation can be examined. This parsimonious design allows the EGD and the IRA to be stress-tested under maximally contrasting, yet internally coherent, conditions (Epasto, 2025).

2.6 Expert elicitation and validation

A two-round expert consultation was used to support the validation of the methodological framework. The consultation involved a small purposive panel of specialists selected on the basis of their expertise in energy geopolitics, territorial development, just transition governance, infrastructure resilience, and/or foresight methodologies. The panel was not intended to provide a statistically representative sample, but to strengthen the plausibility, internal coherence, and interpretative robustness of the variables, indicators, scenario axes, and policy scores.

In the first round, experts were asked to assess the clarity and relevance of the variables, the appropriateness of the indicators, and the consistency of the cross-impact scoring logic. In the second round, feedback was used to test the internal coherence of the four scenarios, refine territorial-justice indicators, and identify contested or uncertain judgements. The process helped to preserve traceability, flag areas of disagreement, and distinguish between empirical, expert-based, and conjectural assessments (Strambo, 2020; Epasto, 2025).

2.7 Policy stress-testing and pathways

The EGD and the IRA were stress-tested across the four scenarios using eight criteria: mineral exposure; grid adequacy and flexibility; industrial competitiveness; distributional outcomes; procedural justice; cross-border coordination; cyber-physical resilience; and emissions-pathway alignment. Each policy–scenario combination was assessed on an ordinal scale from 1 to 5, where 1 indicates severe misalignment between the policy framework and the scenario conditions, associated with high vulnerability or limited implementation capacity, while 5 indicates strong alignment, low vulnerability, and high implementation capacity. Scores of 2, 3, and 4 represent intermediate degrees of performance. The criteria were assigned equal weight in order not to privilege economic competitiveness over justice, coordination, or resilience dimensions.

The assessment considered three elements: the presence and strength of the policy instruments relevant to each criterion; their implementation capacity and territorial reach; and their exposure to the constraints generated by the different geopolitical, infrastructural, and governance configurations. The scoring was informed by the policy documents and academic literature used in the analysis, cross-checked against the relationships identified through the cross-impact matrix, and refined through the expert-validation process described in Section 2.6 (Epasto, 2024, 2025).

To strengthen scoring transparency, the scores should be read as structured, expert-informed judgements rather than direct measurements. Their robustness derives from the explicit scoring criteria, the triangulation of policy documents, academic literature and expert feedback, and the sensitivity check reported below Table 2. The scoring exercise is therefore comparative and diagnostic: it identifies relative strengths and vulnerabilities across scenarios rather than producing definitive quantitative rankings.

Outputs include a pathways map linking short-term actions to medium-term capabilities (Epasto, 2025), together with a comparative assessment of how competitive and co-operative transition logics reshape geopolitical risks, territorial vulnerabilities, and policy opportunities (Kuzemko et al., 2024).

2.8 Limitations and reflexivity

Three limitations are acknowledged: data sparsity for sub-national justice indicators; expert bias in cross-impact scoring (mitigated via transparent tagging and iteration); and path-dependency of morphological choices (addressed by reporting discarded axes). Consistent with relational geopolitics, scenarios serve as heuristics to interrogate the co-production of power and space rather than as forecasts (Kuzemko et al., 2024; Strambo, 2020).

3 Global actors and evolving geopolitical dynamics

The geopolitics of JGTs is increasingly structured by how major powers reposition around technologies, standards, and critical materials, rather than only around fossil chokepoints. What follows maps the emerging roles of key actors—China, the EU, the United States (U.S.), and Russia—together with multilateral initiatives that condition co-operative versus competitive transition pathways.

3.1 China: from manufacturing hub to standards setter

China's pivotal role in mining, processing, and manufacturing for clean-energy value chains concentrates leverage along multiple stages from upstream minerals to downstream batteries, solar photovoltaic (PV) systems and components, thereby reshaping asymmetries of interdependence (IRENA, 2023). Policy debates now emphasise that critical-materials geopolitics differs from fossil geopolitics: risks cluster around processing bottlenecks, export restrictions, and standard-setting, not only resource endowment (IRENA, 2023). This implies that diversification, recycling and responsible supply initiatives become core security policies for others, while Beijing's capacity to shape market norms and certification ecosystems elevates its agenda-setting power. From a territorial-development perspective, this concentration produces uneven adjustment capacities: regions dependent on imported technologies and components remain more exposed to external disruptions, whereas territories able to attract processing, recycling, and clean-technology manufacturing may capture new employment, investment, and value-added opportunities (Bridge et al., 2013; IRENA, 2023).

3.2 European Union: between open strategic autonomy and "green protectionism" anxieties

Within the EU, the transition has been geopoliticised: trade, investment screening, and foreign-policy tools are increasingly mobilised to manage dependencies in green technologies and materials (Herranz-Surrallés, 2024). This shift is visible in debates around the Net-Zero Industry Act (European Parliament & the Council of the European Union, 2024a) and the Critical Raw Materials Act (European Parliament & the Council of the European Union, 2024b), where the imperative to reduce over-concentration in supply chains coexists with the need to avoid sliding into perceived "green protectionism" vis-à-vis partners (Borrell, 2023). Strategically, EU energy security moves from fuels to grids, flexibility, and technology access, with more regional energy relations and residual fossil/nuclear exposures during the transition (IRENA, 2024). The balance the EU seeks—open strategic autonomy without new dependencies—will influence whether

Europe catalyses co-operative regional standards and interconnections or hardens competitive industrial policy and trade defences. These choices have direct territorial implications within the Union, since the capacity to benefit from reindustrialisation, grid investment, and supply-chain diversification differs markedly among regions according to their industrial legacies, infrastructure endowments, fiscal capacity, and access to transition funding (Strambo, 2020; Herranz-Surrallés, 2024).

