Jan, 2025
GRINS DISCUSSION PAPER SERIES DP N° 119/2026 ISSN 3035-5576

GRINS

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KEYWORDS

EU Cohesion Policy | Green funds | PM2.5 pollution | Carbon abatement | Territorial capital | spatial spillovers | Italy

JEL CODE

Q52, Q58, R11, R15, C33

ACKNOWLEDGEMENTS

This study was funded by the European Union - NextGenerationEU, in the framework of the GRINS - Growing Resilient, INclusive and Sustainable project (GRINS PE00000018). The views and opinions expressed are solely those of the authors and do not necessarily reflect those of the European Union, nor can the European Union be held responsible for them.

CITE THIS WORK

Title: The contribution of green Cohesion Policy funds to carbon abatement: a heterogeneity analysis across Italian municipalities. Publication Date: 2025.

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Through the application of panel Spatial Durbin Models (SDM), the study highlights that such programs of financial support display both a significant direct and indirect effect in municipalities characterized by a high economic capital. Indeed, funds targeting carbon abatement tend to reduce PM2.5 concentration levels both in the municipalities where such projects are implemented and in the neighbouring administrative units. This contribution rather shows how these green funds are associated only with significant spillovers in the cluster of Italian 2 municipalities exhibiting a strong presence of Tourism infrastructures.
The study does not find either significant direct or indirect effects in the municipalities mainly located in the Centre-South of Italy with high levels of human capital. The study also discusses

how these findings might be related to the local institutional capacity and to the capability to select and implement projects actually contributing to carbon abatement.

The contribution of green Cohesion Policy funds to carbon abatement: a heterogeneity analysis across Italian municipalities

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January 7, 2025

Abstract

During the programming period 2014-2020 the sustainability transition represented a key pillar of the EU Cohesion Policy. However, the bulk of extant studies still investigates the impact of such regulatory framework on socio-economic growth, neglecting its contribution to achieving environmental targets such as carbon abatement. This study aims to fill this gap, by analysing the effects of green Cohesion Policy funds in terms of PM2.5 reduction across municipalities with a heterogeneous level of territorial capital in Italy. Through the application of panel Spatial Durbin Models (SDM), the study highlights that such programs of financial support display both a significant direct and indirect effect in municipalities characterized by a high economic capital. Indeed, funds targeting carbon abatement tend to reduce PM2.5 concentration levels both in the municipalities where such projects are implemented and in the neighbouring administrative units. This contribution rather shows how these green funds are associated only with significant spillovers in the cluster of Italian municipalities exhibiting a strong presence of Tourism infrastructures. The study does not find either significant direct or indirect effects in the municipalities mainly located in the Centre-South of Italy with high levels of human capital. The study also discusses how these findings might be related to the local institutional capacity and to the capability to select and implement projects actually contributing to carbon abatement.

Keywords: EU Cohesion Policy; Green funds; PM2.5 pollution; Carbon abatement; Territorial capital; Spatial spillovers; Italy.
JEL Codes: Q52, Q58, R11, R15, C33.

1. Introduction

Complete ex-post assessments on the impact of the EU Cohesion Policy suggest that the effectiveness of this regulatory framework was negatively affected by the wide set of targeted development axes, leading to fragmented spending across the different priorities with a lack of critical mass (Barca, 2009). Furthermore, the EU Cohesion Policy was characterized by insufficient consideration of the ”logic of intervention”, meaning that the regulation missed a clear implementation strategy to achieve the defined targets (CPMR, 2014, 2015).
As a consequence, in 2013 this policy framework was subject to significant and substantial regulatory changes, ensuring a stronger alignment between policy objectives and funds allocation and 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 161 billion euros corresponding to more than 30% of the total available budget. Indeed, the sustainability transition is commonly seen as a key option to combat climate change and comply with international targets established by the European Commission aiming to reduce greenhouse gas emissions to at least 55% below 1990 levels by 2030 and achieve carbon neutrality in 2050.
Despite such growing interest on the effects generated by environmental funds in terms of carbon abatement, extant literature has mainly focused on the analysis of the socio-economic impact of Cohesion Policy funds, considering the GDP per capita and employment as main outcome variables (see e.g., Gripaios et al. (2008), Mohl and Hagen (2010), Pienkowski and Berkowitz (2016), Dall’Erba and Fang (2017) and Scotti et al. (2022)). Moreover, the still limited set of studies discussing how public funds may contribute to reducing CO_2 emissions has not adequately investigated how the effects of such programs of financial support targeting the environmental sector may vary depending on the local set of capacities, representing the stock of tangible and intangible assets that contribute to the local sustainable development. Indeed, there is a strong debate on the role of the local context in mediating the impact of EU Cohesion Policy

funds (Fratesi et al., 2014, Fratesi and Perucca, 2016, 2018, 2019, Bachtrogler et al., 2020). If existing contributions show that public funds have a larger impact on firms growth in regions with lower income or limited endowments of territorial assets, we still lack evidence on how the local set of capacities may influence the outcome of financial support initiatives targeting carbon abatement.

