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The Intra-regional Divide in the Face of the Green Transition: Empirical Analysis for the Municipalities of Cantabria

Diferencias intrarregionales ante la transición verde: análisis empírico para los municipios de Cantabria

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Abstract

The European Union is implementing an ambitious strategy to carry out a just green transition. Evidence shows, however, deep inter-regional differences in vulnerability to the green transition, which pose a risk for this strategy. This paper analyses intra-regional differences in vulnerability to the green transition, using data for the municipalities of a Spanish region: Cantabria. The results show a deep intra-regional divide, where deprived, rural and depopulated municipalities are the most vulnerable to the green transition. These results complement the existent evidence on inter-regional differences in vulnerability to the green transition in the European Union, extending it to the analysis of intra-regional differences. This shows that the green transition may increase polarisation not only between regions, but also within regions.

Keywords: Green transition, just transition, regions, municipalities, territorial cohesion.

Resumen

La Unión Europea está impulsando una ambiciosa estrategia orientada a lograr una transición verde justa. La evidencia existente muestra profundas diferencias interregionales en la vulnerabilidad ante la transición verde, lo cual supone un riesgo para esta estrategia. Este artículo analiza las diferencias intrarregionales en la vulnerabilidad ante la transición verde, a partir de datos para los municipios de una región española: Cantabria. Los resultados reflejan una profunda brecha intrarregional, siendo los municipios más pobres, rurales y despoblados los más vulnerables ante la transición verde. Estos resultados complementan la evidencia existente sobre las diferencias interregionales en la vulnerabilidad ante la transición verde en la Unión Europea, extendiéndolo al análisis de las diferencias intrarregionales. De ello se deriva que la transición verde afronta el riesgo de incrementar no solo las diferencias entre regiones, sino también las diferencias dentro de las regiones.

Palabras clave: Transición verde, transición justa, regiones, municipios, cohesión territorial.

JEL Classification/ Clasificación JEL: O18, O25, Q58, R11.

1. Introduction

The European Union (EU) aims to position itself as a relevant global actor in the fight against climate change through the transition towards a low-carbon economy: the green transition. The green transition is expected to have net positive effects on the world economy and society. However, the process is not exempt from challenges, as these effects will not be equally distributed across countries, regions, societal groups and citizens: some of them will get net benefits, while others will bear net losses (European Commission, 2024a). In this light, significant actors at the global, national and local level underline that if the green transition aims to be successful, it has to be well-balanced between countries, as well as between territories and societal groups within countries: a just green transition (United Nations, 2022).

The EU is implementing what attempts to be the most ambitious strategy towards a just green transition in the world: the European Green Deal, which aims to achieve net zero emissions by 2050 and, at the same time, that "no person and no place" are left behind (European Commission, 2025). This strategy will require significant regional policies. Calls for resilience will not be enough for a successful deployment of the European Green Deal, as it is hindered by deep structural inequalities across territories (Christopherson et al., 2010): not all of them are equally able to be "resilient". Given the salience of this topic, an emerging literature has started to analyse the green transition from a territorial perspective. It is unknown whether the green transition will enhance or undermine the productive structure and the institutional capacity of both territories that are economically successful and those that lag behind. However, there are theoretical reasons and incipient evidence to figure out which territories may be better and worse positioned to face the green transition. Grashof and Basilico (2024) show that both the richest and the poorest EU regions can benefit from the green transition, through the diversification to economic activities based on green technologies. However, these authors point out that, to get these benefits, a region needs the capacities for adopting the new green technologies.

Emergent literature on the topic shows also that, while some territories are better positioned to gain the potential benefits derived from a green transition, others face higher risks of bearing the potential costs. Rodrīguez-Pose and Bartalucci (2024) measure EU regions' exposure to negative consequences of climate mitigation policies, from information on regions' structural characteristics (such as productive structure, fossil fuel dependency and climate). They find that less-developed, peri-urban, and predominantly rural EU regions, in general more reliant on transitioning sectors such as agriculture, heavy industry, tourism, and transport, are those identified as more vulnerable to the green transition. This evidence has crucial implications for public policy: if the green transition most positively affects the better-endowed regions, and most negatively affects the deprived and depopulated ones, it can (as an undesired consequence) increase polarisation between regions, negatively affecting territorial cohesion. In this light, this evidence and the subsequent concerns are already being considered in the design of EU regional policy (European Commission, 2024a).

Recent literature shows that vulnerability to the green transition largely differs between EU regions. It is insufficiently known, however, if it also differs within EU regions, which is hindered by the lack of appropriate comparable information for a more disaggregated territorial level in the EU.

The aim of this paper is to construct an indicator of vulnerability to the green transition for local units (municipalities) within a Spanish region: Cantabria. The resulting Municipal Green Transition Vulnerability Index is based on Rodríguez-Pose and Bartalucci's Regional Green Transition Vulnerability Index, using the same methodology and similar variables (adapted to the case of Cantabrian municipalities), which facilitates its comparability. The data needed to calculate the Index at the municipal level is available for several Spanish regions, although not directly comparable across them. We chose to focus on Cantabria because it is one of the Spanish regions for which the most detailed data required at the municipal level are available, and the region has a significant deep internal diversity across municipalities in terms of geographical and socio-demographical characteristics and economic structure, which is key for drawing a meaningful intra-regional analysis of vulnerability to the green transition. Cantabria is, according to Rodríguez-Pose and Bartalucci's categorization, a middle-income region with a medium-low level of vulnerability to the green transition. However, within this categorization, significant intra-regional differences coexist. Our results show a deep intra-regional divide in vulnerability to the green transition across municipalities of Cantabria, where deprived, rural and depopulated municipalities are found as the most vulnerable. From these results, this paper illustrates intra-regional heterogeneity in vulnerability to the green transition in the EU context, which complements existent evidence from the literature on inter-regional differences on this regard. These results indicate that the successful implementation of a just green transition in the EU from a territorial point of view should consider heterogeneity not only between regions, but also within them.

The rest of the paper is structured as follows. After this introduction, section 2 describes how territories' vulnerability to the green transition is measured in existent literature, and which factors are found related to it. Section 3 describes the data and methodology used to calculate our Municipal Green Transition Vulnerability Index for Cantabrian municipalities. Section 4 presents the main results found. Section 5 concludes, focusing on the implications of these results for a successful implementation of the green transition from a territorial point of view, both in the EU and beyond.

2. Vulnerability to the green transition in a territorial perspective: a literature review

Recently, the green transition has become a major policy issue, particularly within the EU. The literature has increasingly focused on understanding territorial vulnerability to the green transition and its policy implications. Vulnerability to the green transition is influenced by several factors, including economic dependence on high-carbon sectors, socio-economic conditions, institutional capacity, and geographical characteristics (Gambhir et al., 2018; McDowall et al., 2023). It encompasses both exposure to potential risks and the capacity of territories to adapt to changes derived (Carley et al., 2018).

