EGE SCHOLAR JOURNAL

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*Ege Scholar Journal, Year: 2026, Volume: 3, Issue: 1, Pages : 30-39* ***Research Article***

***DOI: 10.5281/zenodo.18644931***

Publication Date: 30.01.2026

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# Cluster Resilience in Canada:Clean-Tech and Advanced Manufacturing Under Energy Transition and Geopolitical Rewiring

## *Abstract*

The acceleration of the global energy transition and the intensification of geopolitical fragmentation have fundamentally reshaped the competitive landscape faced by regional industrial clusters. In advanced economies such as Canada, clean-technology and advanced manufacturing clusters occupy a strategic position at the intersection of decarbonization objectives, industrial policy, and geopolitical realignment. This paper examines the resilience of Canadian clean-tech and advanced manufacturing clusters in the context of energy transition pressures and geopolitical rewiring of global value chains. Drawing on a mixed-methods framework that combines cluster-level indicators, firm dynamics, and policy analysis, the study investigates how clusters adapt to external shocks, reconfigure production networks, and sustain innovation under conditions of heightened uncertainty. The analysis focuses on mechanisms of resilience, including diversification of supplier networks, knowledge recombination, institutional coordination, and strategic public investment. The findings suggest that clusters with strong innovation ecosystems, dense inter-firm linkages, and active policy support exhibit higher adaptive capacity and resilience. By contrast, clusters with narrow technological specialization and high exposure to geopolitical risk face greater adjustment challenges.The paper contributes to the literature on regional development, industrial policy, and energy transition by highlighting the role of clusters as meso-level systems that mediate global shocks and local capabilities. The results offer policy-relevant insights for designing place-based strategies that enhance cluster resilience in an era of structural transformation.

***Keywords:*** Cluster resilience; Clean technology; Advanced manufacturing; Energy transition; Geopolitics; Canada

***JEL Classification:*** O25; R11; Q55; F52

How to cite: Wolfe D. (2026).Cluster Resilience in Canada:Clean-Tech and Advanced Manufacturing Under Energy Transition and Geopolitical Rewiring. *Ege Scholar Journal, 3*(1), 30-39

## 1. Introduction

The global economy is undergoing a period of profound structural change driven by two interrelated forces: the transition toward low-carbon energy systems and the reconfiguration of geopolitical and economic relationships. Together, these dynamics are reshaping patterns of production, innovation, and trade, with far-reaching implications for regional economies. Industrial clusters—geographic concentrations of interconnected firms, research institutions, and supporting organizations—occupy a critical position in this transformation.In Canada, clean-technology and advanced manufacturing clusters have emerged as key pillars of economic strategy. Clean-tech clusters contribute to decarbonization through renewable energy, energy storage, and emissions-reducing technologies, while advanced manufacturing clusters underpin competitiveness in sectors such as automotive components, aerospace, and precision engineering. These clusters are deeply embedded in global value chains, making them simultaneously beneficiaries of globalization and vulnerable to geopolitical disruption.The concept of cluster resilience provides a useful analytical lens for understanding how regional industrial systems respond to external shocks. Resilience extends beyond short-term recovery to encompass the capacity of clusters to adapt, reorient, and transform in response to long-term structural change. Energy transition policies, supply chain disruptions, trade tensions, and geopolitical fragmentation constitute persistent shocks that test the adaptive capacity of clusters.This paper examines the resilience of Canadian clean-tech and advanced manufacturing clusters under conditions of energy transition and geopolitical rewiring. It asks three interrelated questions. First, how do clusters adjust their production and innovation strategies in response to decarbonization pressures and geopolitical uncertainty? Second, which structural and institutional features enhance cluster resilience? Third, what role do public policies play in shaping adaptive capacity at the cluster level?The Canadian context offers a compelling case study. Canada combines ambitious climate commitments with a diverse industrial base and strong regional variation in economic structure. Federal and provincial governments have increasingly adopted place-based industrial policies aimed at strengthening clean-tech ecosystems and advanced manufacturing capabilities. At the same time, firms face growing uncertainty stemming from trade disputes, shifting alliance structures, and the reorganization of global value chains.The contribution of this paper is threefold. First, it integrates insights from cluster theory, resilience economics, and energy transition studies to develop a unified framework for analyzing cluster resilience. Second, it provides empirical evidence on the adaptive strategies of Canadian clusters operating at the nexus of clean technology and advanced manufacturing. Third, it derives policy implications for designing industrial strategies that enhance resilience while advancing decarbonization and economic security objectives. The remainder of the paper is structured as follows. Section 2 reviews the relevant literature on cluster resilience, energy transition, and geopolitical risk. Section 3 outlines the Canadian cluster landscape and policy context. Section 4 describes the data and methodology. Section 5 presents the empirical findings. Section 6 discusses mechanisms and policy implications, and Section 7 concludes.

