

Who Bears the Burden? Deconstructing Regional Vulnerability to the Green Transition

by Federico Bartalucci, Maria Abreu, Andrés Rodríguez-Pose

The transition to climate neutrality represents one of the most profound structural transformations in contemporary European history. Anchored in the European Green Deal and the legally binding objective of net-zero emissions by 2050, decarbonisation entails far-reaching changes in industrial production, labour markets, infrastructure, energy systems, and governance. While the long-term aggregate benefits of climate action are widely acknowledged, the short- and medium-term costs of transition are unevenly distributed across space. Some regions are well positioned to capture new growth opportunities in green industries, renewable energy, and clean technologies, while others face industrial contraction, labour-market disruption, fiscal strain, and heightened political resistance. Understanding who bears the burden of Europe's green transition therefore requires a territorial perspective that goes beyond sectoral or national aggregates and examines how structural pressures interact with local socio-economic conditions and institutional capacities.

This paper develops and applies a multidimensional Regional Green Transition Vulnerability Index (RGT-VI) for European NUTS-2 regions, grounded in the interactionist framework advanced by the Intergovernmental Panel on Climate Change (IPCC). Rather than equating vulnerability with industrial exposure alone, the RGT-VI conceptualises vulnerability as the joint outcome of three distinct yet interrelated pillars: exposure to decarbonisation pressures, socio-economic sensitivity that amplifies or dampens their effects, and adaptive capacity that enables regions to adjust, reorganise, and renew. Exposure captures structural dependence on carbon-intensive sectors such as fossil-fuel extraction, energy-intensive manufacturing, transport, and emissions-intensive agriculture. Sensitivity reflects underlying demographic, labour-market, and social fragilities, including ageing populations, unemployment, poverty risks, low productivity, and persistent development traps. Adaptive capacity encompasses human capital, innovation ecosystems, governance quality, infrastructure, and environmental conditions that shape the ability of regions to convert transition pressures into opportunities for renewal. By integrating these dimensions within a single analytical architecture, the RGT-VI moves beyond exposure-based assessments and provides a more comprehensive and policy-relevant understanding of regional transition risk.

The composite index reveals substantial and uneven variation in vulnerability across Europe (Figure 1). High-vulnerability regions cluster predominantly in Southern and Eastern Europe,

including parts of Romania, Bulgaria, Greece, southern Italy, and several Iberian regions. These territories combine socio-economic fragility and limited adaptive capacity with, in some cases, significant exposure to climate-related and structural transition pressures. A second belt of vulnerability is visible across industrial regions of Central and Eastern Europe, particularly in Poland, Czechia, and Slovakia, where carbon-intensive industries remain deeply embedded in regional production systems. By contrast, many regions in Northern and Western Europe display lower overall vulnerability, especially those characterised by diversified economic structures, strong innovation systems, and high-quality governance. Yet vulnerability does not align neatly with national borders. Within otherwise prosperous countries, pockets of elevated vulnerability persist, reflecting the localised nature of industrial dependence, demographic decline, or institutional weakness. A pronounced metropolitan effect cuts across these patterns: capital cities and major urban centres consistently exhibit lower vulnerability than surrounding territories, even within high-risk countries. Transition readiness thus appears fundamentally regional rather than national in character.