From a territorial perspective, vulnerability is multifaceted, involving economic, social, and institutional factors. Regions heavily reliant on high-carbon industries, such as coal mining and heavy manufacturing, are more vulnerable to the green transition due to potential job losses and economic decline (Raimi, 2021; McDowall et al., 2023). Acknowledging this, in the case of Spain, the provinces more dependent on coal extraction and coal-fired power plants have been selected by the central government for the Just Transition Fund, which implies receiving aid to mitigate the socio-economic impacts of closures in these activities (European Commission, 2024b). Socio-economic conditions, including income levels, employment rates, education, and health, also shape vulnerability. Regions with low income, low employment and high poverty rates, low educational attainment, and poor health outcomes are expected to be less resilient to the economic shocks of the green transition (Carley et al., 2018; Gambhir et al., 2018). Additionally, the quality and efficiency of local institutions plays a crucial role. Effective governance, strong institutional frameworks, and social dialogue between governments, businesses, and labour unions are essential for a just transition (Gambhir et al., 2018; Rodríguez-Pose et al., 2024).

Geographic factors, such as urban-rural divides and regional infrastructure, further influence vulnerability to the green transition. Rural areas, with limited access to infrastructure and services, may struggle more compared to urban regions with better resources and connectivity (Faggian et al., 2025). As a result, vulnerability to the green transition varies significantly across territories, influenced by economic structures, institutional capacities, and socio-economic conditions. Understanding the spatially uneven opportunity for transformative change is crucial, as highlighted by Binz et al. (2025). These authors emphasized the role of place, scale, and territorial embeddedness in shaping sustainability transitions. This perspective is essential for comprehending how different regions can leverage their unique characteristics to adapt to the green transition. Grashof and Basilico (2024) further explored regional disparities in technology diversification across European NUTS-2 regions. They found that regions' success in the diversification towards green technologies depends on their percentage of population with tertiary education and their previous technological specialization, but not on their GDP per capita. However, they also found that regions specialized in high-carbon technologies face greater challenges in this diversification process.

Another significant issue in the literature on the green transition is how to measure vulnerability to this process. Recent approaches developed to measure vulnerability to the green transition have been usually based on composite indicators that combine multiple dimensions of vulnerability. These composite indicators integrate various factors such as economic dependence, socio-economic conditions, and institutional capacity to provide a comprehensive assessment of regional vulnerability. McDowall et al. (2023) used this method to identify the vulnerability of European regions to decarbonization. In a different approach, Carley et al. (2018) adapted the Vulnerability Scoping Diagrams framework from climate change adaptation literature to the energy context. The Vulnerability Scoping Diagrams framework is a tool for assessing vulnerability, which these authors used to generate vulnerability scores based on exposure, sensitivity, and adaptive capacity to the energy transition policies across US counties. This approach helped identify geographical disparities and target communities with focused assistance programs. While both approaches provide a global vulnerability score, the composite indicators offer a broader, multidimensional assessment, whereas the Vulnerability Scoping Diagrams focus specifically on energy transition and geographical disparities.

Recently, as described in the introduction, Rodríguez-Pose and Bartalucci (2024) developed the Regional Green Transition Vulnerability Index, a composite indicator designed to capture the multi-dimensional vulnerability of European regions to the socio-economic impacts of the green transition. This index incorporates indicators on six pillars: fossil fuel dependency and emissions, tourism, energy, transportation, agriculture and land use, and industry. By using Principal Component Analysis, the index obtains a measure of which EU regions are the most and the least susceptible to the negative impacts of the green transition.

Several studies have provided insights into which policies can address regional vulnerability to the green transition. Christopherson et al. (2010) discussed regional resilience, defined as the capacity to adapt, recover, and prosper in the face of economic, political, and environmental adversities. Regions with diversified economies, strong civic capital, and modern infrastructure are expected to be more resilient to the green transition. However, the concept of regional resilience faces criticism for its sometimes overly optimistic view of region's adaptative capacities without addressing structural inequalities (Christopherson et al., 2010). Faggian et al. (2025) highlighted significant regional disparities in the development and adoption of digital technologies, posing challenges for achieving a just and equitable transition. Rodríguez-Pose and Bartalucci (2024), from their results on the

Regional Green Transition Vulnerability Index, warned of potential increases in territorial polarization and social discontent. McDowall et al. (2023) found that EU regions with high employment shares in carbon-intensive industries and weak adaptative capacity are most at risk. Another example is found in the US, where Raimi (2021) identified several counties (such as those in Appalachia or Texas) as highly vulnerable to the green transition due to their economic dependence on fossil fuels and socio-economic challenges. In a paper focused on Northern and Eastern Spanish regions, Felipe-Andreu et al. (2022) showed how the green transition can have different effects on different territories, depending on their pre-existing capacities, finding significant imbalances between energy producer and consumer areas. This evidence highlights the need for balanced and equitable territorial planning. At the local level, Nguyen et al. (2017) developed a Social Vulnerability Index to assess social vulnerability to climate change at the local scale, demonstrating its application in a case study city in central coastal Vietnam. Pereira da Silva et al. (2023) assessed the spatial correlation between urban green spaces and social vulnerability in five Brazilian metropolitan regions, highlighting the importance of equitable distribution of green spaces to promote environmental justice. In another recent paper, Muscillo et al. (2023) calculated a composite indicator to measure the progress towards the green transition of Italian municipalities, focusing on four dimensions: digitalization, energy and resources, mobility and waste. They found deep geographical differences and differences between cities, towns and rural areas: mountain and rural municipalities were in a worse position as regards dimensions such as digitalization and mobility. This paper measures progress of Italian municipalities towards the green transition, but not vulnerability to this process taking into account socio-economic structural characteristics.

The literature emphasizes the complexity and multifaceted nature of vulnerability to the green transition and the need for tailored policies at a global, national, regional, or local level. Composite indicators and Vulnerability Scoping Diagrams frameworks provide valuable tools for measuring and understanding both the green transition and vulnerability to it. These insights are crucial for policymakers aiming to balance climate action and social equity (Raimi et al., 2022; McDowall et al., 2023).

Despite the emerging body of research on the green transition from a territorial perspective, there remains a significant gap in understanding how vulnerability to the green transition may vary within regions. This paper is, to the best of our knowledge, the first to construct an index of vulnerability to the green transition for municipalities within the EU context, incorporating a diverse range of characteristics at the municipal level. Our approach provides a novel perspective to the existing literature, by addressing vulnerability to the green transition at the municipal level from a comprehensive set of factors. The following sections detail the methodology used and analyse the resulting evidence.

3. Data and methodology

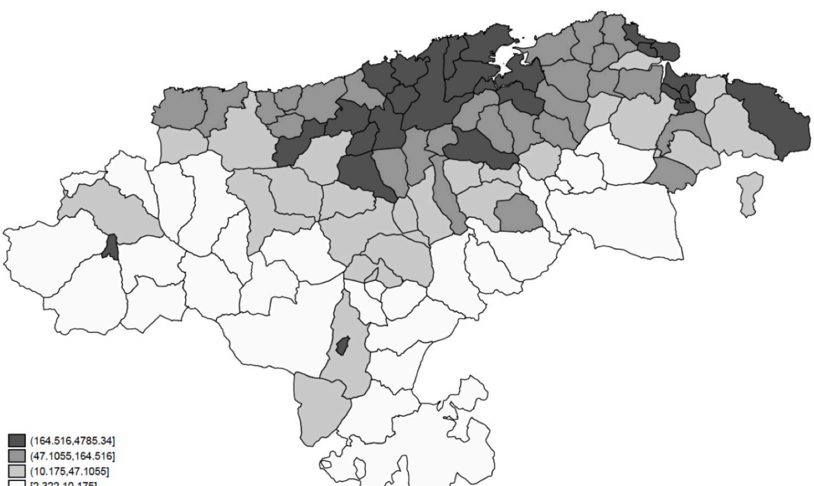
3.1. The Municipal Green Transition Vulnerability Index (MGTVI)

This sub-section describes the data and methodological approach used to develop a Municipal Green Transition Vulnerability Index (MGTVI) for the municipalities of the region of Cantabria. Cantabria is a small region with a population around 600,000 inhabitants in 2023 (ICANE, 2024a) situated in Northern Spain, in the European Atlantic coast. The region is subdivided in 102 municipalities. Despite its small size, the region is quite heterogeneous, with dichotomies between coastal and mountain municipalities, and between urban and rural municipalities (Figure 1).

