Local Environmental Gains from Green Cohesion Policy: A Study of Carbon Abatement in Italian Municipalities

Francesco Scotti*[1, 4], Giovanni Bonaccorsi[1], Alessandro Buongiorno[2], Andrea Gilardi[3], Mario Intini[2], Valeria Maria Urbano[1], Andrea Flori[1], and Angela Stefania Bergantino[2]

[1]*Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Via Lambruschini, 4/B, 20156, Milan, Italy.*

[2]*Department of Economics, Management and Business Law, University of Bari Aldo Moro, Italy, Largo Abbazia S. Scolastica 53, Bari, Italy*

[3]*MOX - Dipartimento di Matematica, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano, Italy*

[4]*Department of Geography and Environment, London School of Economics, Houghton St, London WC2A 2AE, UK*

**corresponding author: francesco.scotti@polimi.it*

Abstract

The sustainability transition emerged as a pivotal focus during the 2014-2020 programming period of the EU Cohesion Policy, absorbing approximately 16% of the total available budget. As a prominent example of place-based policy, we investigate how local context characteristics influence the impact of such regulation, by examining the effects generated by Cohesion Policy funds targeting carbon abatement purposes in terms of PM2.5 reduction between 2014 and 2020. Utilizing panel Spatial Durbin Models (SDM), we analyze these impacts across three clusters of Italian municipalities characterized by distinct local contexts. Our findings reveal significant direct and indirect effects of these financial support programs in municipalities characterized by high economic capital. Moreover, these funds are associated solely with significant spillovers in the cluster of municipalities exhibiting a strong presence of tourism-related infrastructures. Conversely, we do not find a significant impact in the cluster of territories with a low economic endowment, but high-quality human capital. However, we obtain significant direct and indirect effects for a subset of these municipalities displaying higher levels of wealth and availability of financial, public mobility, and tourism-related services. As these municipalities are mainly located in less developed regions and receive the highest portion of EU Cohesion Policy funds, this finding may support a more effective allocation of the EU budget.

Keywords: EU Cohesion Policy; Carbon abatement; PM2.5; Spatial Durbin Model; local context.

Highlights

- We investigate the impact of Cohesion Policy funds targeting carbon abatement.
- The reduction of PM2.5 concentration depends on the local context of territories.
- Municipalities with high economic capital show relevant direct and indirect effects.
- Heterogeneous results characterize territories with a low economic endowment.
- We discuss the drivers of a more effective allocation of the Cohesion Policy budget.

1 Introduction

The Cohesion Policy is a cornerstone among regional development policies aiming to stimulate long-term economic growth patterns while trying to comply with international climate targets (OECD, 2009; Quental et al., 2011; Barca et al., 2012). Although it was originally conceived as a fiscal equalization instrument, pointing to activate economic convergence through a catching-up mechanism between more advanced and less developed regions, the EU Cohesion Policy has recently undergone relevant reforms that have progressively enlarged its scope (Sala-i Martin, 1996; European Commission, 2014; Bachtler et al., 2018). For instance, in 2007 the European Commission (EC) clearly stated that the EU Cohesion policy should integrate climate change as a new relevant priority area to facilitate the transition towards a low-carbon economy (European Commission, 2007; Barca, 2009).

As a consequence, in 2013 this policy framework underwent significant regulatory changes, aimed at strengthening the alignment between policy objectives and funds allocation with a greater thematic concentration focusing on environmental targets (Vironen et al., 2019). Consistently, the sustainability transition constituted one of the main pillars of the programming period 2014-2020 absorbing around 16% of the total available budget.

Despite such focus of the EU Cohesion Policy on sustainability transition, the extant literature has mainly concentrated on the analysis of the socio-economic impact of Cohesion Policy funds, considering GDP per capita and employment as main outcome variables (see e.g., Gripaios et al. (2008), Mohl and Hagen (2010), Becker et al. (2012), Pieńkowski and Berkowitz (2016), Dall'Erba and Fang (2017) and Scotti et al. (2024)).

Limited exceptions are represented by Medeiros (2014), Agovino et al. (2016a), and Agovino et al. (2016b) who investigated the effects of EU Cohesion Policy on the environmental sector in terms of water supply, public sanitation, waste collection, and share of renewable energy sources. However, such contributions overlook the effects of the EU Cohesion Policy in terms of carbon abatement, although the reduction of Green House Gases (GHG) emissions represents a key priority within the wide set of climate actions financed by the EC. Furthermore, they tend to produce aggregate studies that do not adequately account for the heterogeneity of the analyzed territories, using approaches more suited to investigating the impact of "spatially blind" policies. This stands in contrast to the EU Cohesion Policy, which is a prominent example of a placed-based policy, progressively providing tailored interventions based on the specific context, with the local stock of tangible and intangible assets that may significantly mediate the impact of EU funds (Fratesi et al., 2014; Fratesi and Perucca, 2016, 2018, 2019; Bachtrögler et al., 2020).

Against this background, our paper aims to analyze the impact of the EU Cohesion Policy on the PM2.5 air concentration over the time frame 2014-2020 with a specific focus on the allocation of funds supporting the green transition. We rely on an original dataset including 10,468 projects focused on pollution reduction, covering 1.2 € billion of green EU funds expenditures, corresponding to around 40% of the total budget allocated by the EC to low carbon economy projects in Italy for the programming period 2014-2020. To the best of our knowledge, this is the first work aiming to disentangle the interplay between green EU funds[1] and emissions reduction at the municipal level based on the local context, to clarify how the presence of specific local factors may influence the effectiveness of the EU Cohesion Policy in terms of carbon abatement. To this scope, we focus on Italy as it serves as an ideal setting for two main reasons. First, the air quality in Italy ranks among the worst in Europe, exacerbated by the country's geographical structure that renders it highly susceptible to the impacts of climate change (European Environment Agency, 2020). Indeed in 2021, according to the European Environmental Association (EEA), Italy experienced one of the highest air pollution concentration (40 $\mu g/m^3$) among EU old member states (only better than Greece with 46 $\mu g/m^3$), performing significantly worse than the EU average (33 $\mu g/m^3$).[2] Second, Italy, with 3.2€ billion allocated to the low carbon economy, stands out as one of the primary recipients of green EU funds (second only to Spain with 3.3€ billion), offering exceptional and comprehensive data on the EU Cohesion Policy framework for our analysis (Atella et al., 2023; Pellegrini and Tortorella, 2018).[3]

Through the application of panel Spatial Durbin Models (SDM), we show that green EU funds tend to generate heterogeneous results across three alternative clusters of territories with significantly different stocks of economic, human, and physical assets. We find both a direct and an indirect effect in terms of PM2.5 reduction when we restrict the analysis to municipalities

[1]In the rest of the paper we use the expression "green EU funds" to refer to EU Cohesion Policy funds explicitly targeting carbon abatement purposes. See Section 3.1 for further details on how we identify projects financed by the EU Cohesion Policy with a specific focus on pollution reduction.

[2]The information related to the air pollution concentration is available at the following link: `https://www.eea.europa.eu/publications/europes-air-quality-status-2023`.

[3]The information related to budget allocation on the low carbon economy at country level is available at the following link: `https://cohesiondata.ec.europa.eu/countries/IT/14-20`.

in the Centre-North of Italy with high economic capital (Cluster 1). Indeed, these programs of financial support contribute to reducing emissions both in the municipality directly receiving them (-1.7%), but also in the neighboring areas (-1.3%). Conversely, we find evidence of only significant spillovers (e.g., indirect effects equal to -1.1%) in territories with a strong presence of the tourism-related activities (Cluster 2). Neither direct nor indirect effects are observed in our third cluster, including territories mainly located in the Centre-South of Italy with a low endowment of economic assets, but high-quality human capital.

We also investigate the mechanism through which significant spillovers are generated in Cluster 2, due to the absence of associated relevant direct effects. We highlight that such indirect effects may be a consequence of EU funds expenditures implemented in municipalities of Cluster 1 that are geographically close to territories included in Cluster 2. Finally, due to the higher budget allocation to less developed regions, we further analyze the relationship between EU funds and PM2.5 concentration in municipalities in Cluster 3. We show that areas with higher income per capita, lower employment in the manufacturing sector, as well as larger availability of bank deposits, loans, and services in terms of public mobility and accommodation structures are characterized by a significant impact of the EU Cohesion Policy to PM2.5 reduction both in terms of direct and indirect effects.

Furthermore, we analyze how the characteristics of the local context mediate the effect of the Cohesion Policy, thus linking our study to the literature analyzing how the endowment of public, private, material, and immaterial assets affects the outcome of regional development policies (Camagni et al., 2009). In this direction, we highlight the specific factors that may increase the effectiveness of EU funds in terms of emissions reduction. A careful comprehension of the drivers influencing the impact of the EU Cohesion Policy on the sustainability transition may thus support policy makers to improve the cost-effectiveness of current strategies to comply with environmental goals.

The rest of the paper is organized as follows: Section 2 provides an overview of the extant knowledge on the EU Cohesion Policy impact on the environmental sector. Sections 3 and 4 illustrate the data and the methods we employ to investigate our research objective. Section 5 delves into our findings, which are divided into three sections. The first section presents the results in terms of their impact on the three clusters. The second section analyzes the mechanisms explaining the generation of spillovers. Lastly, the third section provides an in-depth exploration of the effectiveness of funds within cluster 3. Following this analysis, the paper concludes by highlighting the main implications of our study.

2 Theoretical Background

Strategies for climate change mitigation and the EU Cohesion Policy are widely scrutinized topics, but they have rarely been jointly investigated (Nekvasil and Moldan, 2018). The limited availability of analyses focusing on their mutual relationship might be explained by the recent inclusion of climate change as a key priority area within the EU Cohesion Policy. Indeed, before the programming period 2014-2020, the environmental dimension did not represent a pillar of the policy (see Council Regulation (EC) No, 1083/2006 and Council Regulation (EU) No, 1303/2013).[4] Due to the impossibility to comply with international climate targets (e.g., Kyoto commitment, Paris Agreement) without a complete integration of the climate change dimension among critical priorities of the EU Cohesion Policy (Nilsson and Nilsson, 2013), the budget allocated by the EC to projects directly focusing on climate-related investments has significantly increased, moving from about 2% during the time window 2000-2006 to 8.4% and 16.3% during the most recent programming-periods 2007-2013 and 2014-2020, respectively.

EU funds may thus constitute critical instruments to re-direct economic capital from dirty incumbent technologies towards the development of clean innovation (Perez, 2010; Schmidt, 2014), contributing to overcoming financial barriers that typically constrain the sustainability transition (Polzin et al., 2016; Chen et al., 2020; Mukanjari and Sterner, 2020). Indeed, they may alleviate firms' financial constraints, enabling research and development activities on new technologies targeting emissions reduction with a still risky return profile (Zhang et al., 2020; Alam et al., 2022). Furthermore, they show the commitment of relevant international institutions such as the EC in favor of the sustainability transition, thus limiting the uncertainty associated with firms' investments in low-carbon technologies (Polzin, 2017; Geddes and Schmidt, 2020). As the decarbonization process is mainly driven by technological innovation from renewable energy sources, electrification of the economy across different sectors (e.g., trans-

[4]These two documents are available at the following links: `https://www.eumonitor.eu/9353000/1/j9vvik7m1c3gyxp/vitgbgikc2zw` and `https://eur-lex.europa.eu/TodayOJ/`.

portation), improved energy efficiency in buildings, industry, and household appliances, as well as secure energy systems, EU Cohesion Policy funds may support the large investments required at the firm level to foster a low-carbon economy (Fragkos et al., 2017; Jamasb and Llorca, 2019; Cambini et al., 2020; Castrejon-Campos et al., 2022; Llorca and Rodriguez-Alvarez, 2024).

Consistently with these expectations, some preliminary evidence suggests that EU Cohesion Policy funds may accelerate the socio-technical transition towards green innovation. For instance, as discussed by Nekvasil and Moldan (2018), operational programs focused on clean energy production fostered the substitution of fossil fuels with renewable energy sources, reaching a value of 7700 MW per year, almost tripling the level observed at the end of the programming period 2007-2013. Furthermore, public and residential buildings, responsible for approximately 36% of CO_2 emissions in the EU, experienced a decrease of primary energy consumption in public buildings by 5.2 TWh per year across all EU Cohesion Policy operational programs. These climate-related projects have translated into a progressively stronger contribution of the EU Cohesion Policy to the achievement of environmental targets, since the overall reduction of GHG emissions associated with finalized projects under this regulatory framework raised from 17.1 to 25.1 Mt of CO_2, corresponding to about 0.5% of total EU emissions.

Although such data highlight that the EU Cohesion Policy stimulated carbon abatement at the aggregate level, heterogeneous results emerge when considering single countries. Indeed, convergence in terms of CO_2 per capita was observed over the period 1990-2010 across EU countries, with territories experiencing higher starting levels of GHG emissions (e.g., Finland, Ireland, Belgium) that were associated with a stronger yearly carbon abatement rate (between -4.0% and -2.0%) (Duro and Padilla, 2013; Liobikienė and Mandravickaitė, 2016). Conversely, the most problematic countries were Estonia, Austria, and Poland, exhibiting a large initial emissions level and still subject to a growth in pollution (between 0.2% and 2.0%).

Such results may be driven by the different intensity of funds targeting the sustainability transition attracted by territories, with more peripheral regions in the North and South of Europe from a geographical, innovation, and socio-economic perspective receiving a larger amount of financial support. Conversely, when focusing on within-country disparities in terms of green funds attraction, peripheral areas tended to experience a lower level of low-carbon investments with respect to territories exhibiting a higher demographic density and a higher level of economic development in terms of GDP and income per capita (Kozera et al., 2022; Peñalosa and Castaldi, 2024).

Overall, the available studies tend to show that the EU Cohesion Policy may have a strong potential to drive the sustainability transition. However, we still lack robust studies clarifying the EU funds' impact on climate change-related targets. With our study, we build a novel dataset linking EU green fund expenditures and PM2.5 levels at the municipal level over the most recently concluded programming period 2014-2020. Therefore, we fill this gap by showing how EU Cohesion Policy funds targeting the environmental sector contributed to carbon abatement across territories with a heterogeneous local context. Such empirical evidence might also be informative to increase the effectiveness of future programming periods (e.g., 2021-2027) to support the achievement of a low-carbon economy.

3 Data

3.1 Beneficiaries Identification

Since our research objective is to disentangle the impact of EU Cohesion Policy funds addressing the goal of GHG emissions reduction, we restrict our analysis to the subset of projects explicitly targeting carbon abatement purposes. We thus build a comprehensive database on the set of projects financed by the EU Cohesion Policy in all Italian regions focused on the sustainability transition, relying on the Open Coesione data platform. We rely on the dataset version disclosed as of December 31, 2023, thereby ensuring that our analysis accounts for all the green EU funds expenditures realized in the period 2014-2020, even in case of a certain time delay between the project implementation and the accounting of related expenditures in the Open Coesione dataset. This is also in line with the "N+3" rule, allowing beneficiaries to spend EU Cohesion Policy funds until three years after the end of the current programming period. [5]

In particular, we consider the European Regional Development Fund (ERDF) and the European Social Fund (ESF), since they represent the main programs of financial support within the EU Cohesion Policy, covering 58.0% and 26.4% of the total available budget for the time

[5] Information related to projects implemented by each Italian region within the EU Cohesion Policy framework is available at the following link: `https://opencoesione.gov.it/it/opendata/#!progetti_regione_section`.

frame 2014-2020. Furthermore, they are expected to be representative of the overall set of climate-related projects financed by the EC, absorbing more than 30% of the 216€ billion fostering the sustainability transition.[6] Moreover, differently from other programs of financial support, such as the European Maritime and Fisheries Fund and the Fund for European Aid to the Most Deprived, the EU funds included in our analysis are allocated to all Italian territories and not only to sub-specific areas, thus allowing us to compare the effects generated by these funds across different municipalities in Italy. We rather do not consider the Cohesion Fund (CF) since it is aimed at Member States whose Gross National Income (GNI) per inhabitant is less than 90 % of the EU average, and thus not concerning Italy over the period 2014-2020.