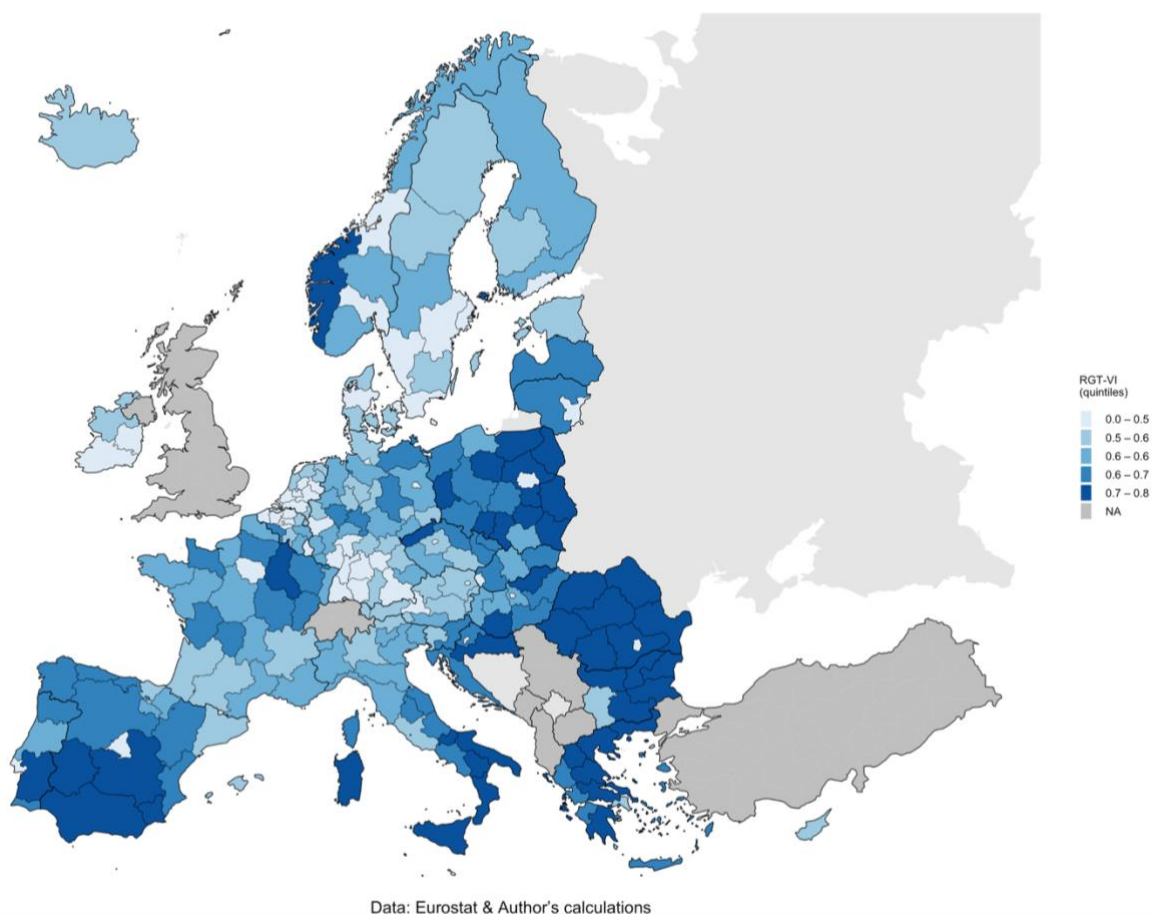


Figure 1 Regional Green Transition Vulnerability Index (RGT-VI) across European NUTS-2 regions (quintiles), min-max scores.

Source: Authors' elaboration.

Disaggregating the index reveals that the three pillars capture distinct geographies and drivers of vulnerability. Exposure is highest in regions structurally dependent on heavy industry, fossil-fuel extraction, and energy-intensive manufacturing. Central and Eastern European coal and steel regions stand out, but high exposure is not confined to lower-income territories. Norwegian regions dependent on oil and gas, as well as advanced industrial hubs in Scandinavia and Western Europe, also display elevated structural exposure. Sensitivity, however, follows a different pattern. Southern Europe and parts of Eastern and South-Eastern Europe record the highest levels of socio-economic fragility, driven by ageing populations, outmigration of younger cohorts, labour-market weaknesses, and persistent poverty risks. Several regions with relatively limited industrial exposure nonetheless exhibit high sensitivity, demonstrating that socio-demographic fragility constitutes an independent pathway to vulnerability. Adaptive capacity, in turn, displays a strong core–periphery gradient. Regions with high educational attainment, dense innovation ecosystems, effective governance, and robust infrastructure—typically metropolitan centres and diversified industrial hubs—are better positioned to anticipate and manage structural change. Conversely, peripheral regions with weaker institutions, thinner labour markets, and limited research and development investment exhibit lower adaptive potential, even where exposure is moderate.

