The Geography of the Green Transition: Big Promises, Uneven Outcomes

Giulio Breglia[1], Giulia Valeria Sonzogno[2]

[1]Gran Sasso Science Institute, [2]Roma Tre University

Abstract

The green transition is a defining challenge for economic and environmental policies, yet its spatial distribution remains highly uneven, raising concerns about territorial equity. While sustainability policies aim to mitigate climate change and foster resilience, they interact with existing regional disparities, potentially reinforcing inequalities (Iammarino et al., 2019). The European Union (EU), through Next Generation EU (NGEU), integrates climate goals into post-pandemic recovery strategies, allocating 37% of the Recovery and Resilience Facility (RRF) to green projects (Commission, 2019). However, how these investments translate into territorial development remains largely unexplored.

Using Italy's National Recovery and Resilience Plan (NRRP) as a case study, we classify over 92,000 green projects through a GPT-supervised clustering approach and analyze their socio-economic determinants using a multinomial logit model. Our findings reveal significant spatial disparities: metropolitan regions attract high-value investments, while peripheral and less-developed areas focus on low-value sustainability measures. These results underscore the need for place-based strategies to ensure a just transition. By integrating machine learning with spatial econometrics, this study advances the understanding of sustainability policies and provides a methodological framework for assessing green transition initiatives.

Keywords: Green Transition, Text Analysis, Sustainable Development, Regional Policy, Next Generation EU

1 Introduction

The green transition is reshaping economies, societies, and geographies worldwide, yet its distribution remains deeply uneven, raising concerns about territorial equity and social justice. While sustainability policies are critical to mitigating climate change and fostering long-term resilience, they interact with pre-existing regional disparities, often reinforcing rather than reducing inequalities (Iammarino et al., 2019). In the European Union (EU), green investments tend to concentrate in core regions with strong institutional capacity, advanced infrastructure, and innovation ecosystems, disproportionately benefiting metropolitan areas while leaving peripheral regions struggling to adapt. The risk of deepening territorial imbalances is particularly high in areas historically reliant on carbon-intensive industries or lacking the technical expertise and administrative capacity to implement large-scale sustainability projects.

At the same time, the green transition presents opportunities for regional economic transformation. The expansion of renewable energy, energy efficiency measures, and nature-based solutions can support local development, fostering economic diversification and resilience. However, these benefits are not automatic. They depend on a region's ability to attract investments, navigate regulatory frameworks, and integrate sustainable technologies into existing economic structures. Without targeted policies that address spatial disparities, the green transition may reinforce existing patterns of uneven development, widening economic and social inequalities between core and peripheral areas. Understanding how green transition projects are distributed across space—and what factors shape these patterns—is therefore essential.

The European Union's Next Generation EU (NGEU) framework marks a critical step in integrating climate objectives into post-pandemic recovery strategies. With 37% of the Recovery and Resilience Facility (RRF) earmarked for green transition projects, NGEU represents an unprecedented alignment between economic recovery efforts and sustainability goals (Commission, 2019). Italy's National Recovery and Resilience Plan (NRRP) is a key case study in this regard, with over €67 billion dedicated to green investments, covering areas such as energy efficiency, renewable energy expansion, sustainable mobility, and environmental restoration. These projects are expected to accelerate decarbonization and modernization efforts, yet their actual territorial distribution and socio-economic impacts remain underexplored. If green funding follows historical investment patterns, favoring already-developed regions, the risk of uneven development remains high, potentially undermining the broader objectives of the European Green Deal.

This study seeks to address these gaps by systematically analyzing how the green transition unfolds spatially, investigating which territories attract specific types of green projects, under what conditions, and why. The green transition is not a uniform process; policy trajectories vary, with some municipalities prioritizing energy efficiency, others focusing on renewable energy production, and others emphasizing environmental restoration (Gan et al., 2023; Ghosh et al., 2024). These different trajectories influence regional development, economic resilience, and social cohesion, making their spatial distribution a crucial subject of analysis.

To examine these dynamics, we introduce an innovative classification framework that systematically categorizes green transition projects using a combination of natural language processing (NLP) and spatial analysis. Our methodology employs a GPT-supervised clustering approach, ensuring that project classification remains interpretable and aligned with policy objectives. Unlike purely unsupervised clustering techniques that group projects based solely on textual similarity, our method enables a structured categorization that reflects the broader policy goals of the green transition.