Based on the thematic code attributed to each project by the EC, in a first stage, we restrict our analysis to projects related to "low carbon economy and energy efficiency" (thematic objective 4). Based on the project description, we verify that such projects strictly relate to activities targeting emissions reduction, thus potentially having a direct impact on carbon abatement. Through this procedure, we initially select 5,736 projects.

Then, based on the title and synthetic description of these selected projects, we identify a set of frequent keywords, allowing us to distinguish projects targeting the sustainability transition in terms of carbon abatement. Table A1 reports the set of keywords occurring at least 50 times in the description of projects and referring to the emissions reduction objective. We use such keywords to identify projects that were not classified in the thematic objective 4 by the EC (thus initially excluded from our selected sample), but that are still contributing to the emissions reduction goal.

Since projects out of thematic objective 4 focus on different dimensions with respect to carbon abatement, we expect that single keywords may not be able to correctly identify projects actually focusing on carbon emissions. Therefore, we manually inspect every single project containing at least one of those keywords to verify that the shortlisted projects aimed to foster

[6]Further details on the amount of funds dedicated to climate change-related projects by the different EU Cohesion Policy funds are available at the following link: `https://op.europa.eu/webpub/eca/special-reports/climate-mainstreaming-09-2022/en`. In particular, the total climate contribution of the ERDF reached 50.9 € billion (24%), while ESF expenditures were equal to 20.5€ billion (9%). We rather exclude the European Agricultural Fund for Rural Development (EAFRD) accounting for 57.7 € billion corresponding to 27% of the overall budget for two main reasons. First, its main contribution to climate change is focused on the agriculture sector and does not directly target carbon emissions reduction. Furthermore, this fund is not included among EU Cohesion Policy funds and thus is not covered in the Open Coesione data platform that we use for our analysis. Therefore, information on projects related to the EAFRD would not be available in the Italian context with the same level of detail as for the ERDF and ESF.

carbon abatement.[7] Through this procedure, we select an additional 5,172 projects.

In this way, we expect to provide a complete overview of the set of projects targeting the sustainability transition with a specific focus on emissions abatement. From this sample, we exclude projects with a realized cost equal to zero, as they have not started, yet. Our final sample consists of 10,468 projects and 1.2 € billion of realized expenditures.[8]

Since our geographical unit of analysis is represented by municipalities, we aggregate our data at the municipal level.[9] Overall, our dataset covers 3,641 Italian municipalities spending public funds from the Cohesion Policy with a specific target on carbon abatement over the time frame 2014-2020. Figure A1 shows the geographical distribution of green EU funds expenditures across Italian municipalities normalized by the total income of the underlying administrative unit. Consistently with the allocation logic of the ERDF and the ESF, mainly targeting less developed areas, we observe a higher level of expenditures in the South of Italy. Indeed, when aggregating data at the macro-area level (NUTS-1), a higher intensity is experienced by the South and Insular Italy (0.35% and 0.32% of total income), receiving 315 and 152 € million, respectively (see Table A4). Conversely, North-East and North-West macro-areas displayed the lowest treatment intensity (0.12% and 0.19% of total income corresponding to 158 and 280 € million, respectively). Consistently, provinces obtaining the highest amount of funds are concentrated in the South of Italy (especially in Basilicata, Campania, Sicilia, and Sardinia regions), whereas provinces in the Centre and North of Italy are recipients of lower green funds (see Tables A2 and A3).

3.2 Dependent Variable

We consider the level of PM2.5 emissions at the municipal level for the time frame 2014-2020 as our dependent variable. We focus on PM2.5 since it is a primary cause of death monitored

[7]For instance, we check that projects containing words related to emissions or the energy sector are actually aiming to achieve energy efficiency or carbon abatement purposes and such aspects are not marginal in the project description. We thus exclude projects where emissions reduction might have been a possible positive externality of the project, without being a central expected outcome of the investment.

[8]The amount of expenditures related to carbon abatement in our dataset (1.2€ billion) is larger than the official figure reported by the EC for low carbon economy projects in Italy during the programming period 2014-2020 (847€ million). This is due to the fact that we identify the additional 5,172 projects with a thematic objective different from "low carbon economy and energy efficiency" but still with a focus on carbon abatement according to their synthetic description.

[9]In particular, we compute the total amount of green EU funds spent by Italian municipalities in each year of the period 2014-2020.

by the European Environment Agency (EEA) and is a reference pollutant used by the EC to establish environmental targets (González et al., 2015; Tarín-Carrasco et al., 2021; Beloconi and Vounatsou, 2023).[10]

National statistical offices and satellite measurements do not usually provide information related to the air concentration of pollutants with the spatial granularity and temporal frequency required by our analysis. For example, the Copernicus Atmosphere Monitoring Service (CAMS) provides real-time air quality predictions using a combination of 11 state-of-the-art chemical, physical, and transportation numerical models (Copernicus Atmosphere Monitoring Service, 2024). Unfortunately, the resolution of the ensemble forecasts is on a $0.1° \times 0.1°$ regular latitude-longitude grid (approximately 10km $\times$ 10km) and such spatial granularity is too coarse for the analyses performed in this paper since we are interested in exploring the air quality variations at the municipality level. Similarly, the National Statistical Office discloses information on air quality either at the province scale or at the level of single installations that do not cover all Italian municipalities, thus providing a too sparse overview of the pollution concentration across territories.

Therefore, we decide to build our dependent variable using raster data disclosed by the European Environmental Agency (EEA) covering the time frame 2014-2020. In particular, we rely on yearly air pollutants concentrations grids[11] (spatial resolution: 1 km $\times$ 1 km) that were derived by combining monitoring air quality data with external covariates (e.g. altitude or population maps) in a "regression-interpolation-merging mapping" methodology (Horálek et al., 2024).

The EEA data and the Italian municipalities are spatially misaligned. Therefore, the yearly average level of PM2.5 is computed using an *Area-Weighted Interpolation* of such pollutant concentration grids (Pebesma and Bivand, 2023, Chapter 5). More precisely, let $\{S_i\}_{i=1}^{n_S}$ be a set of spatially referenced cells where a variable $\{Y(S_i)\}_{i=1}^{n_S}$ is recorded. In this paper, S_i denotes the $i-$th pixel in the EEA grid, and $Y(S_i)$ is the corresponding PM2.5 value. Let $\{T_j\}_{j=1}^{n_T}$ be another grid of spatial units (i.e., the Italian municipalities) where we want to project the Y variable. The *Area-Weighted Interpolation* computes the average pollution value for the j-th

[10] Further information is available at the following links: `https://www.eea.europa.eu/en/analysis/indicators/health-impacts-of-exposure-to` and `https://environment.ec.europa.eu/topics/air/air-quality/eu-air-quality-standards_en`. Last access: March 2024.

[11] The raw data can be downloaded at the following link: `https://www.eea.europa.eu/en/datahub/datahubitem-view/82700fbd-2953-467b-be0a-78a520c3a7ef`. Data was downloaded in December 2023.

municipality ($Y(T_j)$) as:

$$Y(T_j) = \sum_{i=1}^{n_S} \delta_{ij} Y(S_i)$$

where δ_{ij} represents the proportion of area shared by S_i and T_j. Furthermore, considering that the raster units are much smaller than the complete study area and that, at such spatial scale, the $Y(S_i)$ values can be regarded as constant within each pixel, the weights δ_{ij} are specified as

$$\delta_{ij} = \frac{|S_i \cap T_j|}{|S_i|}$$

where $S_i \cap T_j$ is the geographical intersection between the i-th pixel and j-th municipality and $|\cdot|$ denotes the area of the underlying region. If we assume that the two grids, i.e., $\{S_i\}_{i=1}^{n_S}$ and $\{T_j\}_{j=1}^{n_T}$, represent two different partitions of the same observation window, then our choice of weights preserves the "mass" (i.e., the total amount) of the Y variable and does not distort the statistical inference. In fact, we can see that:

$$\sum_{j=1}^{n_T} Y(T_j) = \sum_{j=1}^{n_T} \sum_{i=1}^{n_S} \frac{|S_i \cap T_j|}{|S_i|} Y(S_i) = \sum_{i=1}^{n_S} \frac{Y(S_i)}{|S_i|} \sum_{j=1}^{n_T} |T_j \cap S_i| = \sum_{i=1}^{n_S} Y(S_i)$$

since $\{T_j\}_{j=1}^{n_T}$ completely cover each raster pixel S_i and, therefore, $\sum_{j=1}^{n_T} |T_j \cap S_i| = |S_i|$. [12]

Appendix B provides some details on the average distribution of PM2.5 concentration at the municipal level, over the period 2014-2020. Tables B1 and B3 clearly show that the North of Italy displays a low air quality due to the high values of PM2.5. In particular, areas located in Lombardy and Veneto regions tend to exceed the air quality standard set to 25 $\mu g/m^3$ of PM2.5 by the EC.[13]

[12] The aforementioned operations were performed using the `R` software and, in particular, the packages `sf` and `stars` (R Core Team, 2023; Pebesma and Bivand, 2023).

[13] Additional information related to air quality standards disclosed by the EC according to the Directive 2008/50/EC is available at the following link: `https://environment.ec.europa.eu/topics/air/air-quality/eu-air-quality-standards_en`. Conversely, lower pollution levels are observed in the South and Insular Italy with average PM2.5 levels equal to 20.53 and 17.83 $\mu g/m^3$. Such values are consistent with similar estimates provided by the Italian National Statistical Office (ISTAT) at a higher granular scale (e.g., provinces and regions). See for instance the ISTAT report available at the following link: `https://www.istat.it/it/files/2021/10/BES-Report-2020.pdf`.

4 Methods

4.1 Cluster Analysis

Our analysis aims to disentangle the impact of green EU Cohesion Policy funds across territories, taking into account their local context. To differentiate among alternative groups of Italian municipalities based on their territorial conditions, we conduct a cluster analysis.

Our classification framework identifies three dimensions of territorial characteristics: economic, human, and physical. With respect to other existing approaches to represent the local context (e.g., the framework of territorial capital introduced by Camagni et al. (2009)), our framework broadens the concept of cultural factors to encompass several human aspects and extends the concept of environmental assets to include more general physical characteristics.

The human dimension includes an *active population* indicator (Getzner and Moroz, 2022), measured as the ratio of adults aged 14-65 with respect to the total population, and the educational attainment of the resident population (Fratesi et al., 2014), measured by the number of residents enrolled in higher education institutions, i.e., *university students*.

The physical conditions of territories encompass environmental, infrastructure, and housing resources. Environmental conditions entail the environmental commitment and the available infrastructures within the territory (Fratesi and Perucca, 2016; Fratesi et al., 2014). In this study, we consider the percentage of *Waste sorting*, availability of *Drinking water* (expressed as thousands of cubic meters of water per inhabitant dispensed by the local municipality), and the intensity of *Soil usage* (m^2 per inhabitant) as proxies of the urban ecology, of the quality of local environmental services, and of the level of anthropization of the area, respectively. Infrastructures and services pertain to general services, including tourist facilities and transportation infrastructures (Fratesi et al., 2014). In this study, we incorporate additional local services by including the *Public mobility* index, measuring the number of passengers using public transportation systems, and the number of *Accommodation beds* available within various types of lodging facilities intended to accommodate tourists. Housing resources, also referred to as settlement capital (Blečić et al., 2022), pertain to housing supply and structural quality of the buildings. In our study, we assess these dimensions through the *Housing dispersion index*, measuring the contribution between high and low-density areas, and the *Building expansion* index, measuring the percentage of newly built houses out of the total number of houses.

The economic dimension of the local context includes the overall economic development level (Crescenzi, 2009; Bachtrögler et al., 2020) and the industrial structure of territories (Cappelen et al., 2003; Percoco, 2017). The overall economic development level is assessed through indicators such as *Income per capita*, *Bank branches per capita*, *Bank deposits per capita*, and *Bank loans per capita*. The industrial structure of territories is measured by the percentage of employees in the Manufacturing sector, referred to as *Manufacturing employees*.

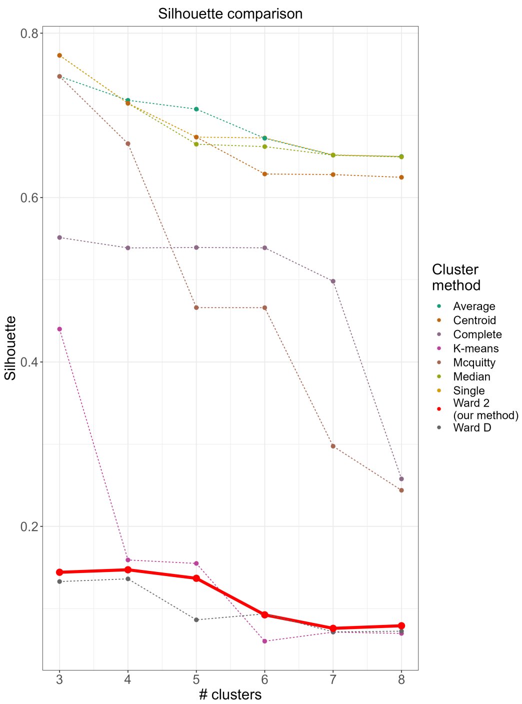
Table 1 presents a comprehensive breakdown of the dimensions, subdimensions, and corresponding indicators utilized in our study, categorizing them into Human, Physical, and Economic domains.

Table 1: The following table summarizes information related to the dimensions (human, physical, economic) included in our cluster analysis. Furthermore, with a progressively higher level of detail, we disclose subdimensions and indicators associated with each dimension. Finally, we clarify the source of our data. All information refers to the municipality level.

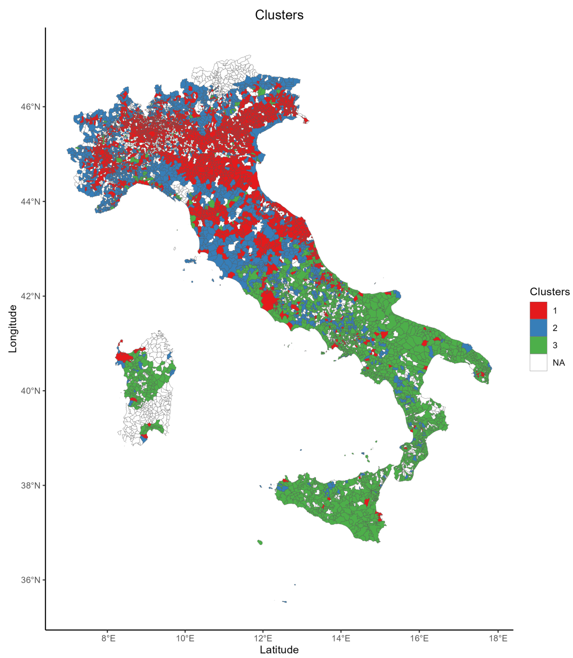
Dimensions	Subdimensions	Indicators	Sources
Human	Demography	Active population	ISTAT
	Education	University students	ISTAT
Physical	Environment	Waste sorting	ISTAT
		Drinking water	ISTAT
		Soil usage	ISTAT
	Infrastructure and Housing	Public mobility	ISTAT
		Accommodation beds	ISTAT
		Housing dispersion	Urban Index
		Building expansion	Urban Index
Economic	Economic Development	Income per capita	ISTAT
		Bank branches	ISTAT
		Bank deposits	ISTAT
		Bank loans	ISTAT
	Industrial Structure	Manufacturing employees	ISTAT

We perform a hierarchical cluster analysis based on these variables using the Ward 2 linkage criterion method as a standard approach to perform such analysis. To select the optimal number of clusters we rely on the silhouette coefficient, allowing us to compare intra and inter-cluster distances, thus providing insight into the quality of the clustering method output (Rousseeuw, 1987). A detailed description of the silhouette definition and the methodology used is provided in Section C of the Supplementary Material. We then assess the stability of our results by comparing the output of different hierarchical clustering methods based on alternative agglomeration methods. We obtain the optimal results in terms of silhouette for a number of clusters equal to 3 (see the left panel in Figure 1).

Figure 1 (right panel) reports the geographical distribution of municipalities across the three clusters [14]. Figure C1 shows the distribution of the variables used in the cluster analysis across the three groups.



Comparison of Silhouette Scores.



Map of clusters.