Importantly, the three pillars are not redundant. Pairwise analysis shows only weak to moderate correlations among exposure, sensitivity, and adaptive capacity. This empirical independence justifies the multidimensional approach. A moderate positive association between exposure and sensitivity suggests that regions facing stronger decarbonisation pressures often also exhibit socio-economic fragility, creating a “double burden” particularly visible in Eastern Europe. A negative relationship between exposure and adaptive capacity indicates that historically carbon-dependent regions frequently lack the institutional and innovation resources required for rapid adjustment, consistent with the notion of transition traps. Yet these relationships are far from deterministic. Several Northern and Western European regions combine high exposure with strong adaptive capacity, illustrating that institutional quality and innovation strength can buffer structural pressures. The multidimensional architecture of the RGT-VI thus captures qualitatively different configurations of risk that would be obscured in exposure-only frameworks.

To further explore these configurations, the paper applies k-means clustering to the three pillar scores, identifying five distinct vulnerability archetypes (Figure 2). The first group, exposed and structurally constrained regions, combines high exposure, high sensitivity, and weak adaptive capacity. Concentrated in Central and Eastern Europe and parts of Northern Italy, these territories face compound vulnerability, where carbon-intensive industrial legacies intersect with demographic fragility and institutional constraints. For them, the green transition poses a profound structural challenge requiring coordinated industrial diversification, workforce retraining, and governance strengthening. The second group, sensitivity-driven vulnerable regions, is characterised by low exposure but high socio-economic fragility and limited adaptive capacity. Predominantly located in Southern Europe, these regions are not heavily industrial but struggle with ageing, outmigration, and weak labour markets. Their vulnerability stems less from coal or heavy industry phase-outs than from deep-seated structural disadvantages. The third group, capacity-constrained regions, displays moderate sensitivity and low adaptive capacity despite limited exposure. Spread across parts of France, inland Spain, the Baltic states, and Central Europe, these territories risk being bypassed by the transition, lacking the institutional and innovation assets needed to attract green investment. The fourth group, exposed but resilient regions, combines high exposure with low sensitivity and strong adaptive capacity. Found in Scandinavia, southern Germany, Austria, and parts of the Netherlands, these regions demonstrate that high industrial exposure does not automatically translate into high vulnerability when governance and innovation systems are robust. Finally, transition-ready metropolitan regions exhibit low exposure, low sensitivity, and strong adaptive capacity. Capital regions and major urban hubs fall into this category, positioning them to capture disproportionate shares of green investment and innovation.