3.3 United States: IRA-driven reshoring and standard-setting

The Inflation Reduction Act (IRA) has reoriented clean-tech investment geography through large, long-dated tax credits and local-content rules, boosting domestic supply chains for batteries, solar PV and hydrogen. In geopolitical terms, this strengthens U.S. capacity to shape market rules and standards, while sharpening regulatory competition with allies (Herranz-Surrallés, 2024). Energy-security debates also broaden beyond fuels to grids, flexibility and materials. Even as the IRA favours domestic capacity, credible risk reduction still benefits from transatlantic coordination on standards, traceability and recycling across critical-materials chains (IRENA, 2023, 2024).

The U.S. tilt raises competitive pressures (subsidies, origin rules) yet creates openings for cooperation on interoperable standards and system resilience—areas where shared vulnerabilities converge (IRENA, 2024). At the sub-national scale, however, the territorial effects of the IRA depend on the geographical distribution of investment, manufacturing capacity, labour skills, and institutional implementation, meaning that the same federal incentives may generate highly differentiated regional development trajectories (Solomon, 2022).

3.4 Russia: from fossil superpower to constrained repositioning

Russia’s war against Ukraine has accelerated Europe’s gas decoupling and reframed the risks of energy interdependence, undermining core liberal assumptions about trade-for-stability. In a world where electrification and renewables advance, Russia’s traditional leverage as a fossil “energy superpower” is structurally weakened, driving attempts to re-route exports and forge alternative infrastructure and market ties, notably in Asia (Skalamera, 2023). For Europe, energy security now hinges less on molecules and pipelines and more on interconnections, storage, flexibility and cyber-physical resilience, with a constant warning not to swap one dependency for another (Borrell, 2023; IRENA, 2024).

Beyond supplier diversification, building resilient electricity networks and shared security standards becomes central to Europe’s power in the emerging order (IRENA, 2024). The resulting territorial effects are uneven: regions historically dependent on fossil-fuel infrastructures, energy-intensive production, or east–west supply routes face particularly demanding adjustment processes, while better-connected and more diversified territories are comparatively more capable of absorbing geopolitical and energy shocks (Skalamera, 2023; IRENA, 2024).

3.5 Multilateral initiatives: from risk to resilience and justice

Multilateral agendas are reframing security around system resilience (flexible, interconnected grids; diversified and transparent supply chains; cyber readiness), not just fuel availability (IRENA, 2023, 2024). In parallel, Just Transition has moved from slogan to policy toolkit: the United Nations Development Programme (UNDP) and partners outline building blocks to embed distributional and procedural justice in Nationally Determined Contributions (NDCs) and Long-Term Strategies (LTS), while EU debates link justice to the political feasibility of accelerated decarbonisation at home and abroad (UNDP, 2022; Strambo, 2020). These strands condition whether pathways skew co-operative (standards harmonisation, responsible value chains, financing for equitable transitions) or competitive (subsidy races, export controls).

Their effectiveness therefore depends not only on international agreement but also on whether financial, technological, and institutional resources reach vulnerable territories and strengthen their capacity to adapt, diversify, and participate in the transition.

In this sense, transition governance must move beyond a negative-security approach centred exclusively on reducing disruption and exposure, and also promote positive security by strengthening participation, equitable access, institutional trust, and territorial adaptive capacity (Kivimaa, 2024).

Synthesis

Across actors, leverage is shifting from fossil chokepoints to technologies, standards and critical-materials processing. How these players choose between competition and cooperation—on standards, interconnections, supply-chain transparency and just-transition finance—will set the geopolitical contour of the JGTs and its distributional outcomes within and beyond Europe (Borrell, 2023; IRENA, 2023, 2024; Herranz-Surrallés, 2024).

4 Comparing the European Green Deal and the U.S. Inflation Reduction Act

Read through a geopolitical lens, the EGD and the IRA differ in instrument mix, governance scale, and distributional design, which shapes how they perform under competitive vs co-operative transition logics (Bazilian et al., 2019; Global Commission on the Geopolitics of Energy Transformation, 2019).

4.1 The EU package: from climate ambition to economic security

Since 2022 the EU has geopoliticised the transition: REPowerEU, the Net-Zero Industry Act (NZIA) and the Critical Raw Materials Act (CRMA) sit alongside looser state-aid rules and tighter foreign direct investment (FDI) and trade screening to manage green-tech and materials exposures (Goldthau & Youngs, 2023). Energy security pivots from fuels to grids, flexibility and technology access, with the Union seeking open strategic autonomy without sliding into green protectionism (Borrell, 2023; IRENA, 2024).

The European policy framework derives considerable strength from the Union's regulatory capacity, its continental approach to energy interconnection, and the availability of cohesion and just-transition instruments designed to address regional vulnerabilities. Nevertheless, these advantages are constrained by uneven fiscal capacities among Member States, persistent differences in energy and industrial structures, and continuing exposure to bottlenecks in critical-material supply chains (IRENA, 2023, 2024). These asymmetries also shape the territorial effects of the transition. Regions with stronger infrastructures, innovation systems, administrative capacity, and access to public and private finance are better positioned to attract clean-technology investment, whereas carbon-intensive or structurally weaker territories may face higher adjustment costs. The effectiveness of the European policy mix therefore depends on the extent to which cohesion funding, state aid, infrastructure investment, and place-based industrial policies can prevent the green transition from reinforcing existing regional disparities (Strambo, 2020; Goldthau & Youngs, 2023).

4.2 The U.S. package: incentives, reshoring and social take-up

The IRA reorients clean-tech investment via long-dated tax credits, local-content rules and consumer rebates, expanding domestic chains for batteries, solar PV and hydrogen. It couples economy-wide decarbonisation with place-based support for coal communities yet retains compromises that keep some fossil support in play (Solomon, 2022).