Our MGTVI is a composite indicator which focuses on measuring Cantabrian municipalities' susceptibility to harm from current and future policies implemented to achieve the green transition. Its definition and purpose, its methodology and the selection of variables from which it is calculated are based on Rodríguez-Pose and Bartalucci's (2024) Green Transition Vulnerability Index for EU regions.

Rodríguez-Pose and Bartalucci's Regional Green Transition Vulnerability Index is a composite indicator which considers not only the direct impacts, but also the indirect impacts of the green transition in the short and medium term. After identifying the green transition's potential effects from a theoretical perspective, these authors classified them in six broad pillars: (i) fossil fuel dependency and emissions; (ii) industry; (iii) agriculture and land use; (iv)

Figure 1. Municipal population density in Cantabrian municipalities, 2023 (inhabitants/km^2)



Source: Authors' own calculation from ICANE (2024a and 2024b).

tourism; (v) energy; and (vi) transportation. (i) and (ii) cover the direct impacts of the green transition, while (iii), (iv), (v) and (vi) cover the indirect impacts.

Rodrīguez-Pose and Bartalucci (2024) calculated their Regional Green Transition Vulnerability Index from 11 indicators on these six pillars for which they found comparable information across EU regions. We calculate our MGTVI from 9 indicators on these six pillars which we find appropriate for Cantabrian municipalities and for which information is available. All our 9 indicators are proxies of those considered by Rodrīguez-Pose and Bartalucci (2024), with some variations next described, resulting from appropriateness of the indicators and availability of the information for the case of Cantabrian municipalities (see footnotes for further details). Data of all the indicators used to construct our MGTVI correspond to the year 2023, except those for the change in CO_2 emissions (which correspond to the period 2012-2023) and the cooling degree days (which correspond to the average in the period 2018-2022). Table 1 illustrates the indicators we use and their source, as well as their correspondence to the six pillars identified by Rodrīguez-Pose and Bartalucci (2024).

As regards "fossil fuels dependency", we take two indicators also considered by Rodrīguez-Pose and Bartalucci (2024): CO_2 emissions from fossil fuels per head in 2023 and the change in those between 2012 and 2023. We estimate these emissions in 2012 and 2023 using ICANE (2024c) data on employment by activity branch and municipality[1], combined with data on CO_2 emissions (INE, 2024a) and employment (INE, 2024b) by activity branch at the national level to obtain the average emissions by employee for each activity branch in Spain (which we extrapolate to Cantabrian municipalities). After estimating the total emissions by municipality in 2012 and 2023, we divide it by municipalities' population in both years (ICANE 2024d and 2024a, respectively). By the actual level of CO_2 emissions, we measure the future impact of the transition towards a low-carbon economy on each municipality, while by the decrease (increase) in CO_2 emissions we measure the (lack of) resilience to the green transition showed by each municipality.

As regards the "industry" pillar, Rodrīguez-Pose and Bartalucci (2024) focused on mining and quarrying activities underlining that, due to their elevated levels of pollution, these activities are likely to be forced to scale down under the green transition. For this pillar, we use an indicator analogous to the one used by Rodrīguez-Pose and Bartalucci (2024): the total value of wages and salaries in mining and quarrying (NACE section B), as a share of total municipal disposable income. We estimate it from data on employment by activity branch and municipality (ICANE, 2024c), combined with data on average salary in mining and quarrying in Spain (taken as proxy of the average salary in the sector for all the Cantabrian municipalities) (INE, 2024c) and

1 These data have been obtained from a request to the Instituto Cántabro de Estadīstica (ICANE), which produced them from microdata of Spanish Social Security.

divided by the disposable income estimated by ICANE for each municipality (ICANE, 2024e)[2].

On the other hand, indirect effects are contemplated from four different perspectives: agriculture and land use, tourism, energy and transportation.

When it comes to "agriculture and land use", we consider two indicators. First, employment in agriculture (NACE section A) as a share of total municipal employment. This is calculated from data on employment by activity branch and municipality (ICANE, 2024c). And second, bovine cattle by municipal population. This is calculated from data on bovine cattle (ICANE, 2024f) and on population (ICANE, 2024a), both at the municipal level. While the first indicator is analogous to that used by Rodríguez-Pose and Bartalucci (2024), the second considers municipal population instead of municipal surface[3]. Vulnerability to the green transition is expected to be related to both factors, as agriculture in general and cow meat production in particular are highly emitting activities.

As regards "tourism", we take two indicators. First, employment in accommodation and in food services (NACE activities 55 and 56, respectively) as a share of total municipal employment, calculated from data on employment by activity branch and municipality (ICANE, 2024c). This is a proxy for Rodríguez-Pose and Bartalucci's indicator on tourist establishments as a share of GDP, considering employment instead of GDP given data availability at the municipal level. And second, tourist arrivals relative to population, a similar indicator to the one used by Rodríguez-Pose and Bartalucci (2024) in this regard. We calculate it from the sum of national and international tourists in the whole year in each municipality (ICANE 2024g and 2024h)[4], divided by the municipal population (ICANE, 2024a). Tourism is also vulnerable to the transition to a low-carbon economy, as certain modes of trip may be affected.

For the "energy" pillar, we estimate an indicator similar to the one considered by Rodríguez-Pose and Bartalucci (2024): the cooling degree days. This is a weather-based technical index that measures the energy demand for cooling (Eurostat, 2024). We estimate a proxy of this indicator from the mean of the average maximum and minimum temperatures in July in the years from 2018 to 2022 (ICANE, 2024i), deducting 21 ºC as the threshold temperature for

2 We dismiss another indicator incorporated by Rodríguez-Pose and Bartalucci (2024) on this pillar: a dummy variable measuring whether the region is a "coal transition region" (at least 100 jobs in the coal industry) or not. We do not consider this indicator as, following this criterion, Cantabria is very far from being a "coal transition region" (in fact, employment in the coal industry is non-existent or residual in any of the Cantabrian municipalities).

3 As regards the bovine cattle, Rodríguez-Pose and Bartalucci (2024) divided it by the surface of each region. In the case of Cantabrian municipalities, we find it more appropriate to divide it by the population instead, as there are several small urban municipalities and the indicator is distorted if considering the surface. In addition, Rodríguez-Pose and Bartalucci (2024) considered a third indicator for this pillar: Gross Value Added in Agriculture, relative to GDP. We dismiss this indicator as there is no official information on Gross Value Added by sector at the municipal level, and we consider the analogous indicator based on employment instead.