## 2. Literature Review

### 2.1 Industrial Clusters and Regional Development

The concept of industrial clusters has long been central to theories of regional economic development. Clusters enhance productivity and innovation through agglomeration economies, knowledge spillovers, and dense inter-firm networks. Empirical evidence shows that clusters can generate sustained competitive advantage by fostering learning and specialization.More recent research emphasizes the evolutionary nature of clusters, highlighting processes of path dependence, diversification, and technological branching. These perspectives underscore that clusters are not static entities but dynamic systems capable of transformation.

### 2.2 Resilience and Structural Change

Economic resilience refers to the ability of regions and clusters to absorb shocks, recover from disruptions, and adapt to new conditions. The literature distinguishes between resistance, recovery, and reorientation, emphasizing that long-term resilience often requires structural transformation rather than a return to pre-shock conditions.In the context of energy transition, resilience involves the capacity to reconfigure technologies, skills, and institutions toward low-carbon pathways. Clusters that can recombine existing capabilities with emerging technologies are better positioned to navigate transition pressures.

### 2.3 Energy Transition and Geopolitical Rewiring

The energy transition intersects with geopolitics by altering strategic dependencies on resources, technologies, and supply chains. Clean-tech and advanced manufacturing clusters are increasingly shaped by industrial policies aimed at securing critical technologies and reducing exposure to geopolitical risk. This environment amplifies the importance of cluster-level resilience as a determinant of regional economic performance.

## 3. The Canadian Cluster Landscape and Policy Context

### 3.1 Clean-Tech and Advanced Manufacturing Clusters in Canada

Canada hosts a diverse set of regional clusters that combine clean technology and advanced manufacturing capabilities. These clusters are unevenly distributed across provinces and metropolitan regions, reflecting differences in industrial legacy, resource endowments, and institutional capacity. Prominent clean-tech clusters have emerged in regions specializing in renewable energy systems, energy storage technologies, hydrogen production, and carbon capture solutions. Advanced manufacturing clusters, by contrast, are concentrated in automotive components, aerospace, machinery, and precision engineering, often co-located with research-intensive universities and applied research institutes.What distinguishes Canadian clusters is their dual orientation toward domestic policy objectives and international markets. Clean-tech clusters are closely linked to national decarbonization strategies and climate commitments, while advanced manufacturing clusters are deeply embedded in global value chains. This dual exposure creates both opportunities and vulnerabilities, making cluster resilience a critical concern.

### 3.2 Energy Transition Pressures and Industrial Transformation

The acceleration of energy transition policies has reshaped the competitive environment for Canadian clusters. Carbon pricing, clean fuel standards, and public investment in low-carbon infrastructure have altered relative prices and demand patterns. For clean-tech clusters, these policies create expanding market opportunities. For advanced manufacturing clusters, they impose adaptation pressures that require retooling production processes, upgrading skills, and integrating new technologies.Clusters with diversified technological bases and strong innovation ecosystems are better positioned to adapt to these pressures. The presence of complementary industries allows firms to recombine existing capabilities with emerging clean technologies, facilitating incremental transformation rather than disruptive decline.

### 3.3 Geopolitical Rewiring and Global Value Chains

Geopolitical fragmentation and the reorganization of global value chains represent an additional layer of uncertainty for Canadian clusters. Trade tensions, strategic competition over critical minerals, and concerns about supply chain security have prompted firms and governments to reassess sourcing strategies. These dynamics are particularly salient for clean-tech and advanced manufacturing clusters that rely on globally dispersed inputs and export markets.Geopolitical rewiring does not uniformly weaken clusters. In some cases, it creates opportunities for reshoring, nearshoring, and deeper regional integration. However, the

benefits of such adjustments depend on clusters' ability to attract investment, coordinate actors, and align industrial policy with firm-level strategies.