The principal strength of the IRA lies in the scale and long-term predictability of its incentives, which stimulate demand, reduce investment uncertainty, and support the expansion of domestic clean-technology manufacturing. Consumer rebates and place-based provisions also broaden the social and territorial reach of the policy framework, particularly in communities affected by the decline of fossil-fuel industries. At the same time, local-content requirements may intensify trade tensions with allies, while differences in regulatory capacity, infrastructure, labour-market conditions, and policy implementation across states may produce uneven outcomes. Moreover, reshoring selected stages of clean-technology production does not fully eliminate dependence on geographically concentrated mineral-processing chains (IRENA, 2023; Solomon, 2022). The territorial effects of the IRA therefore depend on the interaction between federal incentives and pre-existing regional conditions: areas endowed with manufacturing capacity, skilled labour, infrastructure, and institutional resources are more likely to capture investment, whereas disadvantaged territories may benefit less unless federal support is accompanied by targeted implementation and capacity-building measures. Operational contrasts are summarised in Tab. 2, while the scenario logic is detailed in Tab. 1.

Table 1 – Scenario Axes and States

Axis	Left State	Right State	Name	Rationale
A1	Competitive	Co-operative	Transition geopolitics	Degree of international coordination on standards, trade and supply security
A2	Centralised / large-scale	Distributed / meshed	System architecture	Balance between utility-scale assets and distributed resources
A3	Efficiency / security-first	Justice / resilience-first	Governance norm	Weight of distributional/procedural criteria in decision-making

Source: Author's elaboration based on Epasto (2024, 2025); Jean (2003); Antonsich (1995); Brunetta et al. (2020); Kuzemko et al. (2024); Blondeel et al. (2021)

4.3 Comparative policy logics and stress-points

The comparison across the eight stress-test criteria reveals both common vulnerabilities and significant differences between the EGD and the IRA. With regard to critical minerals, the European framework seeks to reduce exposure through supply diversification, recycling, domestic processing, and the permitting measures introduced by the Critical Raw Materials Act. The IRA, by contrast, relies more strongly on reshoring and local-content incentives. Neither approach, however, fully overcomes the continuing geographical concentration of mineral processing and refining. Both policy packages therefore remain dependent on international cooperation concerning traceability, responsible sourcing, recycling standards, and supply-chain transparency (IRENA, 2023).

Grid adequacy and flexibility constitute a second area of differentiation. The EU benefits from an established framework for cross-border interconnection and continental coordination, although permitting delays, congestion, and uneven investment continue to constrain implementation. In the United States, grid modernisation is supported by federal incentives but remains strongly conditioned by differences among states, regional transmission organisations, and regulatory authorities. These institutional differences affect not only technical system performance but also the territorial distribution of access to renewable generation, storage, and demand-response capacity (IRENA, 2024).

The contrast is particularly visible in industrial competitiveness. The IRA's large-scale fiscal incentives and local-content provisions exert a strong and immediate investment pull, while the European approach relies more heavily on regulation, state aid, market integration, and strategic coordination. This divergence risks generating subsidy competition, investment diversion, and tensions between allies, especially under competitive geopolitical conditions (Goldthau & Youngs, 2023). Under more co-operative scenarios, however, regulatory convergence and mutually recognised standards can reduce these tensions and transform industrial rivalry into forms of shared risk management.

The two frameworks also differ in their treatment of justice. The EU combines cohesion instruments and the Just Transition Mechanism with place-based support for regions affected by industrial restructuring, whereas the IRA uses tax credits, household incentives, and targeted support for coal and energy communities. The existence of such instruments does not automatically guarantee equitable outcomes: their effectiveness depends on implementation capacity, accessibility, participation, and the degree to which vulnerable communities influence decisions rather than merely receive compensation (Solomon, 2022). Procedural justice is therefore assessed separately from distributional outcomes in the stress-test, since policies may redistribute resources without necessarily strengthening participation, recognition, or local agency.

Cross-border coordination, cyber-physical resilience, and emissions-pathway alignment complete the comparison. The EGD possesses a stronger institutional basis for transnational coordination, while the IRA is primarily organised around domestic investment and industrial renewal. Both nevertheless depend on secure grids, storage capacity, cyber protection, and resilient supply chains. Their contribution to emissions reduction consequently varies according to whether policy incentives are accompanied by infrastructure expansion, regulatory consistency, and the progressive avoidance of new fossil-fuel lock-ins (Bazilian et al., 2019; Global Commission on the Geopolitics of Energy Transformation, 2019; IRENA, 2024).

Table 2 reports the comparative results of the policy stress-test conducted according to the scoring protocol described in Section 2.7.

Table 2 – Policy stress-test across scenarios: EGD and IRA scores (1–5)

Criterion	Policy	S1	S2	S3	S4
Mineral exposure	EGD	2	3	4	5
	IRA	3	4	4	5
Grid adequacy &	EGD	3	4	4	5
flexibility	IRA	2	3	3	4

Industrial competitiveness	EGD	3	3	4	4
	IRA	5	4	4	4
Distributional outcomes (jobs/income)	EGD	3	4	4	5
	IRA	3	4	4	5
Procedural justice & participation	EGD	3	4	3	5
	IRA	2	3	3	5
Cross-border coordination	EGD	2	2	5	5
	IRA	2	2	4	4
Cyber-physical resilience	EGD	3	4	4	5
	IRA	3	3	4	4
Emissions pathway alignment	EGD	3	4	4	5
	IRA	3	4	4	5

Source: Author's scoring informed by IRENA (2023, 2024); Borrell (2023); Goldthau & Youngs (2023); Bazilian et al. (2019); Global Commission on the Geopolitics of Energy Transformation (2019); Solomon (2022).