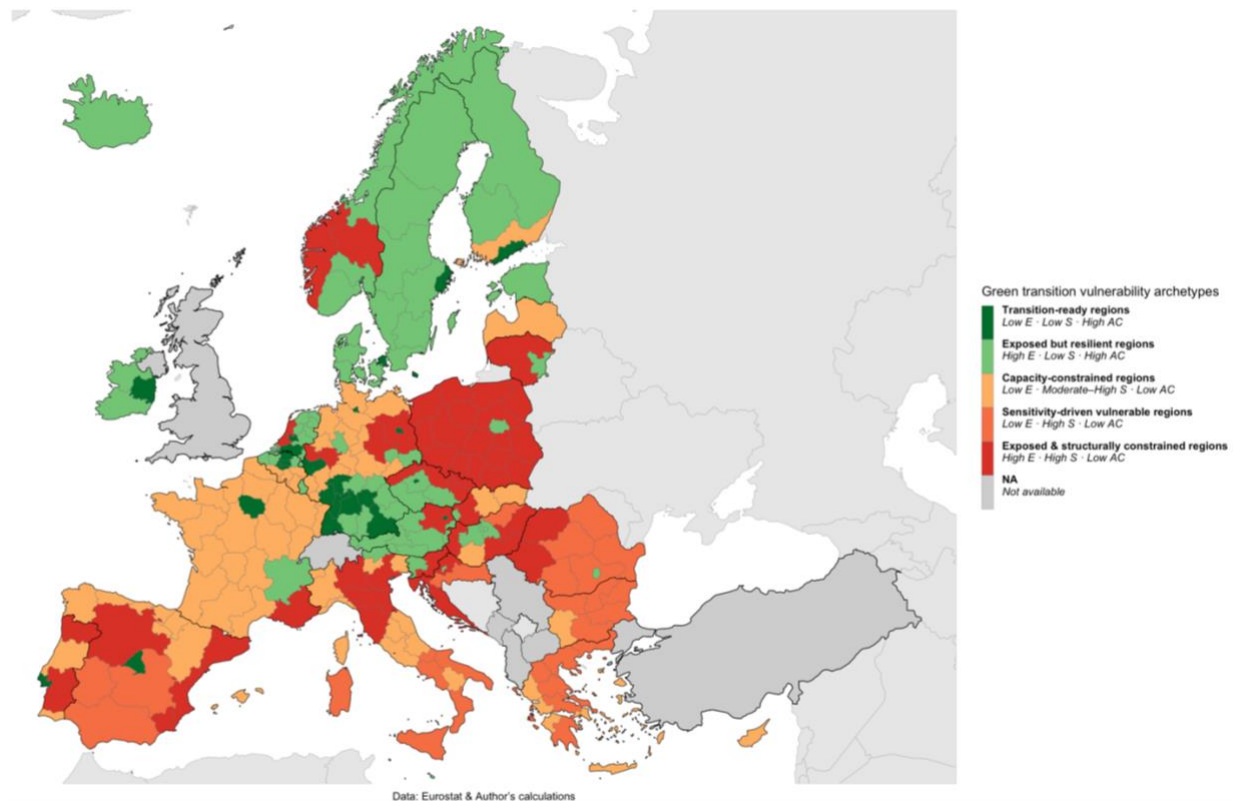


Figure 2 Green transition vulnerability archetypes across European NUTS-2 regions.

Note: Archetypes are derived through k-means clustering on the three standardised pillar scores.

Labels indicate the dominant pillar profile for each cluster.

Source: Authors' calculations.

These archetypes underscore that similar composite vulnerability scores can arise from fundamentally different structural conditions. A coal-dependent region facing demographic decline and weak governance requires a different policy mix from a rural region experiencing ageing and outmigration but limited industrial exposure. Uniform policy instruments are therefore ill-suited to the heterogeneity revealed by the RGT-VI. The findings carry important implications for European cohesion and just transition policies. Current targeting mechanisms under the Just Transition Mechanism rely heavily on exposure indicators, such as coal employment. While such criteria capture acute industrial phase-out challenges, they overlook regions where socio-economic sensitivity and weak adaptive capacity generate comparable vulnerability. Moreover, the spatial distribution of adaptive capacity raises concerns about the geography of green investment. Regions already endowed with strong institutions and innovation ecosystems are better positioned to attract renewable energy projects, clean-tech manufacturing, and research funding. Without deliberate territorial balancing, the transition

may concentrate opportunities in already prosperous regions while imposing adjustment costs on disadvantaged territories, exacerbating existing inequalities and fuelling political discontent.

In sum, the green transition is not only a technological and environmental transformation but also a deeply spatial and institutional one. By integrating exposure, sensitivity, and adaptive capacity into a unified analytical framework, the RGT-VI provides a more complete understanding of regional vulnerability across Europe. The evidence suggests that vulnerability is highly uneven, multidimensional, and structured by distinct regional archetypes. Recognising and addressing this heterogeneity is essential to ensuring that decarbonisation contributes not only to climate mitigation but also to territorial cohesion and social equity. Without such place-sensitive strategies, there is a risk that the green transition becomes another driver of regional divergence rather than a catalyst for more balanced and inclusive European development.