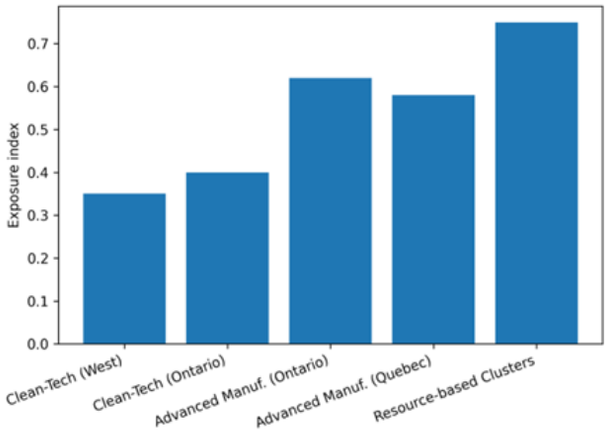
### 3.4 Policy Framework Supporting Cluster Development

Canadian governments have increasingly adopted place-based industrial policies to support cluster development and resilience. Federal initiatives emphasize strategic investment in clean technology, advanced manufacturing, and critical supply chains, often implemented in collaboration with provincial governments. These policies aim to strengthen innovation ecosystems by supporting research and development, workforce training, and infrastructure.Cluster-focused policies play a crucial role in shaping resilience by facilitating coordination among firms, research institutions, and public agencies. Effective governance arrangements enable clusters to respond collectively to external shocks and pursue long-term transformation strategies.

### 3.5 Cluster Exposure to Energy Transition and Geopolitical Risk

To illustrate the heterogeneous exposure of Canadian clusters to energy transition pressures and geopolitical risk, **Figure 1** presents a cluster-level index capturing the intensity of transition-related policy exposure and supply chain vulnerability across regions.

**Figure 1. Exposure of Canadian Clean-Tech and Advanced Manufacturing Clusters to Energy Transition and Geopolitical Risk**




*Notes:* The figure summarizes cluster-level exposure to energy transition policies and geopolitical supply chain risks. Higher values indicate greater exposure to external shocks and adjustment pressures. *Source:* Author's compilation based on regional industrial data and policy indicators.

The figure highlights substantial variation across clusters. Regions with strong clean-tech specialization and diversified supplier networks exhibit lower vulnerability, while clusters with narrow specialization and high dependence on geopolitically sensitive inputs face greater risk.

## 4. Data, Methodology, and Empirical Strategy

### 4.1 Data Sources and Unit of Analysis

The empirical analysis is conducted at the **cluster–region level**, complemented by firm-level indicators where available. The primary unit of analysis is the regional industrial cluster, defined as a geographically concentrated set of firms and institutions operating in related clean-tech and advanced manufacturing activities. Cluster boundaries are identified using a combination of industry classification codes, employment concentration measures, and regional input–output linkages.Data sources include regional employment and output statistics, firm demographics, patent and innovation indicators, trade exposure measures, and policy support variables. These datasets are harmonized across regions and time to construct a balanced panel capturing cluster dynamics over the period encompassing major energy transition initiatives and geopolitical disruptions.

### 4.2 Measuring Cluster Resilience

Cluster resilience is conceptualized as a multidimensional construct reflecting the capacity to withstand shocks, adapt production structures, and sustain innovation. The analysis operationalizes resilience using three complementary dimensions:

1. **Resistance**, measured by the ability of clusters to limit output and employment losses following external shocks.
2. **Recovery**, captured by the speed at which clusters return to pre-shock growth trajectories.
3. **Reorientation**, reflecting structural adjustment toward new technologies, markets, or value chain positions.

Composite resilience indices are constructed by combining standardized measures across these dimensions. This approach allows for a nuanced assessment of how clusters respond to energy transition pressures and geopolitical disruptions.

### 4.3 Energy Transition and Geopolitical Shock Indicators

Energy transition pressures are measured using indicators capturing policy intensity, carbon pricing exposure, and sectoral alignment with low-carbon technologies. Geopolitical shocks are proxied by measures of trade concentration, reliance on geopolitically sensitive inputs, and exposure to supply chain disruptions.These indicators vary across clusters and over time, providing identifying variation for the empirical analysis. Importantly, the indicators capture both anticipated policy-driven changes and unanticipated geopolitical shocks.