Figure 1: We show the output of our cluster analysis (right) and a comparison of silhouette scores across various clustering methods (left) where our preferred method (Ward 2) is represented by a continuous red line. Municipalities left blank (NA) are administrative units with missing values on one or more covariates employed in the cluster analysis.

To assess the robustness of the clusters in terms of differences across each variable, a pairwise t-test with Bonferroni correction was conducted. This test allowed for comparisons of variable levels between different clusters, highlighting any statistically significant differences. The results indicate that differences between clusters are significant in the majority of cases, suggesting a robust segregation of data into distinct groups. The results of the t-tests are available in Section C of the Supplementary Material for further reference.

The first cluster is distinguished by its high level of economic development, particularly evident in terms of income, bank deposits, and loans, as well as a significant presence of employees in manufacturing industries. From the point of view of environmental resources, it exhibits low soil usage, high waste sorting, and low availability of drinkable water. Regarding

[14]The clustering analysis covers a total of 6242 municipalities, with an NA percentage of 21% relative to the total number of Italian municipalities.

Table 2: We show the median value of covariates for the 3 clusters.

Cluster	1	2	3
Income pc	18,538.840	15,864.640	12,953.470
Bank branches	0.001	0.001	0.000
Bank deposit	4.305	0.000	0.000
Bank loans	4.021	0.000	0.000
Manufacturing employees	0.399	0.153	0.134
University students	0.020	0.020	0.033
Drinkable water	76.000	81.400	67.700
Public mobility	9.700	10.800	12.600
Waste sorting	61.700	43.700	26.400
Soil usage	497.150	818.200	497.300
Accommodation capacity	0.017	0.071	0.019
Housing dispersion	0.050	0.110	0.040
Building expansion	11.900	3.700	4.000
Active population	0.651	0.615	0.628

infrastructure and services, it stands out for high building expansion and low public mobility. In terms of human capital, it boasts a high active population but a low number of university students. We refer to this cluster as the group of municipalities with high economic capital, as it represents the set of characteristics mainly distinguishing these administrative units.

The second cluster is characterized by many bank branches in economic terms. From an environmental perspective, it is marked by a high availability of drinkable water and soil usage. In terms of infrastructure and services, it is notable for its high tourist accommodation capacity, while in housing, it shows high housing dispersion. Regarding human resources, it is characterized by a low active population. We indicate this cluster as the group of municipalities with a high presence of accommodation infrastructures. Notice also how from a geographical perspective administrative units in this cluster tend to include municipalities on the coast or in mountain areas with a high presence of tourism-related activities.

The third cluster showcases high human capital, with a significant number of university students and active population but a lower level of economic development with respect to the other clusters. This cluster is characterized by low income, bank deposits, and loans, as well as a low number of employees in manufacturing. With respect to environmental resources, it exhibits low levels of drinkable water, waste sorting, and soil usage. In terms of services, it is marked by high public mobility. Finally, it is characterized by low housing dispersion. We denote this cluster as the group of municipalities with high-quality human capital but low economic endowment.

Table 2 reports the median values of all the covariates for the 3 clusters.

4.2 Spatial Panel Models

To investigate our research question, we implement a panel Spatial Durbin Model (SDM), since it allows us to disentangle the marginal effect of green EU Cohesion Policy Funds between the direct effect and the associated spatial spillover (Debarsy et al., 2012; Elhorst et al., 2014). In formula:

$$\begin{aligned} Y_{i,t} = \lambda \sum_j w_{i,j} * Y_{j,t} + \beta_0 + \beta_1 \ Environmental \ Funds_{i,t} + \\ + \beta_2 \ \sum_j w_{i,j} * Environmnetal \ Funds_{j,t} + \gamma \ X_{i,t} + \epsilon_{i,t} \end{aligned} \tag{1}$$

where $Y_{i,t}$ is our dependent variable computed as the annual percentage variation of PM2.5 concentration in municipality i in year t (see Section 3.2 for further details). We include the spatial autoregressive component $\sum_j w_{i,j} * Y_{j,t}$ to account for potentially similar pollutant concentration dynamics in geographically close municipalities. Moreover, as explained in Section 3.1, $Environmental\ Funds_{i,t}$ is the expenditure of green EU funds (expressed as a percentage of the total income of the underlying municipality) allowing us to capture the direct contribution of such programs of financial support to the reduction of pollution in the municipality where projects are implemented (direct effect). The term $\sum_j w_{i,j} * Environmnetal \ Funds_{j,t}$ is rather responsible for spillover effects (indirect effect) since the expenditures of green EU funds in a municipality may also have an impact in terms of PM2.5 reduction in neighbor municipalities. Jia et al. (2021) employ a similar approach relying on an SDM model to investigate the impact of high-speed rail investments and CO_2 emissions in China.

Finally, $X_{i,t}$ is a vector of control variables including meteorological factors that could affect the concentration of the pollutant such as the wind speed, precipitation level, temperature, and humidity (Zhou and Levy, 2007; Chai et al., 2014; Zhang et al., 2015; He et al., 2017; Yang et al., 2019). Table 3 reports information related to the descriptive statistics and source of our dependent and control variables.

We test the robustness of our results through alternative specifications of the spatial matrix

Table 3: We report information related to the descriptive statistics and source of our dependent and control variables.

	Q1	Mean	Q3	Sd	Source
PM2.5 variation	-0.182	0.001	0.165	0.273	Copernicus & Authors' elaboration
Environmental funds (% income)	0.000	0.001	0.003	0.008	Open Coesione & Authors' elaboration
Environmental spillover	0.000	0.001	0.002	0.009	Open Coesione & Authors' elaboration
Temperature	14.142	15.665	16.782	1.741	ISTAT
Precipitation	9.021	10.598	11.725	2.273	ISTAT
Wind speed	1.936	2.293	2.551	0.513	Copernicus & Authors' elaboration
Humidity	71.862	75.386	79.246	5.457	Copernicus & Authors' elaboration

$W = \{w_{i,j}\}_{i,j=1}^{n}$ (with n being the number of municipalities in our model). First, we rely on the spatial exponential decay matrix:

$$w_{i,j} = exp(-\alpha d_{i,j})$$

where $d_{i,j}$ is the distance in kilometers between municipality i and j and α is the spatial decay parameter. We use a value equal to 2 in our main analysis since it is the value minimizing the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). Then we run a set of robustness checks for different values of α (0.1, 0.5, 1.0, 1.5, 2.5) in line with alternative specifications of the spatial decay exponent (see e.g., LeSage and Pace (2007); Benos et al. (2015); Piribauer and Fischer (2015)). Consistently with other studies relying on spatial models to investigate the impact of the EU Cohesion Policy (Dall'Erba and Le Gallo, 2008; Ramajo et al., 2008; Scotti et al., 2022), we consider different spatial weight matrices based on the application of the K-Nearest Neighbors (KNN) algorithm or relying on the "Queen" and inverse geographical distance logics.

A preliminary investigation of the relevance of direct and indirect effects could be performed based on the estimates of the parameters λ, β_1, and β_2 derived from Equation 1. However, LeSage and Pace (2009) illustrate how a more valid inference on direct effects and spillovers may be obtained by analyzing the matrix of partial derivatives of the dependent variable (PM2.5 variation) with respect to our variable of interest (environmental funds). Indeed, this approach takes into account all the relevant parameters contributing to generating the direct and indirect effects in a more precise manner. In line with the terminology in Elhorst et al. (2014), we thus define direct, indirect and total effects based on our equation 1.[15] In formula:

[15] With the term $\partial E(Y_i)/\partial EF_j$, we refer to the change of PM2.5 concentration in municipality i due to a variation of environmental funds (EF) in municipality j.

$$\begin{pmatrix} \partial E(Y_1)/\partial EF_1 & \dots & \partial E(Y_1)/\partial EF_n \\ \dots & \dots & \dots \\ \dots & \dots & \dots \\ \dots & \dots & \dots \\ \partial E(Y_n)/\partial EF_1 & \dots & \partial E(Y_n)/\partial EF_n \end{pmatrix} = (\text{I-}\lambda\text{W})^{-1}\ [\beta_1 I_n + \beta_2\ \text{W}] = \text{Sr(W)}$$

$$\text{Direct Effects} = \frac{1}{N} trace(Sr(W))$$

$$\text{Total Effects} = \frac{1}{N}\sum_i \sum_j Sr(W)_{i,j}$$

$$\text{Indirect Effects} = \text{Total Effects} - \text{Direct Effects}$$

In particular, direct effects measure the average direct contribution of a variation in the amount of green EU funds allocated to a certain municipality to the reduction of PM2.5 concentration in the same underlying administrative unit where the project is implemented. Indirect effects measure the average level of spillovers denoting the carbon abatement obtained in a municipality as a result of projects realized in neighboring municipalities. Total effects are the sum of direct and indirect effects.

5 Empirical Evidence

5.1 The impact across clusters

In this section, we analyze the impact of green EU Cohesion Policy funds across different clusters of municipalities displaying a heterogeneous local context in terms of economic, human, and physical characteristics as shown in Section 4.1.

In Table 4 we separately estimate the panel-spatial models by restricting the sample to municipalities included in one single cluster. On the one hand, we observe a significant direct and indirect impact of funds targeting carbon abatement in Cluster 1. In particular, these programs of financial support reduce the level of PM2.5 emissions in the municipality implementing the project (β_1 = -0.007) as well as in the neighbor administrative areas (β_2 = -0.005). On the other hand, we only find statistically significant spillovers for municipalities in Cluster 2 with a slightly lower magnitude (β_2 = -0.004) with respect to those identified in Cluster 1. Finally, we do not obtain relevant effects of green funds for municipalities located in Cluster 3.

As explained by LeSage and Pace (2009) such estimated parameters do not allow for immediate interpretation of the marginal effect of environmental fund expenditures on carbon abatement. Indeed, such parameters do not account for feedback in the variation of PM2.5 levels from other neighboring regions due to the presence of a spatial autoregressive component (λ parameter). Table 5 reports our complete estimates for direct, indirect, and total effects generated by green EU Cohesion Policy funds as explained in Section 4.2.

For Cluster 1 we find that a 1% growth of EU funds, expressed as a portion of local total income, contributes to reducing PM2.5 levels by 1.7% in the same municipality. Moreover, it generates a decrease in emissions by 1.3% in neighboring municipalities. A similar impact in terms of spillovers is observed in municipalities of Cluster 2 where the green funds reduce PM2.5 levels by 1.1%, whereas we do not obtain evidence of significant direct effects. We confirm the absence of both direct and indirect effects in Cluster 3. Figure 2 highlights the geographical distribution of spillovers across municipalities. Furthermore, Tables D2, D3, and D4 also show average direct and total effects when we aggregate results at the province level.[16] We confirm that on average higher indirect effects are generated in municipalities of Cluster 1 with Provinces in the North of Italy (e.g., Imperia, La-Spezia, Trieste, Reggio Emilia, and Cremona) experiencing the highest spillovers (between -1.9% and -1.5%). Conversely, significantly lower indirect effects are generated in municipalities of Cluster 3 with values below -0.5%.

Such results fuel the debate on the contribution of the EU Cohesion Policy to support countries in the achievement of international climate targets. Based on OECD estimates, Italian regions decreased their emissions by 0.67% per year between 1990 and 2018. This is below the 1.93% yearly reduction rate needed to reach the EU target of a 55% reduction in emissions by 2030, with respect to 1990 levels.[17] Similarly, E3Mlab and IIASA (2016) designed alternative policy scenarios to satisfy 2030 climate objectives with alternative energy efficiency targets, highlighting an annual GHG emissions reduction rate ranging between -4.0% and -2.4% for

[16]Direct, indirect and total effects at province level are computed for each cluster as the average of direct, indirect and total effects experienced by municipalities located in the considered province and classified in the underlying cluster.

[17]The OECD study is available at the following link: `https://www.oecd.org/regional/ITA-RCG2022.pdf`.

Italy. Such estimates are consistent with other studies made at a European or global level and suggesting carbon emissions annual reduction rates around -2.0% (Fragkos et al., 2017; Liu and Raftery, 2021). Our results suggest that in terms of total effects, the EU Cohesion Policy may significantly support territories of Cluster 1 to reduce the environmental quality gap and comply with EU targets. It is worth noting how such areas also represent the Italian territories with the highest pollution levels (see Figure B1) and frequently not complying with the EU air quality standards in terms of PM2.5 (threshold equal to 25 $\mu g/m^3$). Although municipalities in Cluster 2 and 3 are characterized by better conditions in terms of the starting level of PM2.5 concentration, our empirical evidence highlights a limited contribution of green EU Cohesion Policy Funds to comply with climate targets.

However, it should be noted how the EU Cohesion Policy is not the only policy instrument at the EU level fostering the sustainability transition and coordination and integration with alternative regulatory frameworks may represent an effective solution to swift effective climate actions (Flanagan et al., 2011; Crespi, 2016; Rogge and Reichardt, 2016; Fischer, 2017). For instance, EC estimates suggest that thanks to the combination of alternative policy instruments such as the EU Emission Trading System (ETS), the EU Cohesion Policy, and incentives in favor of renewable energy sources, Italy was able to reduce total carbon emissions by 28% between 2005 and 2019 (above the required target of 19%).[18] The EU ETS in particular is expected to further contribute to emissions reduction in Italy (-55.9%) by 2030, while electricity production from renewable energy sources will almost triple and satisfy around 55% of final consumption by 2030. Lower results have been achieved in Italy in non-ETS sectors such as Agriculture and Transportation. A careful comprehension of the impact of green EU Cohesion Funds across territories may thus support policy makers in a better design of this regulatory framework to comply with EU climate targets.

Overall, our model also captures a significant spatial autoregressive spillover (λ between 0.74 and 0.79), meaning that neighbor municipalities tend to experience a variation of PM2.5 in the same direction and with a similar intensity. Such estimated values are in line with that obtained by Jia et al. (2021) in an SDM assessing the contribution of high-speed rail investments to CO_2 emissions reduction in China. The magnitude of this coefficient is also consistent with other

[18] The EC document is available at the following link: `https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/690663/EPRS_BRI(2021)690663_EN.pdf`.

studies analyzing the contribution of the EU Cohesion Policy on economic growth (Ramajo et al., 2008; Le Gallo et al., 2011; Fiaschi et al., 2018). Finally, our λ is larger than the estimate obtained by Le Gallo and Ndiaye (2021) when studying the spatial dependence of expenditures in the environmental sector in OECD countries. However, this seems reasonable considering that the level of PM2.5 is expected to have a higher degree of spatial correlation with respect to countries' investments in climate-related projects.

Finally, also for our control variables, we obtain results consistent with the previous findings on the relationship between meteorological factors and the concentration of pollutants. Indeed, we find that higher wind speed (in Cluster 1) and rainfall (Cluster 1 and 2) are associated to lower PM2.5 levels, as they may favor a dispersion of alternative pollutant agents (Chai et al., 2014; Zhang et al., 2015; He et al., 2017). We also highlight that higher humidity levels tend to improve the air quality in all analyzed clusters, while we do not find a statistically significant impact for temperature, differently from Yang et al. (2019) who suggest that higher temperatures increase atmospheric turbulence, leading to a faster dispersion of pollutants.

We further investigate the heterogeneity of the contribution of green EU Cohesion Policy funds across Italian municipalities by estimating a model with all the municipalities in Italy that receive carbon abatement funds, where we insert the clusters (categorical variable) and the interaction between the clusters and *Environmental funds* and *Environmental funds spillovers* as additional regressors (see Table D1). The reference group is Cluster 3. This robustness analysis corroborates our main findings since Cluster 1 experiences a statistically higher direct (β_1 = -0.006) and indirect (β_2 between -0.011 and -0.010) impact of the funds compared to Cluster 3. Moreover, we corroborate the presence of larger spillovers in Cluster 2 with respect to Cluster 3 (β_2 = -0.007).

Table 4: We show the estimates of a Spatial Durbin Model analyzing the impact of funds targeting carbon abatement on the variation of pollutant intensity in terms of PM2.5 across clusters. Results are obtained using a spatial exponential decay matrix with $\alpha = 2$.
* $p-value < 0.10$, ** $p-value < 0.05$, *** $p-value < 0.01$.