Reading and sensitivity notes. *The scores should be interpreted as comparative and ordinal assessments rather than as precise cardinal measurements. Using equal weights across the eight criteria, the aggregate mean scores for the EGD are 2.75 in S1, 3.50 in S2, 4.00 in S3, and 4.88 in S4; the corresponding IRA scores are 2.88, 3.38, 3.75, and 4.50. A one-cell-at-a-time sensitivity check, in which each individual score was alternatively increased or decreased by one point while the remaining scores were held constant, did not alter the overall ordering of the scenarios for either policy: S4 remained the most favourable configuration, followed by S3, S2, and S1. The precise distance between the EGD and the IRA within individual scenarios is more sensitive and should therefore be read as indicative. Minerals and cross-border coordination improve markedly under co-operative settings, while the IRA performs particularly strongly on industrial competitiveness in S1. The EGD progressively closes and reverses this gap in S3–S4, where regulatory coordination, interconnection, and justice-oriented instruments acquire greater weight (IRENA, 2023, 2024; Goldthau & Youngs, 2023).*

4.4 Policy performance across scenarios

The stress-test shows that policy performance is shaped not only by the instruments contained in the EGD and the IRA, but also by the geopolitical, infrastructural, and governance conditions under which those instruments are implemented. Under S1—a competitive, centralised, and efficiency-first configuration—the IRA benefits from the scale and immediacy of its fiscal incentives and therefore performs particularly strongly in terms of industrial competitiveness. The EGD, by contrast, is constrained by fragmented fiscal capacity and slower implementation across Member States. Both frameworks nevertheless remain comparatively weak in relation to mineral exposure, cross-border coordination, and procedural justice, since competitive pressures encourage subsidy races, supply-chain nationalism, and rapid decision-making with limited territorial participation (Bazilian et al., 2019; Global Commission on the Geopolitics of Energy Transformation, 2019).

S2 combines geopolitical competition with a more distributed system architecture and a stronger justice orientation. In this setting, both policy packages perform better on distributional outcomes, participation, and local energy-system flexibility. These gains remain partial, however, because continuing international rivalry limits cooperation on critical-material supply chains, standards, and cross-border infrastructure. The scenario therefore illustrates that decentralisation and justice-oriented governance can reduce some territorial vulnerabilities without fully resolving geopolitical dependencies.

Under S3, greater international cooperation improves mineral diversification, regulatory coordination, and infrastructure planning, while the continued emphasis on centralised systems and efficiency-first governance limits the social and territorial reach of these benefits. The EGD performs relatively well in this configuration because its regulatory and cross-border coordination capacities become more effective under co-operative conditions. Nevertheless, the persistence of centralised decision-making may reproduce uneven access to investment and infrastructure across regions.

S4—co-operative, distributed, and justice-first—produces the strongest overall performance for both policy packages. Standards convergence, interconnection, diversified supply chains, participation mechanisms, and place-based support reinforce one another, improving not only technical system resilience but also territorial legitimacy and adaptive capacity. The EGD records particularly high scores because its regulatory, cohesion, and cross-border instruments are most effective under conditions of cooperation and justice-oriented implementation. The IRA also benefits substantially, although its predominantly national and incentive-based structure gives it a comparatively weaker basis for cross-border coordination.

These findings should not be interpreted as forecasts or as evidence that S4 will necessarily emerge. Rather, they show that the robustness of the EGD and the IRA depends on the institutional environment in which they operate. The same policy instrument may concentrate advantages in already competitive regions under S1, while contributing to broader territorial development under S4, where investment, infrastructure, participation, and transition capacities are more evenly distributed.

4.5 Policy implications: from rivalry to risk-sharing

The comparison suggests that the principal policy challenge is not to eliminate competition between the European Union and the United States, but to prevent such competition from producing fragmented standards, duplicated investments, and new forms of systemic vulnerability. Interoperable rules for materials traceability, recycling, environmental safeguards, and technological safety can transform regulatory rivalry into a mechanism of risk-sharing, while reducing the strategic leverage associated with concentrated processing and opaque supply chains (IRENA, 2023, 2024).

A second implication concerns grids and storage. Interconnections, flexibility markets, demand-response systems, storage capacity, and shared cyber-security standards should be treated not merely as national infrastructure investments, but as common resilience assets. Their coordinated development would strengthen energy-system adequacy on both sides of the Atlantic and reduce the risk that rapid electrification reproduces new territorial and technological bottlenecks (IRENA, 2024).

Finally, industrial policy needs to be combined systematically with place-based justice safeguards. The EU's Just Transition Mechanism and the IRA's support for coal and energy communities offer different institutional models, but both demonstrate that investment incentives alone are insufficient. Retraining, social protection, local participation, community benefits, and access to transition finance must be integrated into policy implementation if clean-technology expansion is to generate durable territorial development rather than reinforce existing spatial inequalities (Solomon, 2022; Strambo, 2020).

The movement from rivalry to risk-sharing therefore depends on aligning industrial competitiveness with cross-border coordination, technical resilience, and territorial justice. This alignment is precisely what distinguishes the more robust S3 and S4 configurations from the fragmented and vulnerability-producing dynamics associated with S1.

5 Social justice and territorial vulnerabilities

This section situates the JGTs within a justice-first lens and a whole-systems geopolitics, linking distributional and procedural equity to place-based vulnerabilities and uneven power across scales. Recent scholarship stresses that transitions unfold across co-evolving high- and low-emissions sub-systems and are socially produced and contested—hence justice cannot be an "add-on" but a constitutive axis of transition governance (Kuzemko et al., 2024; Blondeel et al., 2021).

These dimensions are operationalised in the following subsections by linking the four forms of justice to territorial indicators and, subsequently, to the scenario-based scorecard.

At the global level, governance remains patchy. Newell et al. identify horizontal gaps (between economic and labour/environmental institutions), vertical gaps (global principles vs national/local realities), and rhetoric–reality gaps in financing and delivery of just transitions; without addressing these, the scaling and legitimacy of just transitions may stall (Newell et al., 2023).