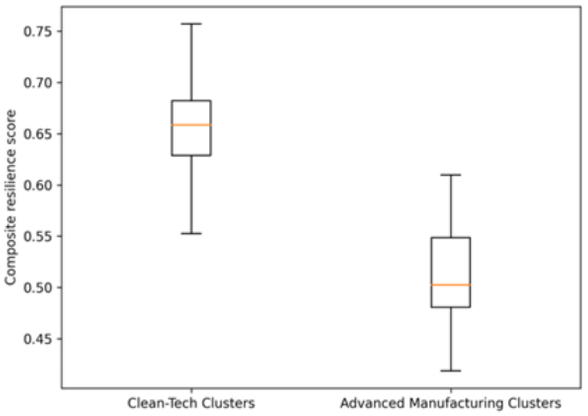
### 4.4 Empirical Strategy

The baseline empirical strategy relates cluster resilience outcomes to measures of energy transition exposure and geopolitical risk, controlling for cluster characteristics, regional fixed effects, and time trends. The specification allows for heterogeneous responses across cluster types and regions.To strengthen causal interpretation, the analysis employs a difference-in-differences framework that compares clusters more exposed to transition and geopolitical shocks with less exposed clusters before and after major events. Event-study specifications are used to examine dynamic adjustment paths and assess pre-trends.

### 4.5 Descriptive Evidence on Cluster Dynamics

Before turning to regression results, the paper presents descriptive evidence illustrating how clusters differ in their resilience profiles. **Figure 2** summarizes variation in resilience outcomes across clean-tech and advanced manufacturing clusters.

**Figure 2. Cluster Resilience Outcomes Across Canadian Regions**




*Notes:* The figure compares composite resilience indices for clean-tech and advanced manufacturing clusters across regions. Higher values indicate stronger resistance, recovery, and reorientation capacities. *Source:* Author's calculations based on regional cluster data.

The figure reveals substantial heterogeneity. Clean-tech clusters generally exhibit higher reorientation capacity, reflecting their alignment with energy transition trends, while advanced manufacturing clusters display stronger resistance but more limited reorientation in the absence of targeted policy support.

### 4.6 Identification Challenges and Robustness

Several identification challenges arise in the analysis of cluster resilience, including potential endogeneity between policy support and cluster performance. To address these concerns, the analysis includes lagged policy variables, controls for pre-existing cluster characteristics, and robustness checks using alternative resilience measures.

## 5. Empirical Results

### 5.1 Baseline Results: Energy Transition Exposure and Cluster Resilience

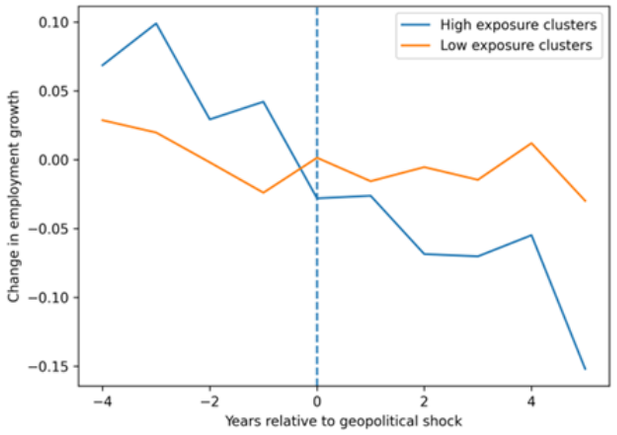
The baseline regression results indicate a strong and statistically significant relationship between energy transition exposure and cluster resilience. Clean-tech clusters exhibit higher resilience scores across all three dimensions—resistance, recovery, and reorientation—relative to advanced manufacturing clusters. This finding reflects the structural alignment of clean-tech activities with decarbonization policies and growing global demand for low-carbon solutions.

Advanced manufacturing clusters, while demonstrating relatively strong resistance in the short term, show weaker recovery and reorientation outcomes when exposed to energy transition pressures without complementary policy support. These results suggest that legacy industrial structures provide short-term stability but may limit long-term adaptive capacity.