	Dependent variable: PM2.5 variation		
	Cluster 1	*Cluster 2*	*Cluster 3*
Lambda	0.794***	0.740***	0.762***
	(0.004)	(0.005)	(0.004)
Environmental funds	-0.007***	0.000	-0.002
	(0.001)	(0.002)	(0.001)
Environmental funds spillovers	-0.005***	-0.004**	-0.001
	(0.001)	(0.002)	(0.001)
Temperature	-0.001	-0.002	-0.001
	(0.001)	(0.002)	(0.001)
Precipitation	-0.006***	-0.006***	-0.001
	(0.001)	(0.002)	(0.001)
Wind speed	-0.003***	-0.002	0.000
	(0.001)	(0.002)	(0.001)
Humidity	-0.007***	-0.004*	-0.003*
	(0.001)	(0.002)	(0.001)
N	7,343	7,315	6,832
AIC	-12,775.62	-5,893.453	-14,235.75
BIC	-12,727.30	-5,845.17	-14,187.95

Table 5: We show direct, indirect, and total effects generated by green funds across the three analyzed clusters.
* $p-value < 0.10$, ** $p-value < 0.05$, *** $p-value < 0.01$.

	Cluster 1	Cluster 2	Cluster 3
Direct Effect	-0.017***	-0.004	-0.004
	(0.003)	(0.004)	(0.002)
Indirect Effect	-0.013***	-0.011**	−0.009
	(0.004)	(0.005)	(0.006)
Total Effect	-0.030***	−0.015	−0.013
	(0.009)	(0.011)	(0.008)

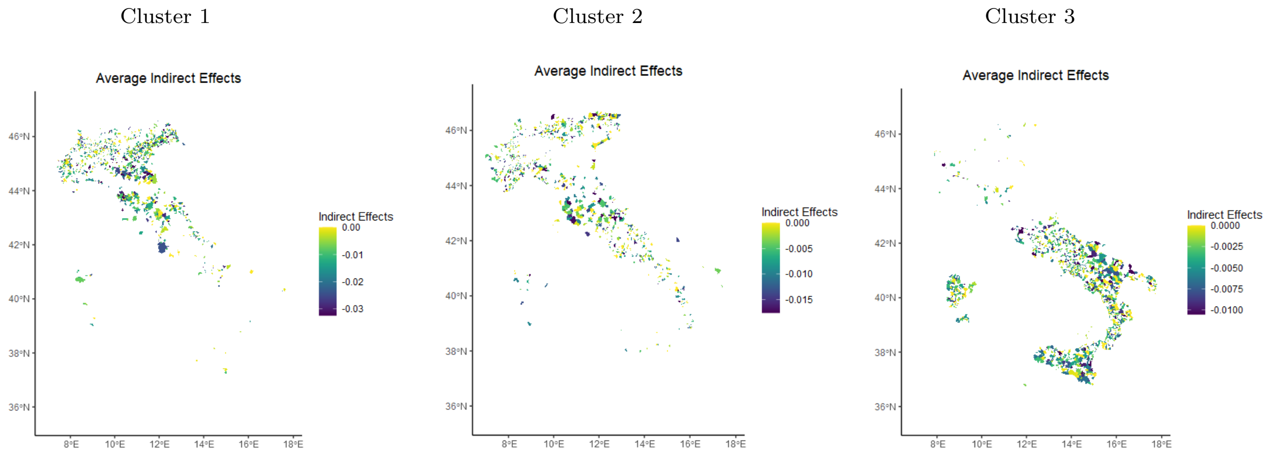


Figure 2: We show spillovers generated by green funds across the municipalities in the three analyzed clusters.

5.1.1 The impact across clusters: robustness analysis

Our previous analysis highlights the heterogeneity of the direct and indirect effects of green EU funds across Italian territories. However, previous results may also be affected by the different intensity of EU funds spent at the municipality scale. Indeed, depending on the level of local development, territories benefit from alternative amounts of financial support. For instance, during the programming period 2014-2020, Cohesion Policy Funds accounted for 32.2€ billion in Italy, and about 69% of the available budget was allocated to less developed regions (e.g., Campania, Puglia, Basilicata, Calabria, and Sicilia).[19] When focusing on green EU funds targeting carbon abatement, differences across territories may be less pronounced than when considering expenditures related to the local socio-economic development. For instance, the ERDF foresees that a higher portion of financial resources is channeled to the low carbon economy in more developed (20%) with respect to transition (15%) and less developed regions (12%).[20]

However, since differences might still exist across analyzed territories, we perform a pair-wise comparison t-test with Bonferroni correction to compare the expenditures of municipalities across the three analyzed clusters. Table 6 shows that Cluster 3 experiences a higher expenditure level in terms of green EU funds expressed as a percentage of total income. This finding is consistent with the fact that Cluster 3 encompasses a higher portion of municipalities located in less developed regions.

We propose two alternative strategies to deal with these different expenditures of green EU funds across clusters. First, we restrict our analysis to a subgroup of municipalities included in each cluster obtained by performing a Propensity Score Matching (PSM) for each pair of clusters, using green EU funds expenditures and income per capita as drivers of the matching procedure.[21] Our final sample is constituted by the municipality of each cluster that is included

[19] Additional information on the Cohesion Policy budget for the period 2014-2020 and territorial allocation of these funds is available at the following link: `https://commission.europa.eu/system/files/2017-01/partnership-agreement-italy-summary-oct2014_en.pdf`.

[20] Further information related to the allocation of the EU Cohesion Policy budget during the programming period 2014-2020 across alternative priority areas is available at the following link: `https://ec.europa.eu/regional_policy/funding/erdf/2014-2020_en`.

[21] We rely on a PSM model where each unit in one cluster is associated with a control unit (a municipality in another cluster) exhibiting the closest value of the propensity score based on the K-Nearest Neighbour approach with $K = 1$ (each unit in one cluster is assigned one single control unit without replacement). Since our goal is to find municipalities with a similar level of wealth and green EU funds expenditures across the three clusters, we apply the following procedure. One cluster of reference is considered as the treated group, and one of the two remaining clusters as the control group (e.g., when considering municipalities in Clusters 1 and 2, we define

in all sub-samples of administrative units after the PSM has been implemented. Table 6 highlights that our final sample presents a comparable intensity of green EU funds expenditures.

Table 6: P-values of pairwise comparison t-tests with Bonferroni correction on the amount of funds targeting carbon abatement spent across municipalities within the different clusters.
* $p-value < 0.10$, ** $p-value < 0.05$, *** $p-value < 0.01$.

	Cluster 1	Cluster 2	Cluster 1	Cluster 2
	Before PSM		*After PSM*	
Cluster 2	0.314		0.645	
Cluster 3	0.018**	0.037**	0.144	0.190

Table 7: We show the estimates of a Spatial Durbin Model analyzing the impact of funds targeting carbon abatement on the variation of pollutants intensity in terms of PM2.5. The model is estimated across alternative clusters after having applied a PSM to increase the comparability of the intensity of funds received by analyzed municipalities in the different clusters. Results are obtained using a spatial exponential decay matrix with $\alpha = 2$.
* $p-value < 0.10$, ** $p-value < 0.05$, *** $p-value < 0.01$.

	Dependent variable: PM2.5 variation		
	Cluster 1	*Cluster 2*	*Cluster 3*
Lambda	0.729***	0.665***	0.670***
	(0.007)	(0.013)	(0.011)
Environmental funds	-0.006***	-0.006	0.003
	(0.002)	(0.004)	(0.003)
Environmental spillovers	-0.007***	-0.014***	0.002
	(0.002)	(0.005)	(0.003)
Temperature	-0.001	-0.002	0.001
	(0.002)	(0.005)	(0.003)
Precipitation	-0.007***	-0.006	-0.005
	(0.002)	(0.004)	(0.003)
Wind speed	0.000	-0.002	-0.003
	(0.002)	(0.005)	(0.003)
Humidity	-0.004*	-0.003	0.004
	(0.002)	(0.005)	(0.003)
N	2,793	889	1,134
AIC	-3,666.60	-850.66	-1,999.93
BIC	3,625.19	-817.13	-1,964.69

Second, we separate municipalities in each cluster into two groups, based on the fact their income per capita is above or below the 75% of the EU average GDP per capita. We do this since the highest amount of ERDF and ESF is allocated to less developed regions, which are

municipalities in Cluster 1 as those treated and municipalities in Cluster 2 as control units). We do this for every combination of couples of clusters. For every couple of clusters considered, we compute the PSM based on the following logit regression:

$$Y_i = \alpha_0 + \beta_1 * Environmental\ funds_i + \beta_2 * Income\ pc_i + \epsilon_i$$

where Y_i is a binary variable equal to 1 in case municipality i belongs to the cluster considered as the treated group and 0, otherwise. Moreover, *Environmental funds*$_i$ is the average value of green EU funds expenditures of municipality i in the period 2014-2020, and *Income pc*$_i$ is the average income per capita of municipality i over the time frame 2014-2020. Similar covariates for matching purposes have been used by Di Cataldo (2017) in a PSM and by Barone et al. (2016) in a Synthetic Control Method. Since we aim to find comparable municipalities across the three clusters in terms of income per capita and green EU funds expenditures but with heterogeneity in terms of local context characteristics, we do not include additional covariates in our PSM.

Table 8: We show the estimates of a Spatial Durbin Model analyzing the impact of funds targeting carbon abatement on the variation of pollutants intensity in terms of PM2.5. The model is restricted to municipalities within each cluster whose income per capita is higher or lower than the 75% of the average GDP per capita across EU regions. Results are obtained using a spatial exponential decay matrix with $\alpha = 2$.
* $p-value < 0.10$, ** $p-value < 0.05$, *** $p-value < 0.01$.

	Dependent variable: Variation of pollutants air concentration					
	Cluster 1		*Cluster 2*		*Cluster 3*	
	(High)	(Low)	(High)	(Low)	(High)	(Low)
Lambda	0.799***	0.729***	0.674***	0.742***	0.603***	0.759***
	(0.004)	(0.008)	(0.011)	(0.006)	(0.020)	(0.004)
Environmental funds	-0.004***	-0.010***	0.001	-0.003	-0.002*	0.016
	(0.001)	(0.002)	(0.005)	(0.002)	(0.001)	(0.011)
Environmental spillovers	-0.006***	-0.006**	-0.002	-0.010**	0.007	-0.001
	(0.001)	(0.003)	(0.002)	(0.004)	(0.006)	(0.001)
Temperature	-0.001	-0.001	0.003	-0.003	-0.001	-0.001
	(0.001)	(0.003)	(0.005)	(0.002)	(0.007)	(0.001)
Precipitation	-0.007***	-0.007***	-0.015***	-0.003*	-0.008	0.000
	(0.001)	(0.002)	(0.005)	(0.002)	(0.006)	(0.001)
Wind speed	0.005***	0.000	-0.002	0.000	-0.004	0.001
	(0.001)	(0.003)	(0.005)	(0.002)	(0.007)	(0.001)
Humidity	-0.010***	-0.002	-0.013***	0.000	-0.002	0.001
	(0.001)	(0.002)	(0.005)	(0.002)	(0.006)	(0.001)
N	5,439	1,904	1,904	5,411	294	6,538
AIC	9,034.73	3,481.39	1,886.72	4,981.62	474.72	9,871.83
BIC	8,976.16	3,401.73	1,831.03	4,926.83	456.17	9,816.19

areas whose GDP per capita is below the 75% of the European Union average.[22]

Table 7 shows our estimates on the sub-sample obtained after the implementation of the PSM. We confirm the results exhibited in Section 5.1 with significant direct and indirect impacts in Cluster 1, relevant spillovers in Cluster 2, and the absence of effects in Cluster 3. We corroborate that green EU funds have both direct and indirect effects in Cluster 1 when we repeat our analysis distinguishing between administrative units whose income per capita is above or below the threshold used to identify the less developed regions (see Table 8). Higher heterogeneity of results is obtained for Clusters 2 and 3 with exceptions related to the scenario where we analyze municipalities whose income per capita is above the 75% of the EU average. Indeed, in Cluster 2 we do not obtain significant spillovers, while in Cluster 3 we observe a slightly significant direct contribution of green EU funds to the reduction of PM2.5 levels. However, notice how in both cases we obtain results consistent with those discussed in Section 5.1 when we consider the scenario including the largest number of municipalities of the cluster. Indeed, the "Low" scenarios in Clusters 2 and 3 absorb 74.0% and 95.7% of observations.

[22]Although income per capita is just a component of GDP per capita, we are forced to compare the income per capita of Italian administrative units with the GDP per capita of EU regions since at municipal level the national statistical office only discloses information related to the income per capita.

5.2 The mechanism behind spillovers generation

An interesting result of our analysis is related to the fact that we find only a relevant spillover in municipalities of Cluster 2, without the presence of significant direct effects. This result might be due to the air movement and other meteorological factors such as wind intensity and direction that might move pollutants concentration. These dynamics may be responsible for making the benefits of certain projects implemented in a specific municipality visible and tangible in neighboring administrative units. In particular, the spillovers obtained in a cluster might be also generated by positive externalities of projects realized in municipalities of a different cluster. Since municipalities of Cluster 1 experience a positive direct effect and tend to be spatially close to administrative units in Cluster 2, we investigate the extent to which the relevant indirect effects observed in Cluster 2 might be due to green EU funds expenditures in Cluster 1 municipalities.

To do this, we estimate our panel SDM on a sample of administrative units including Cluster 2 and only those municipalities of Cluster 1 with a centroid distance lower than 20 kilometers from at least one administrative unit of Cluster 2 (see Column 1 in Table 9).[23] In this model, the exponential spatial decay matrix is defined such that neighbor municipalities are restricted to administrative units of the other cluster (e.g., we set to zero w_{ij} where municipalities i and j belong both either to Cluster 1 or to Cluster 2). In this way, we expect that the estimated indirect effect will include the portion of spillovers from municipalities of Cluster 1 toward administrative units in Cluster 2.

Interestingly, we observe statistically relevant direct and indirect effects. The presence of the direct contribution of green EU funds to PM2.5 reduction is reasonably due to the presence of Cluster 1 administrative units, where we also have evidence of significant direct effects from the analyses in the previous section. Furthermore, the presence of relevant spillovers in a model where neighbor municipalities are selected only from administrative units of the other cluster should clarify that areas in Cluster 1 may be responsible also for the spillovers observed in Cluster 2.

Although in Cluster 3 we find neither a direct nor an indirect effect, we repeat a similar analysis replacing Cluster 2 municipalities with Cluster 3 administrative units. In this way,

[23]Similar results hold in case we change the distance threshold from 10 to 50 kilometers by steps of 10 kilometers. Results are available upon request.

we analyze whether municipalities in Cluster 1 generate a similar dynamic also in Cluster 3, thus contributing to inducing a direct or indirect carbon abatement (see Column 2 in Table 9). Finally, Column 3 reports estimates of a panel SDM where we only consider municipalities located in Tuscany, Umbria, Marche, Abruzzi, Lazio, Molise, and Sardinia, since they account for a similar number of municipalities in Cluster 1, 2, and 3. In this way, we further investigate the extent to which the presence of Cluster 1 municipalities may influence the generation of a significant direct or indirect impact in terms of PM2.5 levels.

Interestingly, similar results to those obtained for Cluster 2 are observed when our analysis covers the Centre of Italy, thus strengthening our hypothesis that Cluster 1 municipalities mainly drive a direct contribution to pollution reduction and the related spillovers. We rather find only weakly significant indirect effects for Cluster 3, possibly due to the limited number of Cluster 1 administrative units that are spatially close to municipalities in Cluster 3.

Table 9: We show the estimates of panel SDMs aiming to analyze whether spillovers generated in Clusters different from Cluster 1 are due to direct effects generated by municipalities in Cluster 1. In columns 1 and 2, we thus consider as neighbors of municipalities in Cluster 2 or 3 only the municipalities in Cluster 1 with a distance between centroids lower than 20 km. Finally, in Column 3 we estimate a model considering municipalities in Tuscany, Umbria, Marche, Abruzzi, Lazio, Molise, and Sardinia since they account for a similar number of municipalities in Cluster 1, 2, and 3. Results are obtained using a spatial exponential decay matrix with α = 2.
* $p-value < 0.10$, ** $p-value < 0.05$, *** $p-value < 0.01$.