Recent developments under the United Arab Emirates Just Transition Work Programme confirm the continuing political salience of these gaps. While the thirtieth Conference of the Parties (COP30) brought the programme into a further formal phase, disagreements concerning finance, rights, differentiated responsibilities, and implementation remain central to the challenge of translating global commitments into territorially effective transition policies (UNFCCC, 2025).

5.1 Justice as governance design, not compensation

This article adopts a fourfold justice lens—distributional, procedural, recognitional, intergenerational—embedding it into policy design (targets, standards, funding) rather than post-hoc compensation (Newell et al., 2023). Intergenerational justice concerns the temporal distribution of transition costs, benefits, risks, and opportunities, including whether present policy choices transfer financial, environmental, infrastructural, or social burdens to future generations or instead preserve their long-term adaptive capacity and development opportunities (Wang et al., 2021; Upham et al., 2022). This aligns with a whole-systems approach where governance choices (e.g., standards for transparent supply chains; labour safeguards; participation rules) shape geopolitical interdependence as much as resource endowments (Blondeel et al., 2021).

5.2 Territorial vulnerability: dimensions and indicators

Territorial exposure to transition shocks is multi-scalar and path-dependent (industrial legacy, grid topology, labour markets, fiscal space). Building on the governance gaps above, this article proposes an operational matrix that connects justice dimensions to measurable criteria usable in cross-impact/scenario work.

Table 3 – Justice dimensions × operational criteria (territorial lens)

Justice dimension	What to measure (territorial)	Example indicators (place-based)	Policy hooks
Distributional	Who bears costs/gets benefits in regions and communities	Employment change in carbon-intensive sectors; income share; energy poverty rate; exposure to price shocks	Cohesion and Just Transition Mechanism (JTM) funds; targeted tax credits; retraining and regional smart specialisation strategies
Procedural	Who participates/has voice in decision-making	Participation requirements in permitting; Free, Prior and Informed Consent (FPIC)/consultations; social dialogue coverage; grievance mechanisms	Statutory participation clauses; social conditionality in subsidies; municipal co-ownership
Recognitional	Whose identities/needs are acknowledged	Inclusion of affected workers, Indigenous groups, small and medium-sized enterprises (SMEs); accessibility in governance	Inclusive standard-setting; supplier diversity; community benefit agreements
Intergenerational	Distribution of costs, benefits, risks, and opportunities across generations; preservation of long-term territorial capacity	Long-term public debt and stranded-asset exposure; education and green-skills pipelines; intergenerational distribution of infrastructure costs and benefits; ecosystem integrity; adaptive capacity	Intergenerational transition compacts; green-skills missions; long-term resilience funding; nature-based solutions; lifecycle and future-impact assessments

Source: Author's elaboration drawing on Newell et al. (2023) and Blondeel et al. (2021)

In this framework, intergenerational justice is not limited to environmental preservation but also includes the temporal allocation of economic costs, infrastructure benefits, employment opportunities, and transition risks.

5.3 A territorial scorecard for the JGT

Table 4 translates the justice and vulnerability dimensions identified above into a territorial scorecard applicable at the Nomenclature of Territorial Units for Statistics level 2 (NUTS 2) or local scale. The scores do not measure territorial conditions in isolation, but assess how the interaction between pre-existing regional vulnerabilities and scenario-specific governance arrangements affects the capacity of territories to manage the transition. Higher scores therefore indicate stronger adaptive capacity, more effective policy support, and lower residual vulnerability. The values reported in Table 4 are illustrative and demonstrate how the same territorial criterion may perform differently across the four scenarios.

Table 4 – Territorial JGTs scorecard: illustrative scenario scores (1–5)

Note: S1 = competitive/centralised/efficiency-first; S2 = competitive/distributed/justice-first; S3 = co-operative/centralised/efficiency-first; S4 = co-operative/distributed/justice-first. Abbreviations: DR = demand response; FPIC = Free, Prior and Informed Consent; JT = just transition; JTM = Just Transition Mechanism; MDB = multilateral development bank; PES = public employment services; SDG = Sustainable Development Goal; SME = small and medium-sized enterprise; TSOs/DSOs = transmission system operators/distribution system operators.

Criterion	Definition	Data sources	S1	S2	S3	S4
Employment-transition resilience	Capacity to anticipate, absorb, and manage employment losses in coal, oil, gas, and energy-intensive industries	Labour stats; JTM diagnostics	2	3	3	4
Social protection & re-employment capacity	Coverage/adequacy of benefits; retraining throughput	Social funds; PES records	2	3	4	5
Energy affordability & access	Energy-poverty rate; disconnections; access to DR/efficiency	Regulator; social surveys	2	3	4	5
Participation & consent	Quality of participation; social dialogue; FPIC where applicable	Permitting records; social partners	2	4	3	5
Grid resilience & flexibility (local)	Hosting capacity; congestion; storage/DR penetration	TSOs/DSOs	3	4	4	5
Local value-addition in clean supply chains	Share local content; SME participation; clustering	Industry registries	2	3	4	5
Access to JT finance	Per-capita access to JTM/SDG/MDB funds; leverage ratios	EU/MDB datasets	2	3	4	5

Environmental co-benefit	Air quality; land restoration; biodiversity	Env. agencies	2	3	4	5

Source: Author's elaboration informed by Newell et al. (2023), Italian Climate Network (2025), UNFCCC (2025), and the whole-systems geopolitics framing developed by Kuzemko et al. (2024) and Blondeel et al. (2021).

5.3.1 Illustrative application: employment-transition resilience in Silesia

The employment-transition criterion can be illustrated through the case of the Silesian Voivodeship in Poland. In 2021, coal mining employed approximately 72,000 workers directly and a further 128,000 indirectly, together representing around 4.3 per cent of total regional employment. Direct employment in coal mining is expected to decline by approximately 12,300 jobs by 2030 and by 48,700 jobs by 2050 as the phase-out proceeds (Silesian Voivodeship, 2022). These figures indicate a high level of baseline exposure, although the territorial outcome depends on the governance and policy conditions under which restructuring occurs.