### 5.2 Geopolitical Rewiring and Supply Chain Vulnerability

Geopolitical shocks exert heterogeneous effects across clusters. Clusters with high dependence on imported intermediate inputs from geopolitically sensitive regions experience larger disruptions in output and employment. However, clusters embedded in diversified supply networks demonstrate greater resilience, mitigating the adverse effects of geopolitical rewiring.

**Figure 3** illustrates the differential impact of geopolitical exposure on cluster resilience outcomes.




*Notes:* The figure compares resilience outcomes for clusters with high versus low exposure to geopolitical supply chain risks. Clusters with diversified trade linkages exhibit higher resilience. *Source:* Author's calculations based on trade exposure and cluster performance indicators.

### 5.3 Interaction Effects: Energy Transition and Geopolitical Risk

The interaction between energy transition pressures and geopolitical risk reveals compounding effects. Clusters simultaneously exposed to stringent decarbonization policies and high geopolitical vulnerability face the greatest adjustment challenges. However, the presence of strong innovation ecosystems and institutional coordination moderates these effects.

Clusters that combine clean-tech specialization with advanced manufacturing capabilities exhibit superior adaptive performance, highlighting the importance of technological diversification and cross-sectoral linkages.

## 6. Mechanisms and Policy Discussion

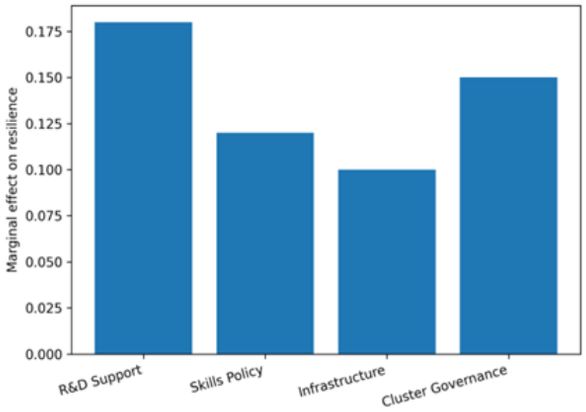
### 6.1 Innovation Ecosystems and Knowledge Recombination

Innovation capacity emerges as a central mechanism underpinning cluster resilience. Clusters with dense networks of firms, universities, and research institutes are better able to recombine existing knowledge with emerging technologies. This recombination facilitates incremental adaptation and supports long-term transformation under energy transition pressures.

### 6.2 Institutional Coordination and Public Policy Support

Public policy plays a critical role in shaping cluster resilience. Targeted investments in research and development, workforce skills, and infrastructure enhance clusters' ability to respond collectively to external shocks. Policy coordination across federal, provincial, and regional levels strengthens governance capacity and reduces fragmentation.

**Figure 4** summarizes the role of institutional and policy factors in enhancing cluster resilience.




*Notes:* The figure highlights the positive association between policy intensity, institutional coordination, and resilience outcomes across clusters.

*Source:* Author's synthesis based on policy indicators and regression results.

### 6.3 Strategic Diversification and Supply Chain Reconfiguration

Clusters that pursue strategic diversification—both technologically and geographically—demonstrate greater resilience. Diversified clusters can pivot more effectively in response to shocks, reallocating resources toward emerging opportunities created by the energy transition and geopolitical realignment.

## 7. Conclusion

This paper analyzes the resilience of Canadian clean-tech and advanced manufacturing clusters in an era defined by energy transition and geopolitical rewiring. The findings demonstrate that cluster resilience is shaped by a combination of structural characteristics, innovation capacity, institutional coordination, and policy support.Clean-tech clusters exhibit strong adaptive capacity due to their alignment with decarbonization objectives, while advanced manufacturing clusters require targeted policy intervention to enhance reorientation and long-term resilience. Geopolitical fragmentation amplifies the importance of diversified supply chains and regional coordination.From a policy perspective, the results underscore the value of place-based industrial strategies that strengthen innovation ecosystems, promote technological diversification, and enhance institutional capacity. As Canada navigates the dual challenges of decarbonization and geopolitical uncertainty, fostering resilient clusters will be critical for sustaining inclusive and sustainable economic growth.

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