The empirical strategy consists of three stages. First, we classify green projects based on their textual descriptions, identifying dominant policy trajectories. Second, we map these clusters at the municipal and regional levels to visualize spatial trends and specialization patterns. Finally, we estimate a multinomial logit model to assess the socio-economic and geographic determinants of different green trajectories, considering factors such as income levels, tourism reliance, urbanization, and institutional capacity.

This paper makes three key contributions. First, it provides a systematic classification of green transition projects, allowing for a deeper understanding of how sustainability policies translate into local and regional development patterns. Second, it develops a methodological framework that integrates machine learning and spatial econometrics, offering a replicable approach for analyzing large-scale policy interventions. Third, it contributes to the policy debate on regional disparities in the green transition, highlighting the role of place-based strategies in ensuring an equitable and effective sustainability agenda.

By examining the Italian case within the broader EU framework, this study sheds light on the emerging geographies of the green transition. The findings underscore the need for policies that go beyond aggregate green investment figures to assess how these investments interact with territorial characteristics, addressing both opportunities and structural constraints. If the green transition is to be a driver of inclusive development, it must actively reduce spatial inequalities rather than exacerbate them.

2 The Green Transition and Spatial Inequalities

The green transition has become a central policy challenge as climate change accelerates its impact on societies. While environmental regulations have long existed (Hughes, 2014), the urgency of mitigating greenhouse gas emissions has driven global efforts, notably through the IPCC and agreements such as the Paris Accord (IPCC, 2021). Despite these commitments, climate change has intensified regional disparities, disproportionately affecting vulnerable areas through extreme weather events, economic disruptions, and migration pressures (Hsiang et al., 2017).

The COVID-19 crisis further highlighted the need to integrate climate action into economic recovery. The European Union's Next Generation EU (NGEU) framework allocates 37% of its Recovery and Resilience Facility (RRF) to green investments (Commission, 2020), marking a shift toward sustainability-driven macroeconomic planning. However, the transition does not follow a uniform trajectory. Three main pathways—energy efficiency, renewable energy, and nature-based solutions—carry distinct spatial implications (Sorrell, 2007).

The distribution of green investments often favors wealthier regions with stronger institutional capacity, while peripheral areas struggle to attract high-value projects. Large-scale renewable initiatives benefit urban economies, while decentralized energy solutions empower local communities. Similarly, nature-based solutions address climate adaptation but may reinforce land-use conflicts (Diffenbaugh and Burke, 2019).

Given these territorial disparities, a place-based approach is necessary to ensure equitable outcomes. Regions with weaker technological and institutional capacity risk being left behind in the green transition. Addressing these imbalances requires policies that integrate economic resilience with sustainability, ensuring that green investments reduce rather than exacerbate inequalities.

3 Examining Green Transition: Missions, Data, and the Territorial Dimension

The Italian National Recovery and Resilience Plan (NRRP), within the Next Generation EU framework, is a €194.4 billion strategy aimed at fostering the twin transition (green and digital), social inclusion, and resilience. It is structured into key missions, of which Mission 2 (*Green Revolution and Ecological Transition*, €59 billion) and Mission 3 (*Infrastructure for Sustainable Mobility*) are central to the green transition, supporting renewable energy, energy efficiency, sustainable mobility, and circular economy initiatives (Commission, 2023). These investments aim to decarbonize Italy's economy while aligning with EU climate objectives.

A critical aspect of the NRRP is its territorial equity approach, with 40% of funds allocated to southern and less-developed regions to address regional disparities (PCM, 2021). Investments in energy, transport, and infrastructure are designed to enhance local resilience and economic development while promoting sustainability.

To assess the spatial distribution of these projects, we utilize the *Italia Domani* open-data portal, which provides granular details on budget allocations and implementation. Green projects are identified through a structured classification process, ensuring alignment with climate goals. This dataset enables a deeper analysis of Italy's green transition, its regional dynamics, and the socio-economic factors shaping investment patterns.

4 Empirical Strategy

This study classifies green transition projects under Italy's NRRP and maps their spatial distribution using a multi-method clustering approach (Maibaum et al., 2024). Given the dataset of approximately 92,000 projects, we implement four techniques: BERT-based clustering, dictionary learning, GPT-supervised classification, and unsupervised topic modeling. These methods ensure thematic and spatial coherence, addressing both textual complexity and policy relevance (Grimmer and Stewart, 2013).

The final classification adopts GPT-supervised clustering, which enhances policy relevance by refining thematic categories and preventing over-concentration in dominant clusters. Unlike unsupervised models, this approach ensures alignment with green transition policies (Rodríguez-Pose and Bartalucci, 2024).