Under S1, the criterion is assigned a score of 2 because a competitive, centralised, and efficiency-first transition would provide comparatively limited scope for anticipatory retraining, economic diversification, and place-based support. Under S4, the score rises to 4: the initial employment exposure does not disappear, but co-operative governance, distributed investment, participation mechanisms, and justice-oriented funding increase the region's capacity to absorb job losses and generate alternative development pathways. The application is illustrative rather than predictive; its purpose is to show that scorecard values reflect the interaction between structural exposure and scenario-specific response capacity.

5.4 Global governance and finance: closing the gap

The finance dimension is pivotal: just transition processes require multilateral development bank (MDB) and climate-finance alignment with labour and industrial policy (e.g., high-level principles, peer learning, partnerships), otherwise rhetoric outpaces delivery; horizontal and vertical gaps persist unless global frameworks recognise distributional/procedural justice and enable national policy space (Newell et al., 2023).

COP agendas continue to stress priorities like phasing out fossil fuels and scaling clean industry (steel, hydrogen) but warn that short-term fossil intensification and subsidy lock-ins undermine credibility—hence the urgency of risk-sharing standards and just-transition finance (Climate Group, 2023).

5.5 Implications for scenarios and policy pathways

Across the scenario axes, S4 (co-operative, distributed, justice-first) yields the best robustness on territorial criteria; S1 (competitive, centralised, efficiency-first) risks under-provision of justice and coordination failures. Embedding justice metrics in permitting, funding, and standards turns justice from a constraint into a capability that reduces social and geopolitical risk.

6 Critical discussion

This section brings together the paper's strands—whole-systems geopolitics, justice, and territorial resilience—to reflect on what the scenario axes (A1–A3) imply for policy. It foregrounds three tensions: the *paradoxes* of the JGTs, the *geopoliticisation* of decarbonisation, and the need to move from risk displacement to risk-sharing architectures.

A distinction between two meanings of resilience is necessary for interpreting the scenarios. Normative resilience concerns the capacity of transition governance to preserve justice, social inclusion, territorial cohesion, and democratic legitimacy over time. Technical resilience instead concerns the operational capacity of energy systems and institutions to withstand disruption through redundancy, flexibility, storage, interconnection, and cyber-physical protection. Although analytically distinct, the two dimensions are mutually dependent: technically robust systems may remain politically fragile if their costs and benefits are distributed unequally, while normatively inclusive policies may fail if the underlying infrastructures cannot absorb geopolitical, climatic, or technological shocks (Brunetta et al., 2020; Strambo, 2020; IRENA, 2024).

6.1 Paradoxes of the JGTs: accelerating and stalling at once

Recent work argues that energy geopolitics must reckon with a live, contested transformation spanning co-evolving high- and low-emissions systems rather than a static end-state (Kuzemko et al., 2024; Blondeel et al., 2021).

This helps explain why the transition can accelerate and stall simultaneously: shocks (war, price spikes) push renewables and efficiency while also triggering short-term fossil responses and infrastructure lock-ins, which the S1 competitive/centralised setting captures. A justice lens shows further paradoxes: distributional burdens concentrate in vulnerable regions and along upstream mineral chains—even when aggregate emissions fall—unless procedural and recognitional justice are embedded ex-ante in standards, finance and permitting (Stark et al., 2023).

6.2 Geopoliticisation risks: from open markets to defensive industrial policy

In the EU, the transition is increasingly geopoliticised: trade, investment screening and industrial policy are reframed through security and dependency concerns (Herranz-Surrallés, 2024).

The A1 axis helps diagnose when this shift is prudential (diversifying real chokepoints) versus counter-productive (fragmenting co-operation). Critical-materials politics differs from fossil geopolitics: leverage clusters in processing, standards and certification, so traceability, recycling, and responsible supply are not "add-ons" but core security tools (IRENA, 2023).

In S1 (competitive), these tools risk morphing into zero-sum subsidy races; in S3–S4 (co-operative), they become risk-pooling regimes (mutual recognition, interoperable audits), which the stress-test scores favour.

Subsequent policy developments reinforce the relevance of this distinction while also showing the temporal contingency of the policy comparison. In the EU, the Clean Industrial Deal and the Affordable Energy Action Plan have further integrated decarbonisation with industrial competitiveness, energy affordability, and economic security, while the implementation of the Critical Raw Materials Act has moved from legislative design towards the designation of strategic projects and new mechanisms for supply diversification (European Commission, 2025a, 2025b, 2025c). In the United States, by contrast, the FY2025 reconciliation law significantly altered elements of the original IRA architecture by restricting major clean-electricity incentives and terminating several tax credits, including those for electric vehicles (U.S. Congress, 2025). These developments do not invalidate the scenario exercise, which stress-tests the policy frameworks as analytical configurations, but they demonstrate that transition strategies remain politically reversible and exposed to electoral and fiscal change.

6.3 Conflict spillovers and regional (in)stability

Geopolitical shocks reshape transition paths beyond energy balances. The Israel–Gaza escalation illustrates how regional insecurity can crowd out co-operative agendas (supply diversification, grid interconnection) and reprioritise short-term security expenditures, pushing systems towards S1/S2 dynamics.

More broadly, strategic fora warn that climate and energy are now arenas of power competition, so credible transition strategies must combine mitigation scale-up with mechanisms to manage disruption (Munich Security Conference, 2021).

The A2/A3 axes imply that distributed architectures and justice-first governance increase shock absorption and political legitimacy relative to centralised, efficiency-only logics.