4 These data, produced by the Instituto Nacional de Estadística (INE) (Estadística experimental. Medición del turismo a partir de teléfonos móviles), have been obtained after a request to the Instituto Cántabro de Estadística (ICANE).

cooling demand. Given that not all the municipalities have a weather station, we take the most representative one (in terms of distance and altitude) for each municipality.

Finally, as regards "transportation", we measure road freight transport needs through the number of trucks and vans (ICANE, 2024j) relative to the population in each municipality (ICANE, 2024a). This is a proxy of the indicator used by Rodrīguez-Pose and Bartalucci (2024) (road freight transport loading), subject to data availability at the municipal level. Territories more dependent on road transport could face increased costs due to the decarbonisation process (European Commission, 2018), and subsequently be more vulnerable to the green transition.

MGTVI is calculated by normalizing these 9 indicators and aggregating them using the weights obtained from a Principal Component Analysis (PCA) (see Appendix 1 for details). From this method, we obtain weights for each indicator which are specific for measuring the index for Cantabrian municipalities, and which differ from those obtained by Rodrīguez-Pose and Bartalucci (2024) for EU regions using the same method. Our weights show thus specifically the relative importance of each indicator in determining Cantabrian municipalities' vulnerability to the green transition. The MGTVI calculated from applying these weights reflects the vulnerability to the green transition of each municipality, where a higher value of MGTVI means a higher vulnerability, and a lower value means a lower vulnerability. Appendix 1 includes the descriptive statistics of the 9 indicators used to calculate the MGTVI for Cantabrian municipalities (see Table A.1).

Table 1. Variables included in the MGTVI

Type of impact	Pillar	Variable (Year)	Source
Direct	Fossil fuels dependency	CO_2 emissions per head (2023)	Own estimation from ICANE (2024a and 2024c) and INE (2024a and 2024b).
		Change in CO_2 emissions per head between 2012 and 2023	Own estimation from ICANE (2024a, 2024c and 2024d) and INE (2024a and 2024b).
	Industry	Total value of wages and salaries in mining and quarrying, as a share of municipal total disposable income (2023)	Own estimation from ICANE (2024c and 2024e) and INE (2024c).
Indirect	Agriculture and land use	Employment in agriculture, relative to total employment (2023)	Own calculation from ICANE (2024c).
		Bovine cattle by population (2023)	Own calculation from ICANE (2024a and 2024f).
	Tourism	Employment in accommodation and food services, relative to total employment (2023)	Own calculation from ICANE (2024c).
		Tourist arrivals relative to population (2023)	Own calculation from ICANE (2024a, 2024g and 2024h).
	Energy	Cooling degree days (2018-2022)	Own calculation from ICANE (2024i).
	Transportation	Road freight transport - Trucks and vans relative to population (2023)	Own calculation from ICANE (2024a and 2024j).

3.2. Data and methods for further empirical analysis

We use the MGTVI Index to conduct further empirical analysis on three directions. First, the correlation between this Index and other variables which represent characteristics of Cantabrian municipalities, to identify patterns of relationship between vulnerability to the green transition and key territorial characteristics. Second, a cluster analysis, to identify groups or clusters of municipalities with shared characteristics encompassing their vulnerability to the green transition. And third, a test for spatial autocorrelation, to conclude if vulnerability to the green transition in municipalities is influenced by that in neighbouring municipalities.

First, the following variables representing key characteristics of the municipalities are selected to analyse their correlation with vulnerability to the green transition:

- *Gross disposable income per capita*, obtained from ICANE (2024e). This is a representative indicator of the standard of living and welfare of the population in each municipality, corresponding to 2019 (last year available, apart from 2020 which was an anomalous year).
- *Population density*, calculated from data on the population of each municipality in 2023 (ICANE, 2024a) and its surface area (ICANE, 2024b), and expressed in logarithms. Population density illustrates the urban or rural characterization of municipalities.
- *Population variation rate* in the last two decades, using 2001 and 2021 census data (ICANE, 2024k). This is a measure of recent trends in population growth or depopulation in each municipality.
- *The percentage of households with 5G coverage*, obtained from Ministerio para la Transición Digital y de la Función Pública (2023). It measures the level of broadband connectivity in households in the municipality on 30 June 2023. This is considered to analyse the twin transition: whether and how vulnerability to the green transition correlates with municipalities' situation as regards the digital transition.

Second, cluster analysis is used to classify municipalities into homogeneous groups according to the four previously described variables and their vulnerability to the green transition (Hedlund, 2016; Jessen, 2024). To do so, an agglomerative hierarchical cluster analysis is performed using the weighted average distance linkage method.

And third, Moran's global I test is used to detect spatial autocorrelation between vulnerability to the green transition across municipalities (Pregi et al., 2025). Moran's I statistic takes values from -1 (perfect dispersion) to 1 (perfect correlation), and is defined as (Moran, 1950):

$$I = \frac{n\left(\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i-\bar{x})(x_j-\bar{x})\right)}{\left(\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\right) * \left(\sum_{i=1}^{n}(x_i-\bar{x})^2\right)} \tag{1}$$

Where *n* is the number of municipalities in Cantabria, X_i is MGTVI in municipality i, X_j is MGTVI in municipality j, $\bar{x}$ is the arithmetic mean for the given variables for all municipalities, and W_{ij} is the spatial weight that represents the spatial relationship between municipalities i and j. The null hypothesis assumes that the MGTVI is randomly distributed across Cantabrian municipalities.

4. Results

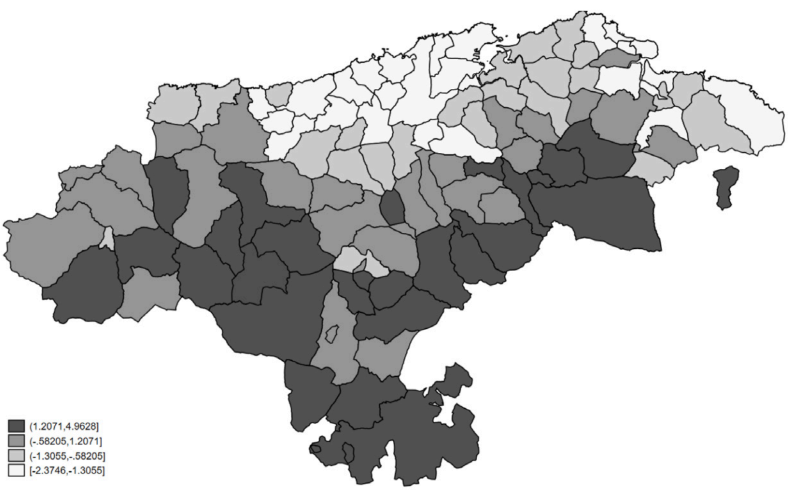
4.1. The green transition vulnerability index of the Cantabrian municipalities (MGTVI): empirical analysis

The MGTVI reflects the vulnerability to the green transition of each of the 102 Cantabrian municipalities. Figure 2 maps the quartile distribution of the MGTVI among the Cantabrian municipalities. Rural municipalities in the mountain range, in the South of the region, are the most vulnerable to the green transition (such as San Pedro del Romeral (4.96), Polaciones (4.61), Soba (4.42) and Lamasón (4.34)). In contrary, urban coastal municipalities, in the Centre-North and the North-East of the region, are the least vulnerable to the green transition (such as Castro-Urdiales (-2.37), Santander (-2.18), Santoña (-1.97) and Laredo (-1.96)).