	Dependent variable: *Variation of PM2.5 concentration*		
	(Cluster 2)	(Cluster 3)	(Centre of Italy)
Lambda	0.774***	0.764***	0.7774***
	(0.003)	(0.004)	(0.005)
Environmental funds	-0.0044***	-0.002	-0.0064***
	(0.001)	(0.001)	(0.001)
Environmental spillovers	-0.0024*	-0.0024*	-0.0024*
	(0.001)	(0.001)	(0.001)
Temperature	-0.001	-0.001	0.0034**
	(0.001)	(0.001)	(0.001)
Precipitation	-0.0064***	-0.0044***	0.000
	(0.001)	(0.001)	(0.001)
Wind speed	0.000	-0.0024*	-0.0034**
	(0.001)	(0.001)	(0.001)
Humidity	-0.0054***	-0.0024**	0.0054***
	(0.001)	(0.001)	(0.001)
N	10,181	9,342	9,013
AIC	11,984.17	16,743.93	13,642.91
BIC	11,901.43	16,687.01	13,599.83

5.3 The effectiveness of green funds in Cluster 3

According to the principle of economic convergence, the bulk of economic support provided by the EU Cohesion Policy is allocated to less developed regions to foster a mechanism of catching up with wealthier areas. Consistently, such areas received 22.2€ billion from the EU Cohesion Policy during the programming period 2014-2020, whereas transition and more developed territories benefited from "only" 1.3 and 7.6 € billion. The majority of municipalities in less developed regions are located in Cluster 3, where we find neither a direct nor indirect contribution of green EU funds to carbon abatement. Considering that such territories will receive the highest portion of financial support also for the next programming period (2021-2027), we perform an additional analysis on this set of municipalities, to understand whether we can find some sub-groups of administrative units where these green EU funds display some relevant results in terms of PM2.5 reduction. Indeed, understanding the characteristics of these areas in Cluster 3 may support policy makers in a better comprehension of the determinants of direct effects and spillovers, thus potentially leading to a more cost-effective budget allocation.

To do this, we first split our set of municipalities included in Cluster 3 into quartiles with respect to the variation of PM2.5 in the analyzed period. The lowest quartile refers to the set of municipalities with the strongest reduction of PM2.5, thus experiencing better dynamics in terms of air quality. Then, we estimate our panel SDM for alternative sub-samples of the selected quartile of administrative units, obtained by restricting the analysis to the set of municipalities where the average variation of PM2.5 in the period 2014-2020 is below a specific quantile Q progressively increasing by 5% (starting from the lower limit of the analyzed quartile).[24]

Interestingly, we observe that over the majority of the distribution, the relationship between green EU Cohesion Policy funds and PM2.5 variation is negative but not significant in line with our main analysis. However, we find evidence of significant direct and indirect effects of green EU funds on carbon abatement when focusing on the lower tail of the distribution of PM2.5 level variation. Indeed, for municipalities experiencing the best outcome in terms of air quality patterns, these programs of financial support seem to exhibit a relevant contribution to pollution

[24] For instance, considering the first quartile, the analyzed samples are municipalities whose average PM2.5 variation over the time frame 2014-2020 are below the 5^{th}, 10^{th}, 15^{th}, 20^{th} and 25^{th} quantile. Concerning the second quartile we analyze municipalities in the following ranges: $25^{th} \leq Q < 30^{th}$; $25^{th} \leq Q < 35^{th}$; $25^{th} \leq Q < 40^{th}$; $25^{th} \leq Q < 45^{th}$; $25^{th} \leq Q < 50^{th}$.

contraction with direct effects between -0.6% and -0.2% and spillovers in the range -1.0% - -0.2%. Notice how such a result is robust only for the set of municipalities where the average PM2.5 variation is below a Q equal to 0.15, whereas such a relationship is not valid for larger values of the quantile.

Based on these considerations, we assess the socio-economic characteristics of the set of municipalities where we identify a relevant impact of green EU funds on carbon abatement. Table 10 reports the p-values of t-tests comparing the distribution of municipalities where this program of financial support seems effective in terms of PM2.5 reduction with respect to the rest of the administrative units included in Cluster 3. Interestingly, we observe consistent results for different levels of Q (ranging between 0.05 and 0.15), with municipalities characterized by relevant direct effects and spillovers exhibiting higher income per capita and lower levels of employment in the Manufacturing sector. Furthermore, they display larger financial resources in terms of bank deposits and loans, as well as higher availability of services in terms of drinkable water, public mobility, and accommodation beds.

Overall, such results fuel the debate on the characteristics of municipalities experiencing a higher capability to spend EU Cohesion Policy funds and obtain consistent results with respect to the targets of the program of financial support. Our findings seem to point to the fact that a higher level of wealth and local efficiency in terms of delivered services may be associated with a better environmental outcome measured as PM2.5 reduction. These results complement extant literature, highlighting that local institutional quality and governance processes affect the successful implementation of projects and the associated economic return (Allain-Dupré, 2020). Indeed, poor local institutions and government quality may design ”good looking, but without substance” development strategies, often resulting in ineffective use of the available financial resources (Crescenzi and Giua, 2016). Adequate administrative capacity, on the other hand, constitutes a key driver for absorbing a larger portion of EU Cohesion Policy funds and managing them in an effective manner (Milio, 2007; Charron et al., 2014).

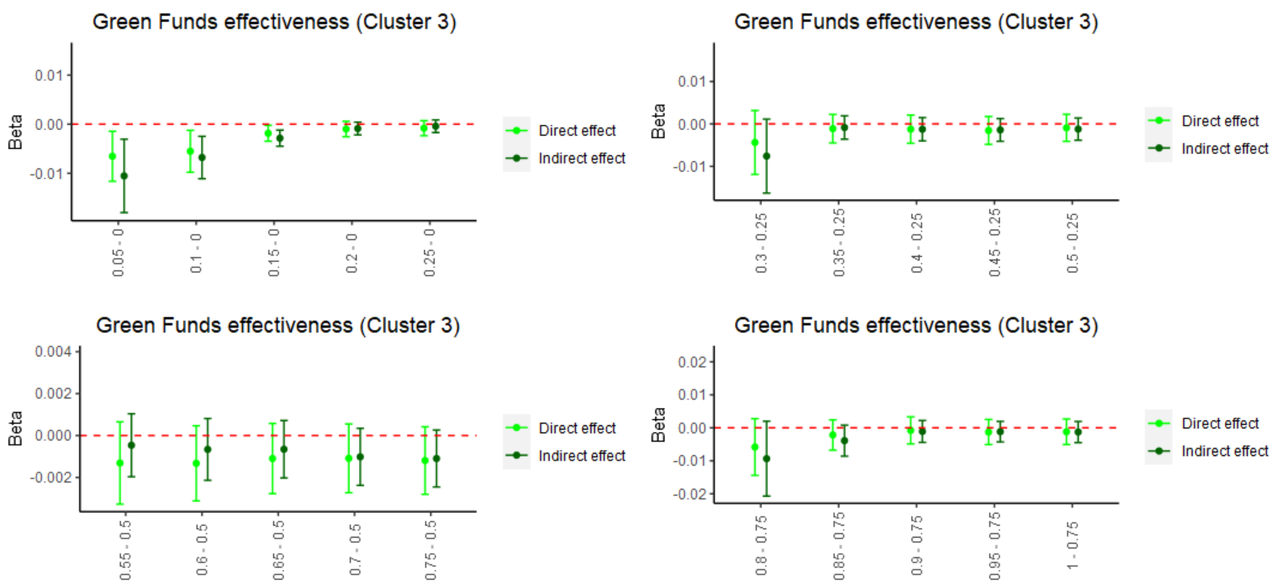


Figure 3: We show direct and indirect effects estimated through an SDM where we restrict the analysis to alternative sub-samples of Cluster 3 municipalities.

Table 10: We show the p-values of t-tests on a set of covariates between municipalities of cluster 3 where green funds show both a significant direct and indirect effect and where are not effective.
* $p-value < 0.10$, ** $p-value < 0.05$, *** $p-value < 0.01$.

	Q < 0.05	Q < 0.10	Q < 0.15
Income pc	0.098*	0.085*	0.058*
Manufacturing employees	0.006***	0.020**	0.016**
Bank branches	0.847	0.639	0.508
Bank deposits	0.093*	0.048**	0.071*
Bank loans	0.075*	0.022**	0.066*
University students	0.536	0.341	0.213
Drinkable water	0.001***	0.056*	0.058*
Public mobility	0.000***	0.000***	0.005***
Waste sorting	0.312	0.808	0.228
Used soil	0.319	0.242	0.127
Accommodation beds	0.061*	0.093*	0.006***
Housing dispersion	0.604	0.868	0.798
Building expansion	0.522	0.347	0.296
Active population	0.245	0.123	0.835

6 Conclusion

This study examines the relationship between EU Cohesion Policy funds aimed at promoting sustainability transition and the resulting carbon abatement outcome. In doing so, we extend the scope of existing studies, which primarily focus on the impact of this regulatory framework on the socio-economic development of EU regions (Pellegrini et al., 2013; Gagliardi and Percoco, 2017; Becker et al., 2018), to include an analysis of its environmental effects. Furthermore, we expand the emerging but still limited literature on the effects of the EU Cohesion Policy on the environmental dimension, by adding a work focusing on the contribution of green EU funds to pollution reduction (Medeiros, 2014; Agovino et al., 2016).

We first show how the effect of such funds in terms of air quality is heterogeneous with respect to the local context. In this way, we fuel the debate on the importance of disentangling the impact of the EU Cohesion Policy across territories with comparable characteristics, since a different endowment of economic, human, and physical assets may significantly mediate the effects of these programs of financial support (Fratesi et al., 2014; Fratesi and Perucca, 2018; Bachtrögler et al., 2020). In this direction, we show that Cluster 1 municipalities, including territories with high economic capital, experience both a direct and indirect effect. Green EU funds are associated with a 1.7% reduction of PM2.5 in the municipalities where these projects are implemented. Furthermore, these expenditures also reduce pollutants in neighbor municipalities with spillovers equal to -1.3%. In municipalities of Cluster 2, we observe relevant indirect effects (equal to -1.1%), whereas direct effects are not statistically significant. Finally, a null relationship between green funds and PM2.5 variation is obtained with regard to the municipalities of Cluster 3.

The results are robust to several alternative definitions of clusters and spatial matrices. Furthermore, they are confirmed when restricting the analysis to a set of municipalities experiencing comparable levels of green EU funds intensity, suggesting that our results are not driven by the heterogeneous allocation of financial resources across territories with a different pre-existing level of socio-economic development.

These findings have significant implications for different economic actors, including regulators at both national and international levels. By highlighting the main determinants of successful project implementation aimed at fostering sustainability transition in Italian municipalities, our analysis may assist policymakers in gaining a thorough comprehension of the key factors contributing to the reduction of PM2.5 levels. This understanding, in turn, can facilitate the design of more cost-effective allocation strategies for the EU Cohesion Policy budget. Furthermore, a precise knowledge of the impact of green EU funds on pollution reduction may help international institutions to better coordinate and integrate alternative policy packages aiming to achieve carbon abatement and comply with EU targets (Stojčić, 2021; Van den Bergh et al., 2021; Greco et al., 2022; Bretschger and Valente, 2023; Rausch and Yonezawa, 2023).

Our paper also discusses the mechanism behind the emergence of relevant spillovers in Cluster 2, where we do not find evidence of a significant direct effect. In particular, we highlight how these indirect effects might be the result of spillovers generated by spatially close administrative units of Cluster 1. Such results may affect the discussion on the geographical concentration of EU funds that may need to be located in areas with specific characteristics in order to generate relevant spillovers. In particular, Crescenzi (2009) critiques the allocation criterion of Cohesion Policy funds, as an insufficient territorial concentration of the expenditure may explain weak spillovers effects across territories (Canova, 2004; Dall'Erba, 2005; Bradley, 2006).

Finally, we investigate the main characteristics of municipalities located in less developed regions that are associated with significant direct and indirect effects of green EU funds. Interestingly, we observe that areas with higher levels of wealth and availability of financial resources, as well as public mobility and tourism-related services are associated with a more effective contribution of EU Cohesion Policy funds to carbon abatement. Such findings enrich the literature discussing the key local characteristics that may drive the effectiveness of EU funds such as the quality of institutions and government processes (Crescenzi and Giua, 2016; Allain-Dupré, 2020). Furthermore, as less developed regions will be allocated the largest portion of EU Cohesion Policy funds also in the next programming period (2021-2027), our analysis might be informative for policy makers aiming to distribute the available budget across territories based on robust empirical evidence.

Despite our main effort to implement methodologically grounded research, our analysis presents some limitations. First, we identified projects targeting carbon abatement purposes based on a careful analysis of the title and description of projects financed by the EU Cohesion Policy. A possible improvement in our work might be related to using an official classification of projects focusing on pollution reduction, directly provided by the EC. In addition, we built our dependent variable based on satellite data by aggregating the PM2.5 concentration of high granular spatial grids at the municipality level. While our measure effectively captures the primary dynamics of pollution in Italy, the reliability of our findings could be further enhanced if the National Statistical Office were to disclose air quality data for all Italian administrative units throughout the period of interest. Moreover, it might be interesting to extend the methods and the analysis presented here to a multivariate context. In fact, the joint study of a series of air pollutants (e.g. PM2.5, PM10, CO_2, NO2, and O3) might provide more meaningful insights regarding the relationship between green funds and air pollution reduction.

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Declarations of interest

Declarations of interest: none

References

Agovino, M., M. Casaccia, and A. Crociata (2016). The impact of european regional development fund on separate waste collection: Evidence from italian regions. *Environmental science & policy 61*, 97–107.

Agovino, M., A. Crociata, and P. L. Sacco (2016). Location matters for pro-environmental behavior: a spatial markov chains approach to proximity effects in differentiated waste collection. *The Annals of Regional Science 56*, 295–315.

Alam, M. S., M. Safiullah, and M. S. Islam (2022). Cash-rich firms and carbon emissions. *International Review of Financial Analysis 81*, 102106.

Allain-Dupré, D. (2020). The multi-level governance imperative. *The British Journal of Politics and International Relations 22*(4), 800–808.

Atella, V., M. Braione, G. Ferrara, and G. Resce (2023). Cohesion policy funds and local government autonomy: Evidence from italian municipalities. *Socio-Economic Planning Sciences 87*, 101586.

Bachtler, J., C. Mendez, and F. Wishlade (2018). Reshaping the eu budget and cohesion policy: carrying on, doing less, doing more or radical redesign. *European Policy Research Paper* (104).

Bachtrögler, J., U. Fratesi, and G. Perucca (2020). The influence of the local context on the implementation and impact of eu cohesion policy. *Regional Studies 54*(1), 21–34.

Barca, F. (2009). *Agenda for a reformed cohesion policy.* European Communities Brussels.

Barca, F., P. McCann, and A. Rodríguez-Pose (2012). The case for regional development intervention: place-based versus place-neutral approaches. *Journal of regional science 52*(1), 134–152.

Barone, G., F. David, and G. De Blasio (2016). Boulevard of broken dreams. the end of eu funding (1997: Abruzzi, italy). *Regional Science and Urban Economics 60*, 31–38.

Becker, S. O., P. H. Egger, and M. Von Ehrlich (2012). Too much of a good thing? on the growth effects of the eu's regional policy. *European Economic Review 56*(4), 648–668.

Becker, S. O., P. H. Egger, and M. Von Ehrlich (2018). Effects of eu regional policy: 1989-2013. *Regional Science and Urban Economics 69*, 143–152.

Beloconi, A. and P. Vounatsou (2023). Revised eu and who air quality thresholds: Where does europe stand? *Atmospheric Environment 314*, 120110.

Benos, N., S. Karagiannis, and S. Karkalakos (2015). Proximity and growth spillovers in european regions: The role of geographical, economic and technological linkages. *Journal of Macroeconomics 43*, 124–139.

Blečić, I., A. Cecchini, V. Saiu, and G. A. Trunfio (2022). Evaluating territorial capital of fragile territories: the case of sardinia. In *International Conference on Computational Science and Its Applications*, pp. 531–545. Springer.

Bradley, J. (2006). Evaluating the impact of european union cohesion policy in less-developed countries and regions. *Regional Studies 40*(02), 189–200.

Bretschger, L. and S. Valente (2023). Effective policy design for a sustainable economy.