6.4 From risk displacement to risk-sharing (what the framework implies)

Across scenarios, three design moves convert rivalry into resilience:

1. **Standards as security policy.** Build interoperable, verifiable standards (materials traceability, recycling, labour safeguards) to reduce processing bottleneck power while lifting social legitimacy along supply chains (IRENA, 2023). This advances A1 co-operation and A3 justice targets.
2. **Meshed grids and flexibility commons.** Prioritise interconnection, storage and demand-response as shared reserves, improving system adequacy under both competitive and co-operative logics, corresponding to the A2 distributed setting.

Evidence from whole-systems reviews supports coupling infrastructure with governance that spans scales (Blondeel et al., 2021).

3. **Justice-first finance.** Operationalise distributional/procedural metrics in permitting and funding (e.g., community benefit agreements; retraining conditionality), addressing the governance "gaps" that undermine just transitions at global and local levels (Stark et al., 2023).

6.5 What this means for the paper's scenarios

Read against Tables 1–2 (axes; stress-test), S4 (co-operative, distributed, justice-first) is the only setting that simultaneously reduces materials risk, strengthens grid adequacy, and builds social licence—hence its robust 4–5 scores. S1 (competitive, centralised, efficiency-first) can deliver near-term industrial competitiveness but at the cost of coordination and justice deficits, thereby raising medium-term instability risks flagged in both the academic and policy literatures (Kuzemko et al., 2024; Munich Security Conference, 2021).

Takeaway. Transition geopolitics is not simply about where resources are, but about how standards, infrastructures and justice are governed. Designing these as risk-sharing institutions—rather than risk-shifting instruments—aligns security with equity and moves trajectories from S1/S2 towards S3/S4.

7 Conclusions and policy roadmap

The article has reframed the geopolitics of the JGTs through a whole-systems lens in which energy change is a socially produced, contested co-evolution of high- and low-emissions sub-systems, rather than a linear substitution story. In that frame, leverage shifts away from fossil chokepoints toward technologies, standards and materials processing, with important consequences for statecraft and energy security: risks aggregate around processing nodes, certification regimes and the pace of grid flexibility, not only around resource endowments. This reading aligns both with the academic reassessment of energy geopolitics and with the policy turn in recent agency reports (Kuzemko et al., 2024; Blondeel et al., 2021; IRENA, 2023, 2024; Global Commission on the Geopolitics of Energy Transformation, 2019).

Read against this backdrop, the European experience since 2022 shows how decarbonisation has been securitised, re-centring industrial policy, trade/FDI screening and state aid while seeking an "open strategic autonomy" that avoids trading one dependency for another (Goldthau & Youngs, 2023).

Developments since the original research was conducted also underline the need to interpret the comparison dynamically. The EU has increasingly connected decarbonisation to industrial competitiveness, affordability, and critical-material security, whereas subsequent changes to the U.S. fiscal framework have reduced the stability of parts of the original IRA policy package. The results should therefore be read as a stress-test of two policy architectures rather than as a static assessment of their current implementation.

The scenario axes (A1 geopolitics; A2 system architecture; A3 governance norm) and the stress-test in Tables 1–2 help to interpret these dynamics comparatively. They suggest that co-operative, distributed, justice-first configurations (S4) consistently outperform competitive, centralised, efficiency-first ones (S1) on materials risk, grid adequacy and social licence, even if the latter may temporarily score higher on narrow competitiveness. In short, pathways that institutionalise coordination and equity tend to be more robust to shocks and deliver more durable legitimacy (IRENA, 2023, 2024; Kuzemko et al., 2024).

The policy implications follow directly and can be expressed without recourse to a checklist. First, standards are security policy: interoperable and mutually recognised rules for materials traceability, recycling, and labour-environmental safeguards reduce the geopolitical value of bottlenecks and lift the legitimacy of supply chains; they also turn transatlantic rivalry into risk-pooling when accompanied by equivalence and joint audit mechanisms (IRENA, 2023; Global Commission on the Geopolitics of Energy Transformation, 2019).

Second, meshed grids and flexibility commons—interconnections, storage and demand response operated as shared reserves—translate cooperation into tangible system resilience and make systems with high shares of renewable energy governable across borders (IRENA, 2024).

Third, critical-materials strategies work when diversification is coupled with circularity mandates and responsible mining partnerships that create local value addition rather than re-inscribing extractive asymmetries (IRENA, 2023).

Finally, justice needs to be designed ex-ante—as distributional and procedural criteria embedded in permitting and funding—so that social consent becomes a capability, not an afterthought; closing the persistent gaps between global rhetoric and territorial delivery requires aligning climate and development finance with these outcomes (Kuzemko et al., 2024; IRENA, 2024).

For the EU, this implies that security and transitions are co-produced: strategic autonomy depends as much on standards, meshed infrastructures and justice-first finance as on the geography of fuels. A pragmatic “open strategic autonomy” would therefore combine targeted state aid with standard-based cooperation—particularly with the United States and resource-rich partners—to avoid subsidy races, duplicate compliance, and new dependencies, while delivering credible value-sharing along supply chains (Goldthau & Youngs, 2023; IRENA, 2024).

Two limits of this approach should be clear. Data heterogeneity on minerals, grid flexibility and labour outcomes constrains tight cross-territorial scoring, and the axes are deliberately parsimonious, leaving room to test hybrid configurations and shock sequences. A near-term research agenda would standardise indicators for justice and territorial vulnerability, evaluate standard-equivalence regimes in batteries/PV, and compare interconnector projects as risk-sharing institutions—each a concrete next step to consolidate the analytical and policy gains proposed here (IRENA, 2024; Global Commission on the Geopolitics of Energy Transformation, 2019).

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Appendix A — Methods and Replication Materials

This appendix provides: (A1) variables with operational definitions, indicators and thresholds; (A2) the cross-impact matrix (M×M) with fixed values c_{ij}; (A3) mandatory rules for uncertainty tagging. Abbreviations: CRM = critical raw materials; DR = demand response; ESG = environmental, social and governance; HHI = Herfindahl-Hirschman Index; RES = renewable energy sources; SRC = source; VRES = variable renewable energy sources; WACC = weighted average cost of capital.