The next figures show the relationship between Cantabrian municipalities MGTVI and other key municipal characteristics.

Figure 3 shows a negative correlation between MGTVI and municipal gross disposable income per capita. That is, poorer Cantabrian municipalities are

Figure 2. MGTVI of Cantabrian municipalities

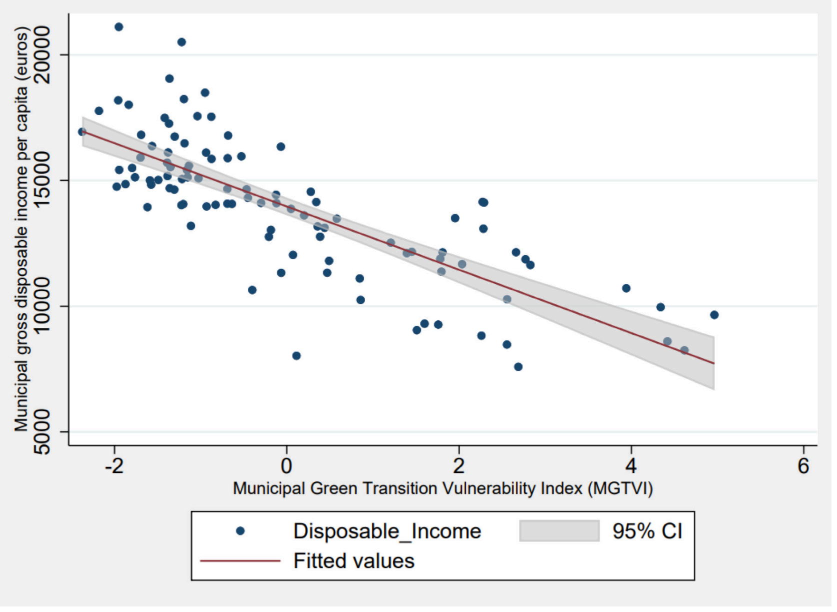


Source: Authors' own calculation.

more vulnerable to the green transition, while the wealthier municipalities tend to be less vulnerable. This is also reflected in Figure 4.a average MGTVI of the first and second quartiles of municipalities by disposable income is -1.29 and -1.02, respectively, while it rises to 0.31 for those in the third quartile, and to 2.03 for those in the fourth quartile. This evidence is in line with the results found by Rodriguez-Pose and Bartalucci (2024) for the EU regions, where they observed that the vulnerability to the green transition is negatively correlated with regions' GDP per capita.

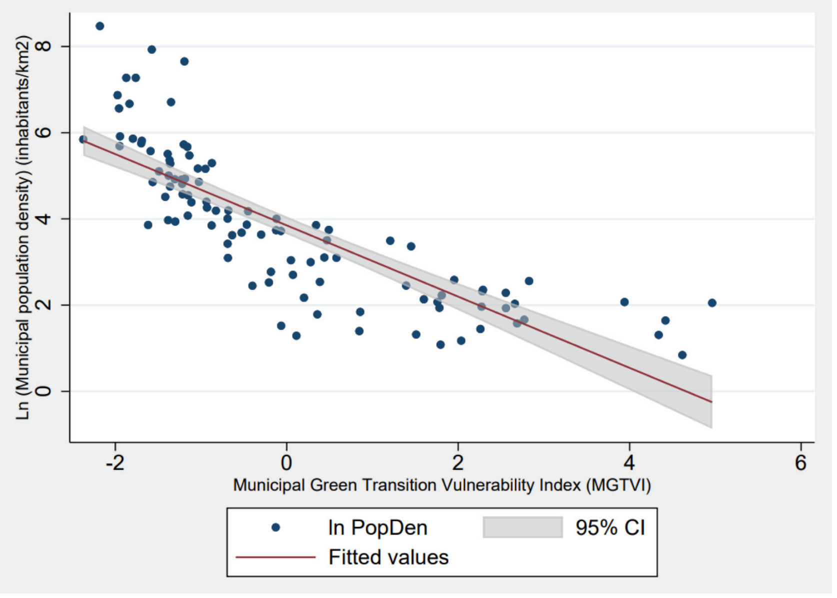
Figure 4 shows a negative correlation between MGTVI and municipal population density (expressed in logarithms). That is, the least densely populated Cantabrian municipalities tend to be more vulnerable to the green transition, while the opposite is observed for the most densely populated municipalities. This is also reflected in Figure 4.b average MGTVI is -1.57 for the first quartile of municipalities by population density (the most densely populated), -1.03 for the second quartile, 0.44 for the third quartile and 2.19 for the fourth quartile (the least densely populated municipalities). These results are also consistent with those obtained by Rodriguez-Pose and Bartalucci (2024) for the EU regions, which showed that peri-urban and rural regions tend to be more vulnerable to the green transition than metropolitan areas. The lag in the progresses towards the green transition affecting rural municipalities, as found by Muscillo et al. (2023) in Italy (particularly as regards digitalisation and mobility),

Figure 3. Correlation between the MGTVI and gross disposable income per capita, 2019 (€)



Source: Authors' own calculation based on ICANE (2024e).

Figure 4. Correlation between the MGTVI and population density, 2023 (in logarithms)



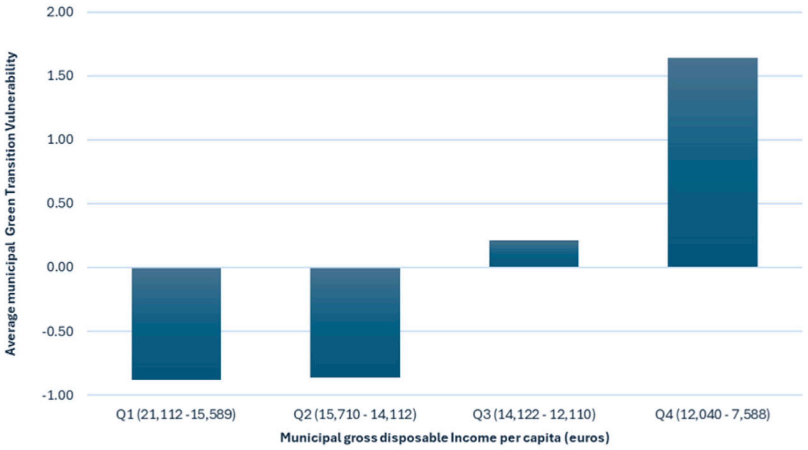
Source: Authors' own calculation based on ICANE (2024a and 2024b).

may aggravate pre-existent vulnerability of these territories (which result from their structural socio-economic characteristics).

Figure 4.c shows there is also a close relationship between MGTVI and municipal population variation rate in the last two decades. Municipalities with the highest decline in population (14% to 38% population loss between 2001 and 2021) are the most vulnerable to the green transition (1.74 of average MGTVI). Average MGTVI is 0.15 for municipalities with a low decline in population (up to 13% population loss), -1.02 for those with low population growth (up to 23%) and -1.34 for those with high population growth (over 24%). In our case of analysis, vulnerability to the green transition is thus closely related to both economic laggard and demographic decline. Nevertheless, Velthuis et al. (2025) pointed out that while many economically declining regions (the so-called "left-behind") in the EU show also a declining population, other "left-behind" regions do not. In this light, economic laggard and demographic decline should not be taken as synonyms in the EU context, and it is adequate to analyse both dimensions separately.