Camagni, R., R. Capello, and P. Nijkamp (2009). Territorial capital and regional development. *Handbook of regional growth and development theories 1*, 118–132.

Cambini, C., R. Congiu, T. Jamasb, M. Llorca, and G. Soroush (2020). Energy systems integration: Implications for public policy. *Energy policy 143*, 111609.

Canova, F. (2004). Testing for convergence clubs in income per capita: a predictive density approach. *International Economic Review 45*(1), 49–77.

Cappelen, A., F. Castellacci, J. Fagerberg, and B. Verspagen (2003). The impact of eu regional support on growth and convergence in the european union. *JCMS: Journal of Common Market Studies 41*(4), 621–644.

Castrejon-Campos, O., L. Aye, and F. K. P. Hui (2022). Effects of learning curve models on onshore wind and solar pv cost developments in the usa. *Renewable and Sustainable Energy Reviews 160*, 112278.

Chai, F., J. Gao, Z. Chen, S. Wang, Y. Zhang, J. Zhang, H. Zhang, Y. Yun, and C. Ren (2014). Spatial and temporal variation of particulate matter and gaseous pollutants in 26 cities in china. *Journal of Environmental Sciences 26*(1), 75–82.

Charron, N., L. Dijkstra, and V. Lapuente (2014). Regional governance matters: Quality of government within european union member states. *Regional studies 48*(1), 68–90.

Chen, Z., G. Marin, D. Popp, and F. Vona (2020). Green stimulus in a post-pandemic recovery: the role of skills for a resilient recovery. *Environmental and Resource Economics 76*, 901–911.

Copernicus Atmosphere Monitoring Service (2024). Cams regional: European air quality analysis and forecast data documentation. `https://confluence.ecmwf.int/display/CKB/CAMS+Regional%3A+European+air+quality+analysis+and+forecast+data+documentation`. Online; accessed April, 11 2024.

Crescenzi, R. (2009). Undermining the principle of concentration? european union regional policy and the socio-economic disadvantage of european regions. *Regional Studies 43*(1), 111–133.

Crescenzi, R. and M. Giua (2016). The eu cohesion policy in context: Does a bottom-up approach work in all regions? *Environment and Planning A: Economy and Space 48*(11), 2340–2357.

Crespi, F. (2016). Policy complexity and the green transformation of the economies as an emergent system property. *Environmental economics and policy studies 18*, 143–157.

Dall'Erba, S. and F. Fang (2017). Meta-analysis of the impact of european union structural funds on regional growth. *Regional Studies 51*(6), 822–832.

Dall'Erba, S. and J. Le Gallo (2008). Regional convergence and the impact of european structural funds over 1989–1999: A spatial econometric analysis. *Papers in Regional Science 87*(2), 219–244.

Dall'Erba, S. (2005). Distribution of regional income and regional funds in europe 1989–1999: an exploratory spatial data analysis. *The Annals of Regional Science 39*(1), 121–148.

Debarsy, N., C. Ertur, and J. P. LeSage (2012). Interpreting dynamic space–time panel data models. *Statistical Methodology 9*(1-2), 158–171.

Di Cataldo, M. (2017). The impact of eu objective 1 funds on regional development: Evidence from the uk and the prospect of brexit. *Journal of Regional Science 57*(5), 814–839.

Duro, J. A. and E. Padilla (2013). Cross-country polarisation in co 2 emissions per capita in the european union: changes and explanatory factors. *Environmental and Resource Economics 54*, 571–591.

E3Mlab and IIASA (2016). Technical report on member state results of the euco policy scenarios.

Elhorst, J. P. et al. (2014). *Spatial econometrics: from cross-sectional data to spatial panels*, Volume 479. Springer.

European Commission (2014). An introduction to eu cohesion policy 2014-2020. Technical report.

European Commission, E. (2007). Adapting to climate change in europe – options for eu action.

European Environment Agency, E. (2020). *Air quality in Europe – 2020 report.* Publications Office.

Fiaschi, D., A. M. Lavezzi, and A. Parenti (2018). Does eu cohesion policy work? theory and evidence. *Journal of Regional Science 58*(2), 386–423.

Fischer, C. (2017). Environmental protection for sale: strategic green industrial policy and climate finance. *Environmental and Resource Economics 66*, 553–575.

Flanagan, K., E. Uyarra, and M. Laranja (2011). Reconceptualising the 'policy mix'for innovation. *Research policy 40*(5), 702–713.

Fragkos, P., N. Tasios, L. Paroussos, P. Capros, and S. Tsani (2017). Energy system impacts and policy implications of the european intended nationally determined contribution and low-carbon pathway to 2050. *Energy Policy 100*, 216–226.

Fratesi, U. and G. Perucca (2016). Territorial capital and eu cohesion policy. *EU Cohesion Policy*, 255.

Fratesi, U. and G. Perucca (2018). Territorial capital and the resilience of european regions. *The Annals of Regional Science 60*(2), 241–264.

Fratesi, U. and G. Perucca (2019). Eu regional development policy and territorial capital: A systemic approach. *Papers in Regional Science 98*(1), 265–281.

Fratesi, U., G. Perucca, et al. (2014). Territorial capital and the effectiveness of cohesion policies: An assessment for cee regions. *Investigaciones Regionales 29*, 165–191.

Gagliardi, L. and M. Percoco (2017). The impact of european cohesion policy in urban and rural regions. *Regional Studies 51*(6), 857–868.

Geddes, A. and T. S. Schmidt (2020). Integrating finance into the multi-level perspective: Technology niche-finance regime interactions and financial policy interventions. *Research Policy 49*(6), 103985.

Getzner, M. and S. Moroz (2022). The economic development of regions in ukraine: with tests on the territorial capital approach. *Empirica 49*(1), 225–251.

González, A., G. Daly, P. Pinch, N. Adams, V. Valtenbergs, M. C. Burns, and H. Johannesson (2015). Indicators for spatial planning and territorial cohesion: Stakeholder-driven selection approach for improving usability at regional and local levels. *Regional Studies 49*(9), 1588–1602.

Greco, M., F. Germani, M. Grimaldi, and D. Radicic (2022). Policy mix or policy mess? effects of cross-instrumental policy mix on eco-innovation in german firms. *Technovation 117*, 102194.

Gripaios, P., P. Bishop, T. Hart, and E. McVittie (2008). Analysing the impact of objective 1 funding in europe: a review. *Environment and Planning C: Government and Policy 26*(3), 499–524.

He, J., S. Gong, Y. Yu, L. Yu, L. Wu, H. Mao, C. Song, S. Zhao, H. Liu, X. Li, et al. (2017). Air pollution characteristics and their relation to meteorological conditions during 2014–2015 in major chinese cities. *Environmental pollution 223*, 484–496.

Horálek, J., L. Vlasáková, M. Schreiberová, J. Marková, P. Schneider, P. Kurfürst, F. Tognet, J. Schovánková, O. Vlček, and D. Damašková (2024, February). European air quality maps for 2020. PM10, PM2.5, Ozone, NO2, NOx and Benzo(a)pyrene spatial estimates and their uncertainties. ETC HE Report 2022/12.

Jamasb, T. and M. Llorca (2019). Energy systems integration. *Economics of Energy & Environmental Policy 8*(2), 7–28.

Jia, R., S. Shao, and L. Yang (2021). High-speed rail and co2 emissions in urban china: A spatial difference-in-differences approach. *Energy Economics 99*, 105271.

Kozera, A., Ł. Satoła, A. Standar, and M. Dworakowska-Raj (2022). Regional diversity of low-carbon investment support from eu funds in the 2014–2020 financial perspective based on the example of polish municipalities. *Renewable and Sustainable Energy Reviews 168*, 112863.

Le Gallo, J., S. Dall'Erba, and R. Guillain (2011). The local versus global dilemma of the effects of structural funds. *Growth and Change 42*(4), 466–490.

Le Gallo, J. and Y. Ndiaye (2021). Environmental expenditure interactions among oecd countries, 1995–2017. *Economic Modelling 94*, 244–255.

LeSage, J. and R. K. Pace (2009). *Introduction to spatial econometrics.* Chapman and Hall/CRC.

LeSage, J. P. and R. K. Pace (2007). A matrix exponential spatial specification. *Journal of Econometrics 140*(1), 190–214.

Liobikienė, G. and J. Mandravickaitė (2016). The eu cohesion policy implications to ghg emissions from production-based perspective. *Environmental science & policy 55*, 178–185.

Liu, P. R. and A. E. Raftery (2021). Country-based rate of emissions reductions should increase by 80% beyond nationally determined contributions to meet the 2 c target. *Communications earth & environment 2*(1), 29.

Llorca, M. and A. Rodriguez-Alvarez (2024). Economic, environmental, and energy equity convergence: Evidence of a multi-speed europe? *Ecological Economics 219*, 108133.

Medeiros, E. (2014). Assessing territorial impacts of the eu cohesion policy: The portuguese case. *European Planning Studies 22*(9), 1960–1988.

Milio, S. (2007). Can administrative capacity explain differences in regional performances? evidence from structural funds implementation in southern italy. *Regional studies 41*(4), 429–442.

Mohl, P. and T. Hagen (2010). Do eu structural funds promote regional growth? new evidence from various panel data approaches. *Regional Science and Urban Economics 40*(5), 353–365.

Mukanjari, S. and T. Sterner (2020). Charting a "green path" for recovery from covid-19. *Environmental and Resource Economics 76*(4), 825–853.

Nekvasil, M. and B. Moldan (2018). Could cohesion policy push eu climate efforts? *Climate Policy 18*(1), 129–139.

Nilsson, M. and L. J. Nilsson (2013). Towards climate policy integration in the eu: evolving dilemmas and opportunities. In *Climate Policy Options Post-2012*, pp. 363–376. Routledge.

OECD, O. (2009). Regions matter: Economic recovery, innovation and sustainable growth. *Paris: Organisation for Economic Growth and Development.*.

Pebesma, E. and R. Bivand (2023). *Spatial Data Science: With applications in R.* Chapman and Hall/CRC.

Pellegrini, G., F. Terribile, O. Tarola, T. Muccigrosso, and F. Busillo (2013). Measuring the effects of european regional policy on economic growth: A regression discontinuity approach. *Papers in Regional Science 92*(1), 217–234.

Pellegrini, G. and W. Tortorella (2018). The impact of cohesion policies in europe and italy.

Peñalosa, P. and C. Castaldi (2024). Horizon europe: a green window of opportunity for european peripheral regions? *Review of Regional Research*, 1–35.

Percoco, M. (2017). Impact of european cohesion policy on regional growth: does local economic structure matter? *Regional Studies 51*(6), 833–843.

Perez, C. (2010). Technological revolutions and techno-economic paradigms. *Cambridge journal of economics 34*(1), 185–202.

Pieńkowski, J. and P. Berkowitz (2016). Econometric assessments of cohesion policy growth effects: how to make them more relevant for policymakers? In *EU cohesion policy*, pp. 55–68. Routledge.

Piribauer, P. and M. M. Fischer (2015). Model uncertainty in matrix exponential spatial growth regression models. *Geographical Analysis 47*(3), 240–261.

Polzin, F. (2017). Mobilizing private finance for low-carbon innovation–a systematic review of barriers and solutions. *Renewable and Sustainable Energy Reviews 77*, 525–535.

Polzin, F., P. von Flotow, and L. Klerkx (2016). Addressing barriers to eco-innovation: Exploring the finance mobilisation functions of institutional innovation intermediaries. *Technological Forecasting and Social Change 103*, 34–46.

Quental, N., J. M. Lourenço, and F. N. Da Silva (2011). Sustainable development policy: goals, targets and political cycles. *Sustainable Development 19*(1), 15–29.

R Core Team (2023). *R: A Language and Environment for Statistical Computing.* Vienna, Austria: R Foundation for Statistical Computing.

Ramajo, J., M. A. Marquez, G. J. Hewings, and M. M. Salinas (2008). Spatial heterogeneity and interregional spillovers in the european union: Do cohesion policies encourage convergence across regions? *European Economic Review 52*(3), 551–567.

Rausch, S. and H. Yonezawa (2023). Green technology policies versus carbon pricing: An intergenerational perspective. *European Economic Review 154*, 104435.

Rogge, K. S. and K. Reichardt (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Research Policy 45*(8), 1620–1635.

Rousseeuw, P. J. (1987). Silhouettes: A graphical aid to the interpretation and validation of cluster analysis. *Journal of Computational and Applied Mathematics 20*, 53–65.

Sala-i Martin, X. X. (1996). Regional cohesion: evidence and theories of regional growth and convergence. *European economic review 40*(6), 1325–1352.

Schmidt, T. S. (2014). Low-carbon investment risks and de-risking. *Nature Climate Change 4*(4), 237–239.

Scotti, F., L. Dell'Agostino, A. Flori, and F. Pammolli (2024). Premature exit from and delayed entrance into the less developed status: An empirical appraisal of the structural funds allocation criterion. *Journal of Regional Science 64*(1), 5–59.

Scotti, F., A. Flori, and F. Pammolli (2022). The economic impact of structural and cohesion funds across sectors: Immediate, medium-to-long term effects and spillovers. *Economic Modelling 111*, 105833.

Stojčić, N. (2021). Social and private outcomes of green innovation incentives in european advancing economies. *Technovation 104*, 102270.

Tarín-Carrasco, P., U. Im, C. Geels, L. Palacios-Peña, and P. Jiménez-Guerrero (2021). Contribution of fine particulate matter to present and future premature mortality over europe: A non-linear response. *Environment international 153*, 106517.

Van den Bergh, J., J. Castro, S. Drews, F. Exadaktylos, J. Foramitti, F. Klein, T. Konc, and I. Savin (2021). Designing an effective climate-policy mix: accounting for instrument synergy. *Climate Policy 21*(6), 745–764.

Vironen, H., I. McMaster, and W. den Hoed (2019). Transition to a low-carbon europe: the supporting role of cohesion policy.

Yang, J., Z. Ji, S. Kang, Q. Zhang, X. Chen, and S.-Y. Lee (2019). Spatiotemporal variations of air pollutants in western china and their relationship to meteorological factors and emission sources. *Environmental Pollution 254*, 112952.

Zhang, D., Z. Tong, and Y. Li (2020). The role of cash holding towards cleaner production in china's manufacturing sectors: A financial constraint perspective. *Journal of Cleaner Production 245*, 118875.

Zhang, H., Y. Wang, J. Hu, Q. Ying, and X.-M. Hu (2015). Relationships between meteorological parameters and criteria air pollutants in three megacities in china. *Environmental research 140*, 242–254.

Zhou, Y. and J. I. Levy (2007). Factors influencing the spatial extent of mobile source air pollution impacts: a meta-analysis. *BMC public health 7*(1), 1–11.

A Beneficiaries identification: additional information

Figure A1 displays the average expenditures of green EU Cohesion Policy funds at the municipality level over the programming period 2014-2020.

Table A1 shows the list of most common words that mainly characterize projects with thematic code objective 4 (“low carbon economy and energy efficiency”). We use such keywords to detect additional projects financed by the EU Cohesion Policy with thematic codes 1-3 or 5-13 fostering GHG emissions reduction.

Furthermore, Tables A2 and A3 show the 10 provinces with the highest and lowest amount of green EU Cohesion Policy funds expenditures, respectively. Finally, Table A4 highlights expenditures of green EU Cohesion Policy funds aggregated at the macro-region level (NUTS 1).