A1. Variables — operational definitions, indicators, thresholds

Code	Variable	Operational definition	Core indicators (brief)	Thresholds (baseline)
V1	Industrial competitiveness & supply security	Ability to ensure secure supply at competitive costs for strategic/energy-intensive sectors.	(i) Median annual wholesale power price (€/MWh); (ii) Gas import price index; (iii) Capacity margin = (available cap − peak)/peak; (iv) RES curtailment = non-dispatched RES/RES generation.	High if: price ≤ 100 €/MWh and margin ≥ 15% and curtailment ≤ 5%.
V2	Distributional justice & affordability	Fair distribution of transition costs/benefits across income groups and regions.	(i) Energy-poverty (% households); (ii) Median bill-to-income ratio; (iii) Coverage of targeted subsidies (% eligible households).	High if: energy-poverty ≤ 8% and bill/income ≤ 6% and coverage ≥ 70%.
V3	Critical raw materials (CRM) availability	Availability/diversification/sustainability of CRMs for RES-storage-manufacturing.	(i) Import concentration (HHI); (ii) Recycling rate (%); (iii) Permitting lead-time (months); (iv) ESG/supply risk score.	High if: HHI ≤ 0.25 and recycling ≥ 25% and lead-time ≤ 24 months.
V4	System flexibility & grid integration	Ability to balance VRES via grid, storage, demand response, and interconnections.	(i) Flexible-to-peak ratio; (ii) Installed storage hours (h*MW/peak); (iii) Interconnection (% of peak); (iv) DR enrolled (MW/peak).	High if: flex/peak ≥ 0.25 and interconnection ≥ 15% and storage ≥ 6 h.
V5	Investment flows & policy credibility	Scale/stability of low-carbon investments and credibility of policy signals.	(i) Low-carbon investment (bn €/year); (ii) WACC for RES (%); (iii) Auction subscription rate (%).	High if: investment growth ≥ 10% y/y and WACC ≤ 6% and subscription ≥ 100%.
V6	Public acceptance & procedural justice	Social consent grounded in participation, transparency, fair siting/compensation.	(i) Average permitting time (months); (ii) Share of projects appealed (%); (iii) Community-benefit agreements (#/MW).	High if: permitting ≤ 12 months and appeals ≤ 10% and ≥ 0.05 agreements/MW.

Method note: if a core indicator is missing, adopt the best national/regional proxy, record it under SRC (A3) and assign confidence 2 until multi-source validation is available.

A2. Cross-impact matrix (final values)

Scale: (-2) strong negative; (-1) weak negative; (0) none/uncertain; (+1) weak positive; (+2) strong positive.

Notation: (c_{ij}) = impact of variable i (row) on j (column). Diagonals are blank.

(c_{ij}) (row → col)	V1 Comp.	V2 Justice	V3 CRM	V4 Flex	V5 Invest	V6 Accept
V1 Competitiveness		0	+1	−1	+2	+1
V2 Justice	−1		0	+1	+1	+2
V3 CRM	+1	0		+1	+1	0

(c_{ij}) (row → col)	V1 Comp.	V2 Justice	V3 CRM	V4 Flex	V5 Invest	V6 Accept
V4 Flexibility	+2	+1	+1		+2	+1
V5 Investment	+1	+1	+1	+2		+1
V6 Acceptance	0	+2	0	+1	+1	

Built-in consistencies:
V4→V1 = +2 (flexibility cuts spreads/curtailment → competitiveness); V1→V4 = −1 (short-term cost pressure can delay flexibility capex); V6→V5 = +1 and V2→V6 = +2 (procedural justice → acceptance → lower auction risk); CRM linkages to Flex/Invest are weak-positive (+1).

This matrix is the official baseline used in the paper; later updates should be versioned (A2-v2, A2-v3, ...).

A3. Uncertainty tagging — mandatory rules

Every matrix cell and every A1 classification ("High/Medium/Low") must carry complete tags.

A3.1 Fields and codes

Field	Code	Rule
Evidence type	E = empirical; X = expert; C = conjectural	Preference for E. If X, use ≥3 experts (median). If C, specify horizon-scanning source.
Confidence	1 / 2 / 3	3 = multi-source or ≥3-year series; 2 = single solid source or partial triangulation; 1 = scarce/heterogeneous data.
Provenance (SRC)	short code + date	e.g., SRC=ENTSOE_CAPPLAN2025 (2025-07-10); SRC=Delphi_R1 (2025-06-15). Mandatory.
Justification (TXT)	≤200 characters	One-sentence causal mechanism for sign/magnitude (no bibliography here).

A3.2 Binding examples

- Cell (V4 → V1) = +2 — Tag: E,3; SRC=ENTSOE_CAPPLAN2025 (2025-07-10); TXT=Interconnectors/storage cut curtailment and price spreads → higher competitiveness.
- Cell (V1 → V4) = −1 — Tag: X,2; SRC=Delphi_R1 (2025-06-15); TXT=Short-term cost pressure can delay flexibility investments.
- V2 = High (A1) — Tag: E,3; SRC=EUROSTAT_SILC2024 (2025-05-30); TXT=Energy-poverty ≤8%, bill/income ≤6%, targeted-subsidies ≥70%.

A3.3 Operational rules

1. Versioning: any change to (c_{ij}) or A1 indicators creates a new time-stamped version.
2. Triangulation: where E is not available, combine X (≥3 experts) with C (≥2 coherent weak signals).
3. Thresholds: A1 thresholds are binding for this baseline; for local case-studies they may be tuned, tagged with SRC, and kept at confidence 2 until validated.
4. Consistency: document strong asymmetries (e.g., (V4 → V1 = +2) vs (V1 → V4 = −1)) in TXT.
5. Reproducibility: keep a spreadsheet with the (6 × 6) matrix, tags per cell, and A1 indicators (not included here).