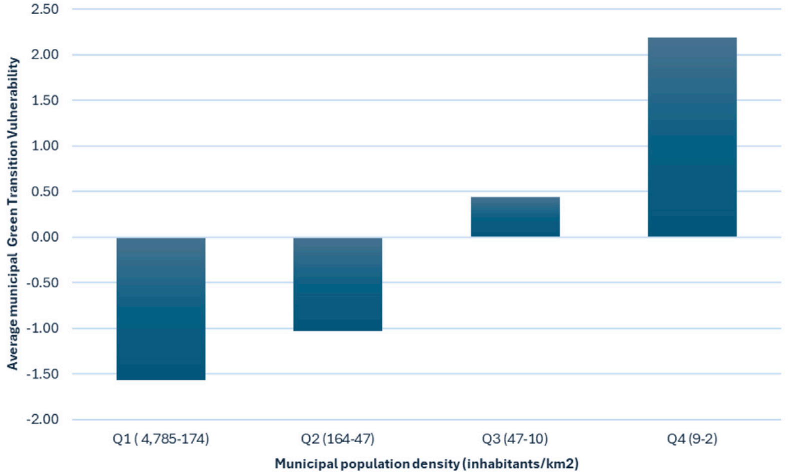
Finally, Figure 4.d shows a deep relationship between MGTVI and municipal percentage of households with 5G coverage. The fourth quartile of municipalities in terms of 5G coverage (that is, those with the poorest coverage) are those with the highest average MGTVI (1.88). Average MGTVI is 0.40 for municipalities in the third quartile, -1.09 for those in the second quartile and -1.16 for those in the first quartile in terms of 5G coverage. Our results, combined with those in the existent literature, reflect the deep complementarities existent between digital transition and green transition, where progresses in the first may decisively help to overcome obstacles in the latter, in the so-called "twin transition" (Damioli et al., 2025; Faggian et al., 2025).

Figure 4.a. average MGTVI by levels of gross disposable income per capita, 2019



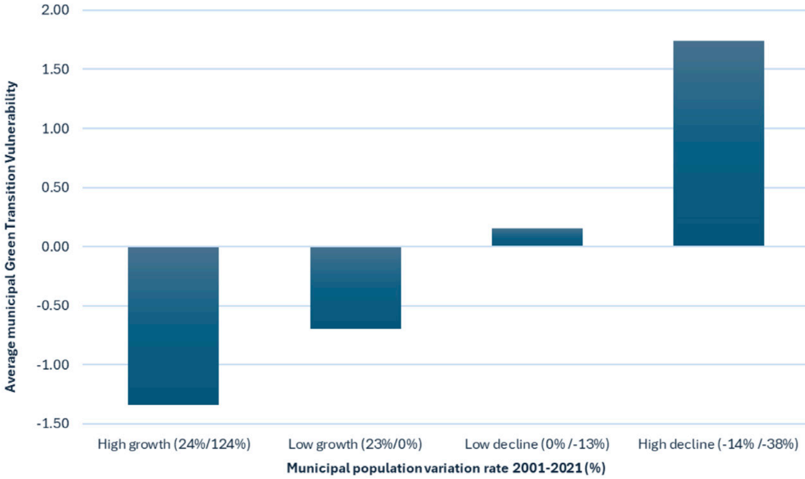
Source: Authors' own calculation based on ICANE (2024e).

Figure 4.b. average mgtvi by population density, 2023



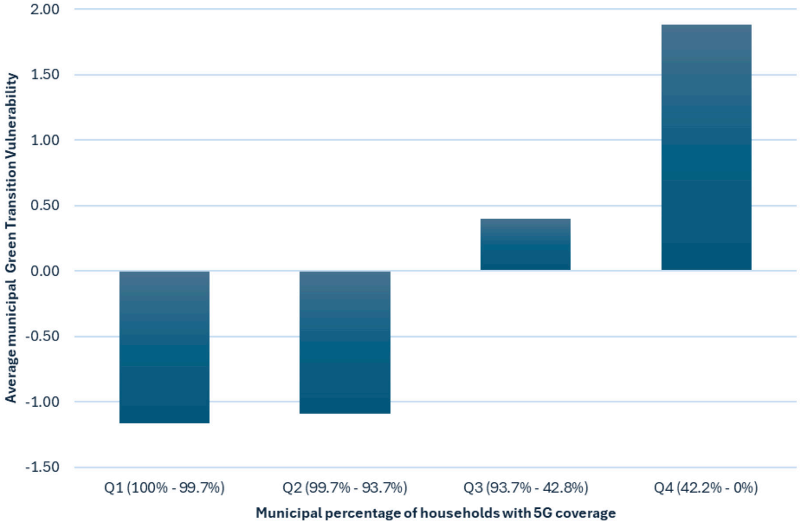
Source: Authors' own calculation based on ICANE (2024a and 2024b).

Figure 4.c. average mgtvi by population variation rate (2001-2021)



Source: Authors' own calculation based on ICANE (2024k).

Figure 4.d. average mgtvi by percentage of households with 5g coverage, 2023



Source: Authors' own calculation based on Ministerio para la Transición Digital y de la Función Pública (2023).

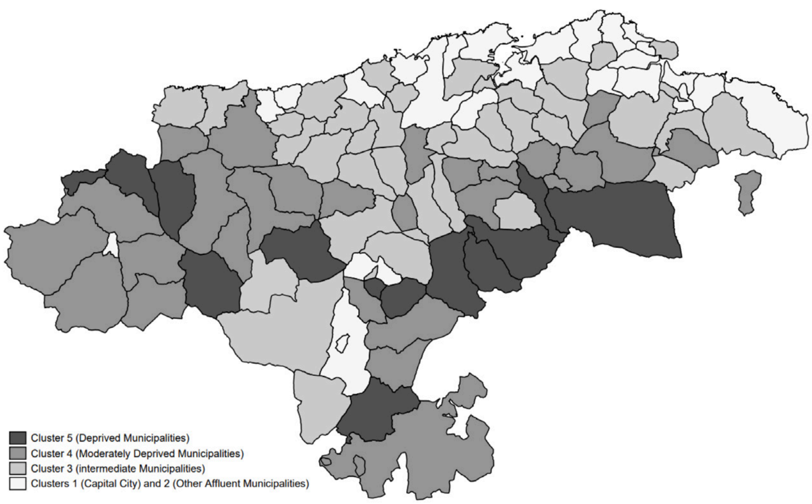
As a robustness check, the analysis was repeated using a composite indicator which considers all the 11 indicators used by Rodriguez-Pose and Bartalucci (2024) weighted according to the coefficients these authors obtained from their PCA for EU regions. All the results obtained were similar[5].

4.2. Cluster Analysis

Cantabrian municipalities are classified according to the variables described in the previous subsection. A five-cluster solution was found to account for a reasonable proportion of the total variance in the data and achieve an acceptable degree of cluster separation (Velthuis et al., 2025). Figure 5 shows the distribution of Cantabrian municipalities in these five clusters.