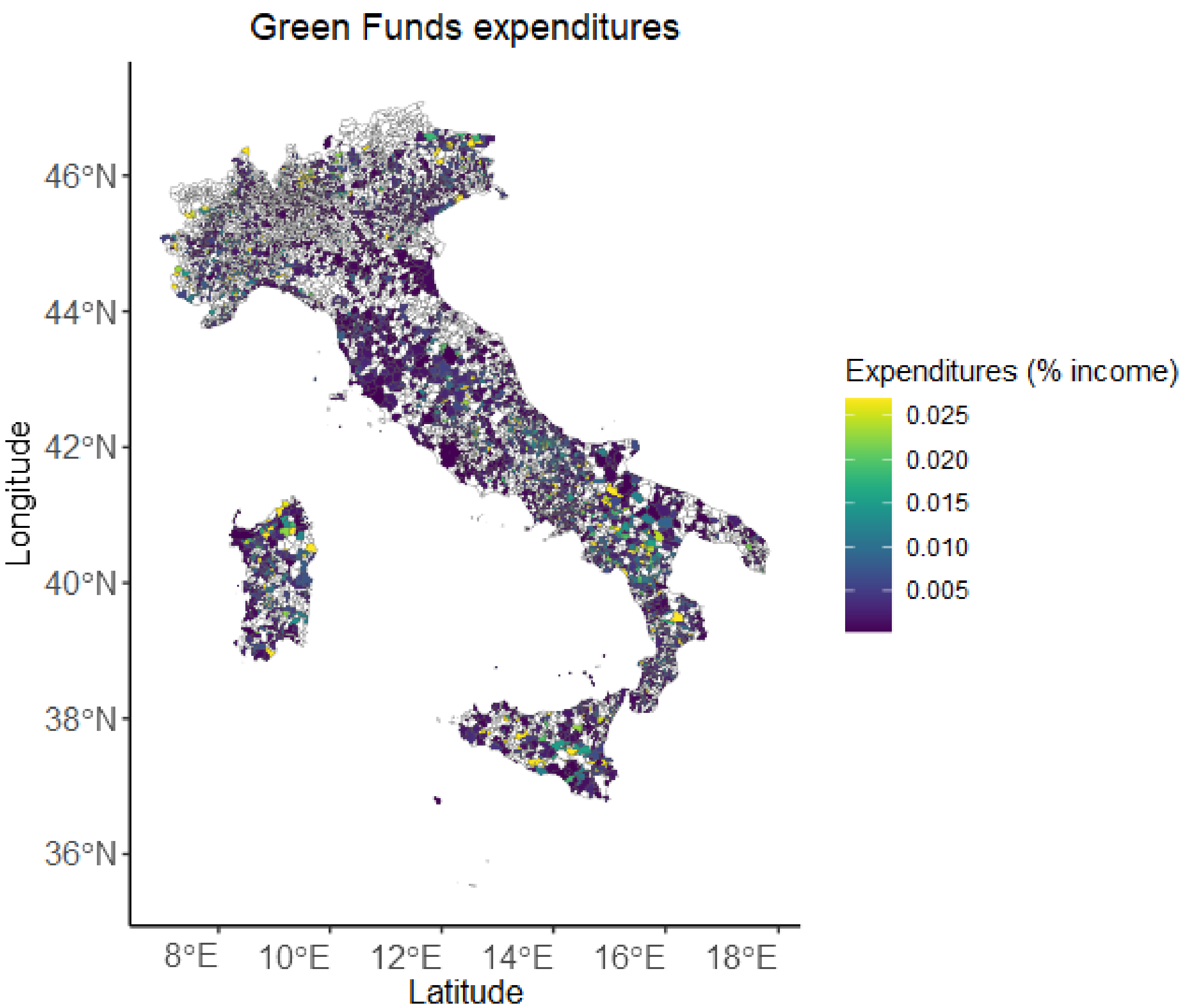

Figure A1: We show the geographical distribution of the green EU Cohesion Policy funds at the municipality level. Values refer to the total expenditures over the programming period 2014-2020 (expressed as a percentage of the total income of the underlying municipality).

Table A1: We show the list of main keywords identified to select additional projects financed by the EU Cohesion Policy with thematic codes 1-3 or 5-13. Since the project description and title are available only in the "Italian" language, we report here a precise translation of the main keywords used. We stop reporting keywords with a frequency below 50 times. We do this since even extending the set of keywords, the manual inspection of projects would lead to the same (or very similar) final sample of analyzed projects. Symbol $*$ is used to refer to any possible string following the previous pattern (e.g., "energ*" will include both energy and energetic words.

Keywords
Energ*
Energ* efficiency
Renewable-energy-source
Photovoltaic
Solar-energy-source
Wind-energy-source
Co-generation
Emissions
Pollution
Carbon-abatement
CO_2
Environmentally sustainable
Green technolog*
Clean technolog*
Electric infrastructure
Energy consumption optimization
Energy-saving
Bio-methane
Fossil fuel*
Methane
Diesel
Lighting systems
Energ* consumption
GHG emission
Air quality
Energy waste
Thermal-power-plant restructuring
Innovative-heat-pump
Efficient heating system
Circular economy
Ecolog*
Dump

Table A2: We show the amount of green EU Cohesion Policy funds expenditures (expressed as a percentage of total income) aggregated at province level. We focus on the 10 provinces with the highest expenditure level.

Province	Expenditures (% of total income)
Potenza	0.0157
Matera	0.01503
Benevento	0.0111
Enna	0.0094
Agrigento	0.00844
La Spezia	0.00791
Nuoro	0.0066
Terni	0.0060
Avellino	0.0057
Cosenza	0.0053

Table A3: We show the amount of green EU Cohesion Policy funds expenditures (expressed as a percentage of total income) aggregated at province level. We focus on the 10 provinces with the lowest expenditure level.

Province	Expenditures (% of total income)
Ascoli Piceno	0.00076
Varese	0.00062
Ravenna	0.00060
Milano	0.00056
Ancona	0.00052
Ferrara	0.00048
Monza e della Brianza	0.00047
Piacenza	0.00046
Parma	0.00042
Roma	0.00026

Table A4: We show the distribution of green EU Cohesion Policy funds aggregated at the macro-region level (NUTS 1).

Macro-area	Total Expenditure (€)	Expenditures (% of total income)
South (ITF)	315,719,044	0.0035
Insular (ITG)	152,869,273	0.0032
Centre (ITH)	257,901,491	0.0022
North-West (ITC)	280,034,789	0.0019
North-East (ITI)	158,819,951	0.0012

B PM2.5 levels: additional information

Tables B1 and B2 show the average concentration of PM2.5 of the 10 provinces with the lowest and highest air quality over the period 2014-2020. Table B3 highlights the average PM2.5 concentration at NUTS 1 level. Figure B1 displays the average PM2.5 concentration at the municipal level over the period 2014-2020.

Table B1: We show the average concentration of PM2.5 [$\mu g/m^3$] in the worst 10 Italian provinces in terms of air quality over the time frame 2014-2020.

Province	PM2.5
Cremona	46.13
Milano	45.11
Lodi	44.68
Monza e della Brianza	43.90
Padova	43.85
Mantova	43.64
Verona	38.92
Treviso	37.89
Venezia	37.47
Rovigo	36.68

Table B2: We show the average concentration of PM2.5 [$\mu g/m^3$] in the best 10 Italian provinces in terms of air quality over the time frame 2014-2020.

Province	PM2.5
Trento	15.36
Grosseto	14.84
Belluno	14.08
Nuoro	13.82
L'Aquila	13.81
Verbano-Cusio-Ossola	13.58
Sassari	13.52
Sondrio	12.64
Bolzano	12.39
Aosta	11.45

Table B3: We show the average concentration of PM2.5 [$\mu g/m^3$] at macro-area level.

NUTS 1	PM2.5
North-West (ITC)	30.75
Centre (ITH)	27.86
South (ITF)	20.53
North-East (ITI)	19.75
Insular (ITG)	17.83

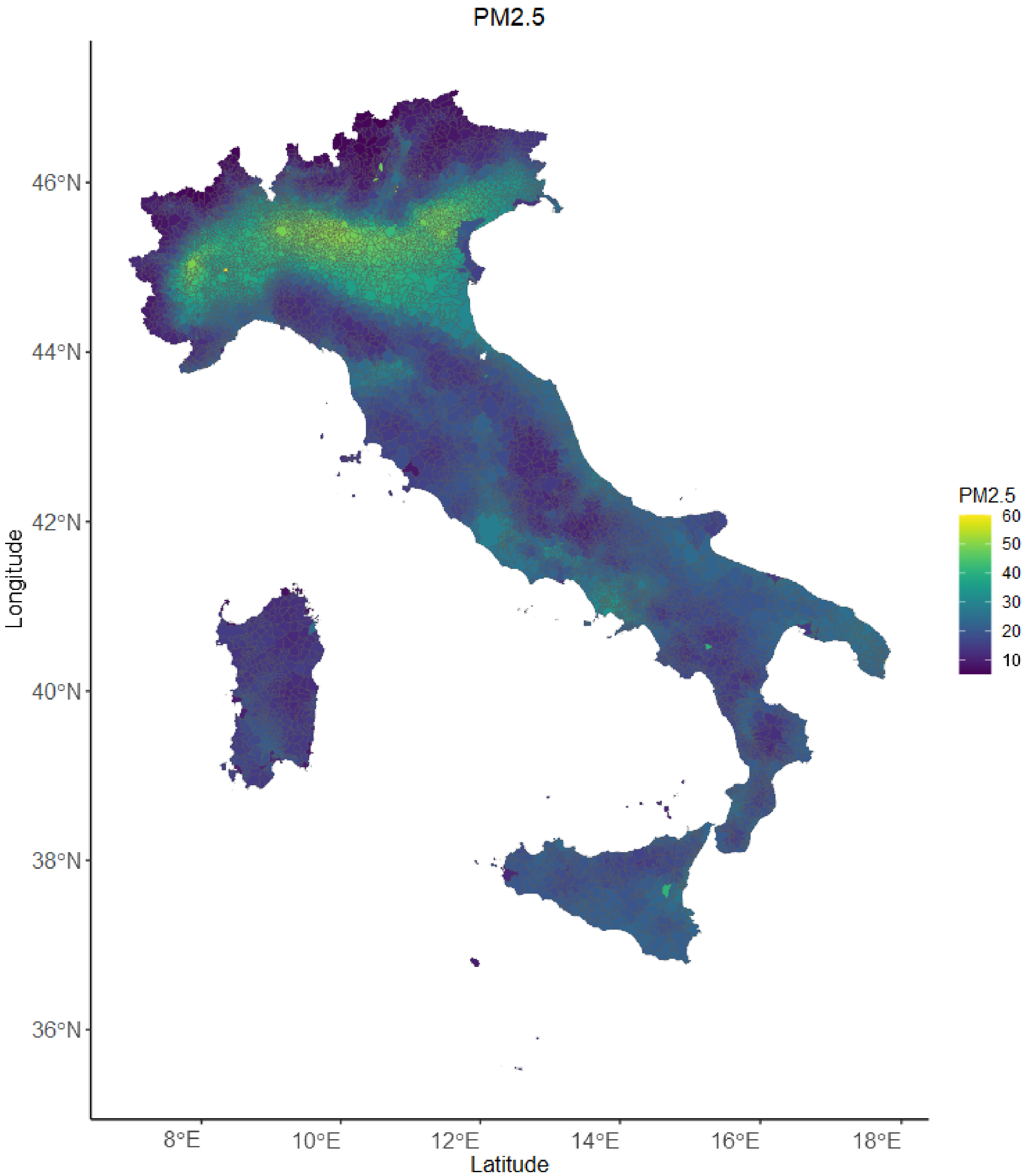

Figure B1: We show the geographical distribution of the average PM2.5 [$\mu g/m^3$] concentration at the municipal level over the period 2014-2020.

C Cluster Analysis: Additional material

C.1 Pre-processing

In order to ensure that all variables are transformed to a common scale for the analysis, the pre-processing involved the normalization of variables between 0 and 1. For variables where higher values indicate better conditions, the formula subtracts the minimum value of the variable and divides by the range (maximum minus minimum). Conversely, for variables where lower values indicate better conditions, the formula subtracts the maximum value of the variable and divides by the range (minimum minus maximum). In this way, higher values of the normalized variables can be interpreted as better conditions in terms of local territorial capital.

Therefore, in case a larger value of the variable can be interpreted as a better condition in terms of local territorial capital we rely on the following formula:

$$Normalized\ Variable_i = \frac{Variabile_i - min(Variable)}{max(Variable) - min(Variable)}$$

where $Variable_i$ is the value of the underlying covariate for the municipality i.

In case a lower value of the variable can be interpreted as a better condition in terms of local territorial capital we rely on the following formula:

$$Normalized\ Variable_i = \frac{Variabile_i - max(Variable)}{min(Variable) - max(Variable)}$$

We show in Fig. C1 the distribution of the normalized covariates. Table C1 shows the median of standardized values of all the covariates for the 3 clusters.

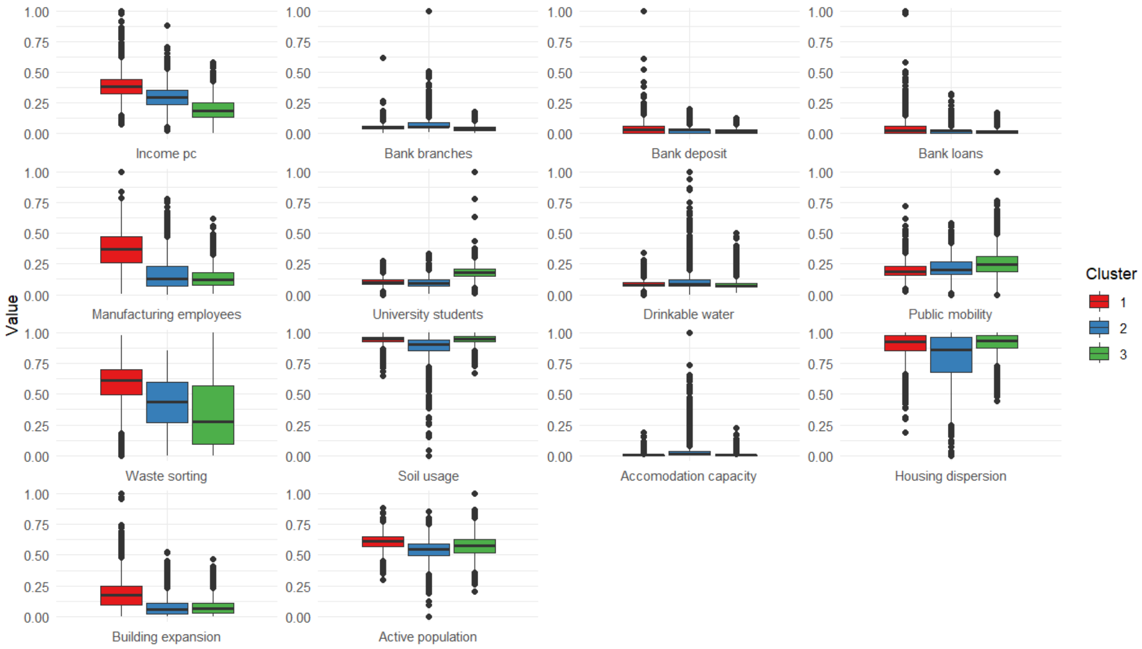

Figure C1: We show the distribution of the normalized covariates used in the cluster analysis across the 3 groups.

Table C1: We show the median value of standardized covariates for the 3 clusters.

Cluster	1	2	3
Income pc	0.382	0.298	0.188
Bank branches	0.055	0.056	0.042
Bank deposit	0.032	0.032	0.020
Bank loans	0.026	0.026	0.013
Manufacturing employees	0.369	0.132	0.118
University students	0.102	0.092	0.176
Drinkable water	0.081	0.087	0.072
Public mobility	0.191	0.202	0.246
Waste sorting	0.615	0.440	0.276
Soil usage	0.950	0.908	0.951
Accommodation capacity	0.002	0.009	0.002
Housing dispersion	0.926	0.864	0.938
Building expansion	0.172	0.057	0.062
Active population	0.613	0.546	0.577

C.2 Silhouette definition

We define the silhouette as:

$$\text{Silhouette}_i = \frac{1}{N} s_i \tag{2}$$

where s_i is the silhouette of observation i and N is the sample size. In particular, s_i can be computed as:

$$s_i = \frac{b_i - a_i}{max(a_i; b_i)} \tag{3}$$

where a_i is the mean distance of observation i from all other units in the same cluster (c_i) and b_i is the minimum average distance of observation i from all units in other clusters.

In formula:

$$a_i = \frac{1}{N_{c_i} - 1} \sum_{j \in c_i, j \neq i} (d_{i,j}) \tag{4}$$

$$b_i = \min_{c_l \neq c_i} \frac{1}{N_{c_l}} \sum_{l \in c_l} (d_{i,l}) \tag{5}$$

where N_{c_i} is the size of cluster c_i and $d_{i,j}$ is the euclidean distance between observation i and j.