4.1 Clustering Approaches

BERT-based clustering represents each project as a vector in $\mathbb{R}^d$ and applies K-means minimization:

$$\min_{\mathbf{C}} \sum_{i=1}^{N} \min_{c \in C} ||\mathbf{x}_i - \mathbf{c}||^2 \tag{1}$$

where $\mathbf{C}$ is the cluster centroids. While effective in capturing latent similarities, it lacks policy-specific alignment.

Dictionary learning applies keyword-based classification from the Council Implementing Decision (CID) (Commission, 2023), computing classification probability:

$$P(c|\mathbf{w}_i) = \frac{\sum_{j \in c} f(w_{ij})}{\sum_j f(w_{ij})} \tag{2}$$

where $f(w_{ij})$ is word frequency. This method aligns with policy categories but results in unbalanced clusters.

GPT-supervised classification refines policy categories using:

$$y_i = \arg\max_c P(c|\mathbf{d}_i, \Theta) \tag{3}$$

ensuring thematic consistency. Misclassifications are corrected post-classification, improving interpretability.

Unsupervised Latent Dirichlet Allocation (LDA) models projects as mixtures of topics:

$$P(d_i|t_k) = \prod_{j=1}^{M} P(w_{ij}|t_k) P(t_k) \tag{4}$$

where $P(w_{ij}|t_k)$ is word probability in topic k. While useful for topic discovery, it lacks policy-specific precision.

4.2 Green Transition Pathways and Determinants

Green transition trajectories are identified by summing total funding per municipality and assigning the dominant cluster. A specialization index at the NUTS-2 level measures regional focus:

$$SI_{r,c} = \frac{\sum_{i \in r} \frac{F_{i,c}}{F_i}}{\sum_i \frac{F_{i,c}}{F_i}} \tag{5}$$

where $SI_{r,c}$ represents specialization, and $F_{i,c}$ is the funding allocated to cluster c in municipality i.

A multinomial logit model estimates the probability of a municipality specializing in a transition cluster:

$$Pr(y = m|\mathbf{x}) = \frac{e^{\mathbf{x}\beta(m|b)}}{\sum_{j=1}^{J} e^{\mathbf{x}\beta(j|b)}} \tag{6}$$

where $\mathbf{x}$ includes explanatory variables such as urbanization, income, and regional fixed effects. This empirical strategy ensures a comprehensive spatial analysis of Italy's green transition investments.

5 Results

This section presents the findings on the spatial distribution of green transition projects under Italy's NRRP. We identify key green transition pathways through cluster analysis, assess regional specialization using NUTS-2 level indices, and estimate municipal-level determinants via a multinomial logit model.

Our analysis identifies nine green transition clusters, reflecting distinct policy priorities. *Building Efficiency* accounts for 68.99% of projects, emphasizing energy-efficient renovations in urban and rural areas. *Renewable Energy (Diffuse)*, representing 16.12%, promotes decentralized solar and wind installations, particularly in rural and peri-urban municipalities. *Logistic Efficiency* (6.56%) and *Transport Emissions* (2.24%) focus on decarbonizing mobility and enhancing sustainable transport infrastructure.

Nature Restoration (4.92%) targets ecological rehabilitation, while *Circular Economy* and *Water Management* support resource efficiency and sustainability. The remaining clusters—*Renewable Energy (Corporate)* and *Industrial Decarbonization*—highlight industrial efforts toward emission reductions.

The regional analysis reveals specialization patterns shaped by economic structure and geography. Northern regions prioritize building efficiency, while Southern Italy exhibits a stronger focus on transport and water management. A multinomial logit model confirms that project distribution correlates with population density, land use, economic performance, and governance capacity, underscoring the importance of place-based strategies for an equitable green transition.

6 Conclusions

The green transition presents both opportunities and challenges, with the risk of reinforcing territorial inequalities. This study classifies Italy's NRRP green investments using a GPT-supervised clustering approach, revealing significant spatial disparities. Wealthier, urbanized regions attract high-tech investments, while peripheral areas receive funding for adaptation projects, potentially limiting long-term economic transformation. Our findings stress the need for place-sensitive policies that enhance institutional capacity in lagging regions. Ensuring an equitable green transition requires tailored policy interventions to prevent sustainability from exacerbating existing socio-economic divides, triggering inclusive regional development instead of reinforcing structural disadvantages.

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