Table 2 describes the average value of the indicators used for the cluster analysis in each of the five clusters. Cluster 1 is the Capital City, with a medium-high income level, high population density, slight population loss, very high 5G coverage and low vulnerability to the green transition. Cluster 2 (Other Affluent Municipalities) are high income municipalities, with characteristics similar to Cluster 1 except for a lower population density and, in general, population growth. Vulnerability to the green transition of municipalities in Cluster 2 is, in general, also low: 22 out of the 24 municipalities in Cluster 2 are in the two quartiles of lowest MGTVI. Cluster 3 (Intermediate Municipalities) are medium income municipalities, with heterogeneous characteristics in terms of

Figure 5. Distribution of Cantabrian municipalities in five clusters



Source: Authors' own calculation.

5 The results obtained in this robustness check are available upon request to authors.

population density and variation and 5G coverage. Most of these municipalities also show a low or medium-low vulnerability to the green transition: 27 out of 37 are in the two quartiles of lowest MGTVI, 8 are in the second quartile and only 2 are in the first quartile. Cluster 4 (Moderately Deprived Municipalities) are low-income municipalities, with medium-low or low population density, most of them with population loss and medium to very low 5G coverage. Most of these municipalities show a medium-high level of vulnerability to the green transition: 14 out of 27 are in the second quartile of highest MGTVI, and 12 are in the first quartile. Finally, Cluster 5 (Deprived Municipalities) are very low-income municipalities with low population density, and, in most cases, population losses and very low 5G coverage. Most of these municipalities show a high or very-high level of vulnerability to the green transition: 11 out of 13 are in the quartile of highest MGTVI, while the other 2 are in the second quartile. The results of our cluster analysis slightly differ from those obtained by Rodriguez-Pose and Bartalucci (2024) for the EU regions. They identified 12 groups of European regions based on their income (high, medium or low) and their vulnerability to the green transition (high, medium-high, medium-low and low). On this regard, these authors identified EU regions highly vulnerable to the green transition: many of them were low-income regions, but also a significant number of highly vulnerable regions were medium income and even high-income regions. In the case of Cantabrian municipalities, the vast majority of the most vulnerable municipalities to the green transition are relatively low-income municipalities, while only some of them are medium income municipalities and none of them is a high-income one. As can be expected, patterns and typologies of territories are simpler in a context where the territorial scope is more specific (as for the Cantabrian municipalities) than in a context where it is broader and more diverse (as for the EU regions).

Table 2. Mean score of the indicators for the five clusters

	Cluster 1	Cluster 2	Cluster 3
Mean score	*Capital City*	*Other Affluent Municipalities*	*Intermediate Municipalities*
Municipal Green Transition Vulnerability Index (MGTVI)	-2.18	-1.26	-0.86
Gross disposable income per capita, 2019, (€)	17,770.0	17,325.4	14,683.0
Population density, 2023 (inhabitants/km^2)	4,785.3	281.3	303.7
Population variation rate, 2001-2021 (%)	-4.82	23.10	19.94
Percentage of households with 5G coverage, 2023 (%)	100	97.82	85.87
Number of municipalities	1	24	37

	Cluster 4	Cluster 5
Mean score	*Moderately Deprived Municipalities*	*Deprived Municipalities*
Municipal Green Transition Vulnerability Index (MGTVI)	1.10	2.63
Gross disposable income per capita, 2019 (€)	12,230.58	9,039.9
Population density, 2023 (inhabitants/km^2),	16.5	5.8
Population variation rate, 2001-2021 (%)	-12.99	-13.62
Percentage of households with 5G coverage, 2023 (%)	55.41	15.30
Number of municipalities	27	13

Source: Authors' own calculation.

4.3. Spatial autocorrelation of MGTVI

Table 3 shows Moran's I-test results for the spatial autocorrelation of MGTVI across Cantabrian municipalities. I coefficient is positive, and the null hypothesis that the MGTVI is randomly distributed among the Cantabrian municipalities is rejected. Therefore, it is concluded that MGTVI is spatially correlated: municipalities whose neighbours are more vulnerable to the green transition tend to be more vulnerable too. This result has a strong practical implication, as it shows deep potential for cooperation across neighbouring municipalities with a similar situation in facing the green transition. This can be done by direct cooperation of municipalities through associations or commonwealths ("mancomunidades", frequently used in Spain to jointly provide public services by several municipalities) or by creating intermediate territorial units between the local and the regional level ("comarcas", a territorial unit which exists in other Spanish regions such as Aragón and Cataluña), which may be useful for the provision of public policy (including monitoring and planning economic activities) and infrastructure.

Table 3. Moran's I-test results for the MGTVI of Cantabrian municipalities

Variable	I	E(I)	Sd (I)	z	p-value
MGTVI	0.07	-0.01	0.02	5.62	0.00

Source: Authors' own calculation.

5. Conclusions

The EU is moving forward and enthusiastically towards a green transition which, as significant political and social actors underline, should also be just: that is, distributed in a balanced way across societal groups and territories. Recent academic research, however, shows deep differences between EU regions in vulnerability to the green transition, whereas less-developed, peri-urban and predominantly rural regions are the most vulnerable (Rodríguez-Pose and Bartalucci, 2024). This has strong implications for regional policy as, without appropriate compensatory mechanisms, the green transition would increase the existent imbalances between EU regions. Little evidence, however, exists on whether and how vulnerability to the green transition may also differ within EU regions.

This paper has produced an index of vulnerability to the green transition for the municipalities within a Spanish region: Cantabria. It used the same methodology and similar indicators than Rodríguez-Pose and Bartalucci (2024), allowing for comparability with that paper and other future papers based on the same approach. The results show that the most deprived and the least densely populated municipalities in the region are also the most vulnerable to the green transition. Furthermore, vulnerability to the green transition in Cantabrian municipalities is strongly connected with two crucial current policy issues in the EU. First, depopulation trends: the municipalities with the highest population loss in the last two decades are the most vulnerable to the green transition. And second, the digital transition: the municipalities with the lowest 5G coverage are also the most vulnerable to the green transition. Cluster analysis confirms the divide between highly-vulnerable deprived areas in the Southern Mountain range of the region, versus the least-vulnerable affluent areas in Northern coastal urban placements. Moran I test shows a clear pattern of association of vulnerability to the green transition across neighbouring municipalities.

These results pose significant implications for the green transition and regional policy in the EU and beyond. First, they illustrate how the green transition faces the risk of increasing existent imbalances in the global economy. In particular, in the EU the green transition may increase inequality not only between regions, but also within them, where urban and affluent areas would be the winners and rural, deprived and depopulated areas the losers. Appropriate compensatory just transition policies are needed if the EU aims to preserve territorial cohesion, and these policies should consider not only differences between regions but also differences within them. In the specific case of Spain, for instance, the Just Transition Fund is helping regions (provinces, or NUTS 3 according to EU nomenclature for territorial units) previously more dependent on coal to cope with the green transition. However, it ignores municipalities holding a high vulnerability to the green transition located in a region that does not. Considering a territorial unit intermediate between municipalities and provinces ("comarcas") would be useful for implementing just transition policies in Spain, given that vulnerability to the green transition is found to be spatially correlated among neighbouring municipalities, and policy action may also benefit from cooperation and coordinated action between close municipalities. Second, the results show that the EU should address the green transition complementarily to the digital transition, in the so-called twin transition (Faggian et al., 2024; Damioli et al., 2025), and incorporate a territorial perspective into the process. Otherwise, without sufficient convergence in digital transition between rural and urban areas, and between deprived and affluent areas, the territories most vulnerable to the green transition face the risk of being left further behind.