C.3 Robustness analysis

Table C2 presents pairwise t-test results between cluster groups with Bonferroni correction. All p-values are significant, except for Bank branches where Cluster 3 does not differ significantly from the other two clusters. Regarding Manufacturing employees, Public mobility, Drinkable water, Soil usage, Housing dispersion, and Active population, there are no differences between Clusters 2 and 3. Clusters 3 and 1 do not differ significantly in terms of Housing dispersion and Building expansion, Accommodation capacity, and Public mobility.

Table C2: Pairwise t-test results between groups for selected variables.
* $p - value < 0.10$, ** $p - value < 0.05$, *** $p - value < 0.01$.

Group 1	Group 2	P.value	Variable
2	1	0.000***	Income pc
3	1	0.0018***	Income pc
3	2	0.000***	Income pc
2	1	0.000***	Bank branches
3	1	1.000	Bank branches
3	2	0.7544	Bank branches
2	1	0.000***	Bank deposit
3	1	0.000***	Bank deposit
3	2	0.000***	Bank deposit
2	1	0.000***	Bank loans
3	1	0.000***	Bank loans
3	2	0.000***	Bank loans
2	1	0.000***	Manufacturing employees
3	1	0.000***	Manufacturing employees
3	2	0.3643	Manufacturing employees
2	1	0.000***	University students
3	1	0.000***	University students
3	2	0.000***	University students
2	1	0.000***	Drinkable water
3	1	0.0635*	Drinkable water
3	2	1.000	Drinkable water
2	1	0.000***	Public mobility
3	1	0.6748	Public mobility
3	2	1.000	Public mobility
2	1	0.000***	Waste sorting
3	1	0.000***	Waste sorting
3	2	0.000***	Waste sorting
2	1	0.000***	Soil usage
3	1	0.0017***	Soil usage
3	2	0.8551	Soil usage
2	1	0.000***	Accommodation capacity
3	1	0.1767	Accommodation capacity
3	2	0.0072***	Accommodation capacity
2	1	0.000***	Housing dispersion
3	1	1.000	Housing dispersion
3	2	1.000	Housing dispersion
2	1	0.000***	Building expansion
3	1	0.4758	Building expansion
3	2	0.0360**	Building expansion
2	1	0.000***	Active population
3	1	0.0001***	Active population
3	2	1.000	Active population

D Robusteness check: green funds impact across clusters

Table D1 shows our estimates for an SDM model with all the municipalities in Italy that receive carbon abatement funds, where we insert the clusters (categorical variable) and the interaction between the clusters and *Environmental funds* and *Environmental funds spillovers* as additional regressors.

Tables D2, D3 and D4 highlight the top five provinces in terms of aggregate direct, indirect, and total effects generated by municipalities in Clusters 1, 2 and 3.

Table D1: We show the estimates of a Spatial Durbin Model analyzing the impact of funds targeting carbon abatement on the variation of pollutant intensity in terms of PM2.5 across all clusters. Results are obtained using a spatial exponential decay matrix with $\alpha = 2$.
* $p-value < 0.10$, ** $p-value < 0.05$, *** $p-value < 0.01$.

	Dependent variable: Variation of PM2.5 concentration	
Lambda	0.957***	0.957***
	(0.002)	(0.002)
Environmental funds	-0.001	-0.001
	(0.001)	(0.001)
Environmental spillover	-0.001	-0.001
	(0.002)	(0.002)
Cluster 1	0.000	0.001
	(0.002)	(0.002)
Cluster 2	0.001	0.001
	(0.002)	(0.002)
Environmental funds*Cluster 1	-0.006***	-0.006***
	(0.002)	(0.002)
Environmental funds*Cluster 2	-0.003	-0.002
	(0.004)	0.004
Environmental spillover *Cluster 1	-0.011**	-0.010**
	(0.004)	(0.004)
Environmental spillover*Cluster 2	-0.007*	-0.007*
	(0.004)	(0.004)
Temperature		0.000
		(0.001)
Precipitation		-0.001*
		(0.001)
Wind speed		0.000
		(0.001)
Humidity		-0.002**
		(0.001)
N	21,490	21,490
AIC	-37,275.43	-37,387.71
BIC	-37,203.65	-37,301.53

Table D2: We show aggregate direct, indirect, and total effects at the province level generated by municipalities in Cluster 1. We show the top five provinces.

Province	Indirect Effects	Direct Effects	Total Effects
Imperia	-0.0190	-0.0068	-0.0258
La Spezia	-0.0163	-0.0063	-0.0227
Trieste	-0.0159	-0.0073	-0.0232
Reggio nell'Emilia	-0.0148	-0.0059	-0.0207
Cremona	-0.0145	-0.0060	-0.0205

Table D3: We show aggregate direct, indirect, and total effects at the province level generated by municipalities in Cluster 2. We show the top five provinces.

Province	Indirect Effects	Direct Effects	Total Effects
Padova	-0.0129	-0.0036	-0.0165
Vicenza	-0.0093	-0.0028	-0.0121
Ravenna	-0.0086	-0.0029	-0.0115
Lodi	-0.0084	-0.0031	-0.0116
Pistoia	-0.0084	-0.0028	-0.0113

Table D4: We show aggregate direct, indirect, and total effects at the province level generated by municipalities in Cluster 3. We show the top five provinces.

Province	Indirect Effects	Direct Effects	Total Effects
Campobasso	-0.0046	-0.0021	-0.0067
Catania	-0.0045	-0.0020	-0.0065
Ragusa	-0.0045	-0.0019	-0.0064
Isernia	-0.0045	-0.0021	-0.0066
Bari	-0.0045	-0.0020	-0.0065

E Spatial matrices: Robustness Analysis

Our results might be driven by the definition of the concept of ”neighbor” municipalities. For this reason, we check the robustness of our findings in case we rely on alternative definitions of our spatial weight matrix W. In particular, Table E1 shows the results for the SDM where our spatial exponential matrix accounts for alternative decay exponents equal to 0.1, 0.5, 1.5, and 2.5. Table E2 shows a sensitivity analysis in case we use the KNN method with k = 20, 30, 40, 50 to identify neighbor municipalities. Table E3 exhibits the results in case we rely on a spatial weight matrix defined based on a queen or inverse spatial distance logic.

Table E1: We show the estimates of a Spatial Durbin Model analyzing the impact of funds targeting carbon abatement on the variation of pollutants intensity in terms of PM2.5. The model is estimated across spatial exponential decay matrices for different values of α (0.1, 0.5, 1.0, 1.5, 2.5).
* $p-value < 0.10$, ** $p-value < 0.05$, *** $p-value < 0.01$.

	Dependent variable: Variation of PM2.5														
	Cluster 1					*Cluster 2*					*Cluster 3*				
	(α=2.5)	(α=1.5)	(α=1.0)	(α= 0.5)	(α= 0.1)	(α=2.5)	(α=1.5)	(α=1.0)	(α= 0.5)	(α= 0.1)	(α=2.5)	(α=1.5)	(α=1.0)	(α= 0.5)	(α= 0.1)
Lambda	0.788***	0.805***	0.823***	0.805***	0.823***	0.736***	0.748***	0.763***	0.748***	0.763***	0.756***	0.773***	0.793***	0.773***	0.793***
	(0.004)	(0.004)	(0.003)	(0.004)	(0.003)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)
Environmental funds	-0.007***	-0.006***	-0.005***	-0.006***	-0.005***	0.000	0.000	0.000	0.000	0.000	-0.002	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Environmental funds spillovers	-0.004***	-0.004***	-0.004***	-0.004***	-0.004***	-0.004**	-0.004**	-0.004**	-0.004**	-0.004**	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Temperature	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002	-0.001	-0.002	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Precipitation	-0.007***	-0.006***	-0.005***	-0.006***	-0.005***	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Wind speed	0.003***	0.003***	0.003**	0.003***	0.003**	-0.002	-0.001	-0.001	-0.001	-0.001	0.000	0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Humidity	-0.007***	-0.007***	-0.006***	-0.007***	-0.006***	-0.004**	-0.004**	-0.004**	-0.004**	-0.004**	0.001	0.001	0.000	0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
N	7,343	7,343	7,343	7,343	7,343	7,315	7,315	7,315	7,315	7,315	6,832	6,832	6,832	6,832	6,832
AIC	12,445.17	12,535.17	12,645.17	12,745.17	12,631.12	5,863.21	5,801.28	5,853.23	5,881.86	5,821.12	14,051.69	14,072.35	14,093.41	14,101.38	14,171.31
BIC	12,387.23	12,481.18	12,594.16	12,695.51	12,703.62	5,812.28	5,756.18	5,701.94	5,634.79	5,661.75	14,001.61	14,021.81	14,019.83	14,042.91	14,031.16

Table E2: We show the estimates of a Spatial Durbin Model analyzing the impact of funds targeting carbon abatement on the variation of pollutants intensity in terms of PM2.5. The model is estimated across alternative spatial matrices using different numbers of K-Nearest Neighbors.
* $p-value < 0.10$, ** $p-value < 0.05$, *** $p-value < 0.01$.

	Dependent variable: Variation of PM2.5											
	Cluster 1				*Cluster 2*				*Cluster 3*			
	(k=20)	(k=30)	(k=40)	(k=50)	(k=20)	(k=30)	(k=40)	(k=50)	(k=20)	(k=30)	(k=40)	(k=50)
Lambda	0.961***	0.965***	0.967***	0.968***	0.944***	0.952***	0.960***	0.964***	0.950***	0.956***	0.962***	0.966***
	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)	(0.004)	(0.005)	(0.005)	(0.005)
Environmental funds	-0.004***	-0.005***	-0.006***	-0.006***	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Environmental spillovers	-0.011***	-0.016***	-0.019***	-0.019***	-0.010*	-0.011*	-0.012*	-0.017*	-0.016	-0.015	-0.005	-0.010
	(0.003)	(0.004)	(0.004)	(0.005)	(0.005)	(0.006)	(0.007)	(0.009)	(0.011)	(0.012)	(0.004)	(0.007)
Temperature	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)
Precipitation	-0.001	-0.001	-0.001	-0.001	-0.002	-0.001	-0.001	-0.002	-0.002	-0.002	-0.002	-0.002
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Wind speed	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)
Humidity	-0.003**	-0.002	0.000	0.001	-0.004*	-0.004*	-0.004	-0.004	-0.003***	-0.004***	-0.005***	-0.005***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
N	7,343	7,343	7,343	7,343	7,315	7,315	7,315	7,315	6,832	6,832	6,832	6,832
AIC	12,445.17	12,535.17	12,645.17	12,745.17	5,863.21	5,901.28	5,953.23	5,981.86	14,351.69	14,472.35	14,593.41	14,701.38
BIC	12,387.23	12,481.18	12,594.16	12,695.51	5,812.28	5,856.18	5,901.94	5,934.79	14,301.61	14,421.81	14,519.83	14,642.91

Table E3: We show the estimates of a Spatial Durbin Models analyzing the impact of funds targeting carbon abatement on the variation of pollutants intensity in terms of PM2.5. The model is estimated across alternative spatial matrices using a distance-based and a queen spatial matrix.
* $p - value < 0.10$, ** $p - value < 0.05$, *** $p - value < 0.01$.

	Dependent variable: Variation of PM2.5					
	Distance			*Queen*		
	(Cluster 1)	(Cluster 2)	(Cluster 3)	(Cluster 1)	(Cluster 2)	(Cluster 3)
Lambda	0.992***	0.994***	0.997***	0.427***	0.248***	0.270***
	(0.003)	(0.002)	(0.001)	(0.009)	(0.011)	(0.010)
Environmental funds	-0.029***	-0.011	-0.005	-0.019***	-0.008	-0.006
	(0.007)	(0.009)	(0.007)	(0.003)	(0.006)	(0.004)
Environmental spillovers	0.019*	-0.097*	−0.062	-0.007**	-0.003*	-0.005
	(0.010)	(0.058)	(0.059)	(0.003)	(0.002)	(0.003)
Temperature	-0.022***	-0.021**	-0.028***	-0.003	-0.002	-0.005**
	(0.007)	(0.010)	(0.007)	(0.003)	(0.004)	(0.002)
Precipitation	-0.027***	-0.018*	-0.006	-0.024***	-0.019***	-0.003
	(0.007)	(0.009)	(0.007)	(0.003)	(0.004)	(0.002)
Wind speed	0.007	0.005	-0.010	0.011***	-0.009**	0.000
	(0.007)	(0.010)	(0.007)	(0.003)	(0.004)	(0.002)
Humidity	0.042***	0.009	0.009	-0.019***	-0.009**	0.005**
	(0.007)	(0.009)	(0.007)	(0.003)	(0.004)	(0.002)
N	7,343	7,315	6,832	7,343	7,315	6,832
AIC	12,345.17	5,751.27	14,199.73	12,351.61	5,762.72	14,236.73
BIC	12,031.81	5,697.37	14,137.73	12,045.23	5,704.23	14,178.81

F Cluster 3 robustness Analysis

Figure F1 shows the distribution of the socio-economic variables of Cluster 3 municipalities where green EU Cohesion funds are effective/ineffective. We show results when we consider a quantile Q equal to 15%. Similar results hold in case $Q = 0.10$ or 0.05.

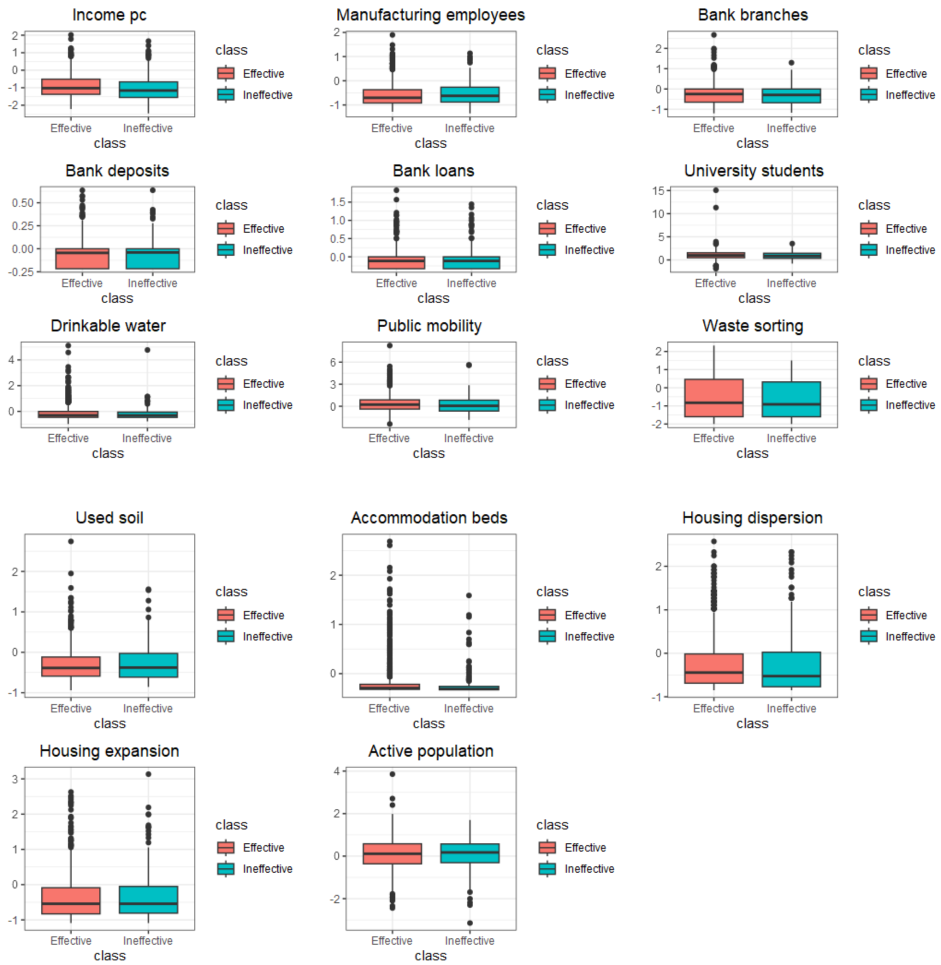

Figure F1: We show the distribution of a set of covariates for municipalities of cluster 3 where green funds are effective/ineffective.