A Clusterwise Approach to Digital and Ecological Transitions of European regions

Introduction

In recent years, the interconnected domains of digitalization and ecological preservation have emerged as critical factors in fostering sustainable and inclusive regional development. The increasing role of artificial intelligence (AI) in driving economic growth and innovation has coincided with an urgent need for strategies that mitigate environmental degradation. European regions, characterized by diverse economic structures, policy frameworks, and infrastructural capacities, exhibit significant variations in their ability to integrate digital and ecological transitions effectively. This paper investigates these dynamics using a Clusterwise methodological approach at the NUTS2 level, aiming to identify regional patterns that reflect the intersection of digital readiness and ecological commitment.

By examining the disparities and commonalities across regions, the study provides a nuanced understanding of how technological and environmental imperatives interact to shape resilience, sustainability, and territorial equity. Furthermore, the research aligns with the broader theme of the 64th ERSA Congress, "Regional Science in Turbulent Times: In Search of a Resilient, Sustainable and Inclusive Future," by addressing the pressing challenges that contemporary European regions face, including economic disruptions, social inequalities, and environmental vulnerabilities.

Digitalization and Ecological Transition in Regional Development

The Role of AI in Regional Economies

Artificial intelligence has become a transformative force across various industries, influencing productivity, labor markets, and decision-making processes. In regional economies, AI applications range from smart infrastructure and predictive analytics to automation in manufacturing and digital public services. The potential benefits of AI-driven advancements include increased efficiency, cost reductions, and enhanced sustainability through optimized resource management. However, the extent to which regions can harness AI technologies is contingent upon factors such as investment levels, workforce skills, and policy support.

Regional disparities in digital capabilities are evident across Europe. While some regions have well-established AI ecosystems supported by strong research institutions and innovation clusters, others struggle due to insufficient digital infrastructure and limited human capital development. This divergence underscores the need for targeted interventions that promote digital inclusivity and capacity-building.

Ecological Transition and Policy Imperatives

The urgency of ecological transition has been magnified by the increasing frequency and intensity of environmental crises. European policy frameworks, such as the European Green Deal and the Fit for 55 package, emphasize the necessity of transitioning towards low-carbon economies. Key areas of focus include renewable energy integration, sustainable mobility, circular economy initiatives, and nature-based solutions.

Despite overarching EU objectives, regional progress in ecological transition remains uneven. Factors such as industrial legacies, energy dependencies, and local governance structures contribute to divergent sustainability trajectories. Regions with strong policy commitment and green investment strategies tend to advance more rapidly, whereas those with economic dependencies on carbon-intensive industries encounter significant challenges in aligning with EU climate goals.

A Clusterwise Approach to Regional Analysis

Methodological Framework

The study employs a Clusterwise approach to categorize European NUTS2 regions based on their levels of digital readiness and ecological commitment. This methodological framework facilitates the identification of distinct regional profiles, enabling a comparative assessment of policy effectiveness, innovation potential, and socioeconomic outcomes.

Key indicators used for clustering include:

- **Digitalization Metrics**: Broadband penetration, AI adoption rates, digital skills index, R&D investments in AI-related fields.
- **Ecological Commitment Metrics**: Renewable energy share, carbon emission reductions, green infrastructure investments, circular economy performance.
- **Economic and Social Context**: GDP per capita, employment in digital and green sectors, education levels, policy initiatives.

By applying machine learning clustering techniques, the study delineates groups of regions that share similar attributes, highlighting both frontrunners and laggards in the twin transitions.

Regional Patterns and Disparities

The findings reveal a spectrum of regional typologies:

- **Innovation Leaders**: Regions with strong digital and ecological performances, often characterized by robust policy support, high R&D expenditure, and established AI ecosystems.
- **Digital Pioneers with Ecological Gaps**: Regions that excel in AI adoption but face challenges in sustainability due to industrial dependencies or insufficient environmental policies.
- **Sustainability Advocates with Digital Gaps**: Regions prioritizing ecological transition but lagging in digital infrastructure and AI integration.
- **Lagging Regions**: Areas struggling with both digital and ecological transformations due to economic constraints, infrastructural deficits, or weak policy frameworks.

These patterns underscore the necessity of differentiated policy responses to ensure that all regions benefit from the twin transitions, rather than exacerbating existing inequalities.

Policy Implications and Recommendations

Towards an Inclusive Digital and Green Transition

To achieve a resilient, sustainable, and inclusive future, policymakers must adopt region-specific strategies that leverage local strengths while addressing existing weaknesses. The following policy recommendations emerge from the study:

1. **Tailored Investment Strategies**: EU funding mechanisms, such as the Recovery and Resilience Facility, should prioritize investments that align with regional needs, ensuring balanced support for both digital and ecological advancements.
2. **Capacity-Building and Skills Development**: Workforce training programs should integrate AI and sustainability competencies to enhance employability and innovation potential.
3. **Multi-Level Governance and Policy Coordination**: Strengthening collaboration between EU institutions, national governments, and regional authorities is essential for coherent and effective policy implementation.
4. **Incentivizing Private Sector Participation**: Public-private partnerships can accelerate AI-driven sustainability solutions, particularly in sectors such as energy, transportation, and urban planning.
5. **Enhancing Data-Driven Decision-Making**: The use of AI and big data analytics can improve policy evaluation, enabling more adaptive and responsive governance models.

Conclusion

The intersection of AI and ecological transition presents both opportunities and challenges for regional development. By adopting a Clusterwise analytical approach, this study highlights the diverse trajectories that European regions are following in the twin transitions. The findings emphasize that a one-size-fits-all approach is inadequate, necessitating context-sensitive policies that foster digital inclusion, environmental responsibility, and economic resilience.

In alignment with the ERSA 2025 theme, the study contributes to the ongoing discourse on how regional science can address contemporary crises and promote a future where economic progress, social equity, and environmental sustainability are mutually reinforcing. Through strategic interventions and innovative governance models, European regions can navigate the complexities of digital and ecological transformations, ensuring a more inclusive and resilient future for all.