This paper contributes to incipient evidence on the territorial heterogeneity in vulnerability to the green transition in the EU, by illustrating it significantly varies not only between regions, but also within regions. It provides results which are replicable and comparable with those obtained by Rodríguez-Pose and Bartalucci (2024) and other future papers which follow a similar approach, and at the same time it moves forward through empirically analysing vulnerability to the green transition for further level of territorial disaggregation: from regions to local units (municipalities). Our approach faces, however, two potential limitations. First, using Rodríguez-Pose and Bartalucci (2024)' approach to analyse vulnerability to the green transition among EU regions may not be appropriate for analysing vulnerability to the green transition among municipalities within any EU region. The indicators (considering their variability, relevance and interpretation), the methodology and even the concept of vulnerability used may need adaptation to each specific context. This, however, may hinder comparability of the results, and may also put into question the indicators and methods used if they largely diverge from the original ones. And second, while the results apply for the region of Cantabria, they may not apply for other EU regions. The approach followed allows for replicability and comparability of the analysis, albeit in practice this is hindered by the lack of comparable information across local units (municipalities or equivalent) at the EU level, and even the difficulties for joining a set of comparable information for regions within a single country (such as Spain). Future research may reproduce and extend this analysis to other Spanish regions, and even to other EU regions beyond Spain, where sufficient comparable information is available. To support this research line, institutions (including statistical offices) should increase efforts in producing information on the determinants of vulnerability to the green transition both at the regional and local levels, including in particular data on employment by activity branch. This would help for designing place-based and place-sensitive approaches to territorial development, following Rodríguez-Pose et al. (2024), that when applied to piloting the green transition in a territorial perspective, imply targeted policies at all levels (global, national, regional and also local) to ensure that the green transition is also a just transition.

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Appendix 1. Methodological considerations (principal component analysis)

Table A.1. shows the descriptive statistics of the 9 indicators used to construct the MGTVI for Cantabrian municipalities. From them, the MGTVI has been calculated as a composite index, following the same methodology and procedure that Rodrīguez-Pose and Bartalucci (2024) used to calculate their Regional Green Transition Vulnerability Index for EU regions.

Principal Component Analysis (PCA) is aimed to compress the size of a certain data set, in order to simplify its description and study the structure of the observations and the variables (Abdi and Williams, 2010).

The use of PCA enables to reduce the number of variables in a data set into a smaller number of "dimensions" by creating indices where each component is a linear weighted combination of the initial variables.

The PCA is applied to the list of 9 indicators selected as determinants of each municipality's vulnerability to the green transition. One mayor issue for the accuracy of PCA-based indices is that the distribution of variables must vary across cases (in this case, across municipalities) as, generally, those variables with the greatest variance across cases are given more weight in the PCA (McKenzie, 2005).

Table A.1. Descriptive Statistics of the indicators used to construct the mgtvi for Cantabrian municipalities

Variable	Obs	Mean	Std.Dev	Min	Max
CO_2 emissions per head, 2023	102	4.309	1.898	1.489	11.344
Change in CO_2 emissions per head between 2012 and 2023	102	-0.102	0.313	-0.746	0.958
Total value of wages and salaries in mining and quarrying, as a share of disposable income, 2023	102	0.002	0.003	0.000	0.019
Employment in agriculture, relative to total employment, 2023	102	0.105	0.095	0.004	0.429
Bovine cattle by population, 2023	102	2.176	2.230	0.006	10.029
Employment in accommodation and food services, relative to total employment, 2023	102	0.104	0.055	0.022	0.333
Tourist arrivals relative to population, 2023	102	14.018	15.344	0.960	108.020
Cooling degree days, 2018-2022	102	55.150	15.751	0.000	82.770
Road freight transport (Trucks and vans relative to population), 2023	102	0.180	0.085	0.066	0.446

Following Rodríguez-Pose and Bartalucci (2024), we take the coefficients of the first component obtained in the PCA to construct our MGTVI. As shown in Table A.2., the first principal component accounts for 32.9% of the total variation in the original dataset.

Table A.2. Proportion of the total variation explained by the pca components

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	2.957	1.020	0.329	0.329
Comp2	1.937	0.785	0.215	0.544
Comp3	1.152	0.172	0.128	0.672
Comp4	0.980	0.262	0.109	0.781
Comp5	0.718	0.195	0.080	0.861
Comp6	0.523	0.060	0.058	0.919
Comp7	0.464	0.272	0.052	0.970
Comp8	0.191	0.115	0.021	0.991
Comp9	0.077		0.009	1.000

The coefficients of this first component emphasize primary sector variables: employment in agriculture relative to total employment (0.532) and bovine cattle by population (0.532). Other factors, such as road freight transport (0.469), CO_2 emissions (0.336) and change in CO_2 emissions (0.215) and cooling degree days (0.191) are also highlighted as variables that contribute significantly to municipalities' level of vulnerability to the green transition.

Wages and salaries in mining and quarrying (0.012) has a very low value, which is coherent with the low size of the sector in Cantabria. Finally, tourism variables are slightly negative, which is coherent with the fact that tourism in Cantabria predominantly comes from surrounding areas, which may be less vulnerable to the green transition than tourism addressed to farther competitive destinations.

Table A.3. Computed coefficients for the PCA components

Variable	*Comp 1*	Comp 2	Comp 3	Comp 4	Comp 5	Comp 6	Comp 7	Comp 8	Comp 9
CO_2 emissions per head, 2023	*0.336*	-0.272	0.230	0.412	0.292	-0.440	-0.528	0.116	0.143
Change in CO_2 emissions per head between 2012 and 2023	*0.215*	0.105	0.356	-0.662	0.603	0.089	-0.026	0.041	-0.062
Total value of wages and salaries in mining and quarrying, as a share of disposable income, 2023	*0.012*	-0.052	0.801	-0.104	-0.581	-0.051	0.018	0.040	-0.051
Employment in agriculture, relative to total employment, 2023	*0.532*	0.119	-0.059	0.005	-0.114	0.063	0.386	0.293	0.669
Bovine cattle by population, 2023	*0.542*	0.005	-0.068	0.184	-0.027	-0.009	0.306	0.232	-0.721
Employment in accommodation and food services, relative to total employment, 2023	*-0.085*	0.636	-0.025	0.063	-0.093	0.212	-0.466	0.556	-0.059
Tourist arrivals relative to population, 2023	*-0.012*	0.593	-0.026	-0.064	-0.022	-0.741	0.171	-0.254	-0.018
Cooling degree days, 2018-2022	*0.191*	-0.280	-0.410	-0.581	-0.404	-0.278	-0.339	0.147	-0.046
Road freight transport (Trucks and vans relative to population), 2023	*0.469*	0.252	-0.041	0.039	-0.164	0.347	-0.343	-0.669	0.008

Source: Authors' own calculation.