Against this background, this paper aims to fill this gap by analysing the impact of green EU Cohesion Policy funds in terms of PM2.5 air concentration reduction in Italy over the time frame 2014-2020. Through the application of panel Spatial Durbin Models (SDM) we study the extent to which green funds generate both a direct and indirect effect in terms of PM2.5 reduction when we analyse the whole sample of Italian municipalities. Indeed, these programs of financial support may contribute to reducing emissions both in the municipality directly receiving them, but also in the neighbour areas. Moreover, we discuss potential heterogeneous dynamics across territories with different levels of territorial capital.

Overall, this report develops an insight on the effects generated by green Cohesion Policy funds in terms of PM2.5 reduction across territories with heterogeneous levels of territorial capital, supporting policy makers to further refine and improve this regulatory framework aiming to contribute to the sustainability transition.

The rest of the paper is organized as follows: Sections 2 and 3 illustrate the data and the methods we employ to investigate our research objective. Section 4 discusses our results, while the paper concludes by highlighting the main implications of our study.

2. Outline of literature 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).

Due to the impossibility of complying 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 (Leete et al., 2013; Iyer et al., 2015; Polzin et al., 2016). 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 derived from renewable energy sources, electrification of the economy across different sectors (e.g., transportation), improved energy efficiency in buildings, industry, and household appliances, as well as secure energy systems, EU Cohesion Policy funds may thus support the large investments required at firm level to foster the 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 support 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 CO2 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 from17.1 to 25.1 Mt of CO2, 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 CO2 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) associated with a stronger yearly carbon abatement rate (between −4.0% and −2.0%) (Duro and Padilla, 2013; Liobikiene and Mandravickaite, 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 level of economic development in terms of GDP and income per capita (Kozera et al., 2022; Penalosa 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 an original 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 green funds, we first restrict our analysis of EU Cohesion Policy funds 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.[1]

In particular, we focus on the European Regional Development Fund (ERDF) and the European Social Fund (ESF), since with 199 and 84 billion € they represent two main funds within the EU Cohesion Policy framework over the time frame 2014-2020. 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 ERDF and the ESF 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.

Based on the thematic code attributed to each project by the European Commission, 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

[1] 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.

to activities targeting emissions reduction, thus potentially having a direct impact on carbon abatement. Through this procedure, we initially select 5,736 projects.

Then with reference to these selected projects, based on the title and synthetic description of such projects, we identify a set of frequent keywords, allowing us to distinguish projects targeting the sustainability transition in terms of carbon abatement. We use such keywords to identify projects whose thematic objective is not classified in the thematic objective 4 by the European Commission (thus initially excluded from our selected sample), but that still are mainly contributing to emissions reduction.

Since projects out of thematic objective 4 might be focused 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 select a very specific set of combination of keywords that must be found in the synthetic description of projects with thematic codes 1-3 and 5-11 in order to be selected as projects fostering carbon abatement. Through this procedure we select other 5,172 projects. In this way, we expect to provide a complete overview on the set of projects targeting the sustainability transition with a specific focus on CO_2 emissions abatement.[2]

In particular, our sample consists of 10,908 (5,736+5,172) projects and 4.1 billion euros of realized expenditures. From this sample, we exclude projects with a realized cost and public funds equal to zero. Indeed, such projects have not started yet to be implemented and do not seem to have received public funds (either from the EC or national government). Our final sample, thus consists of 10,468 projects.

Since our geographical unit of analysis is municipalities, we aggregate our data at the municipal level. Overall, our dataset covers 4,941 Italian municipalities receiving public funds from the Cohesion Policy with a specific target on carbon abatement over the timeframe 2014- 2020. Figure 1 shows the distribution of green 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.

[2] Here, we report an shortlist of keywords combinations we use to select such projects: "energy efficiency", "energy saving", "pollution", "photovoltaic", "emission", "solar", "diesel", "methane", "bio-methane", "CO2 emission", "carbon abatement".

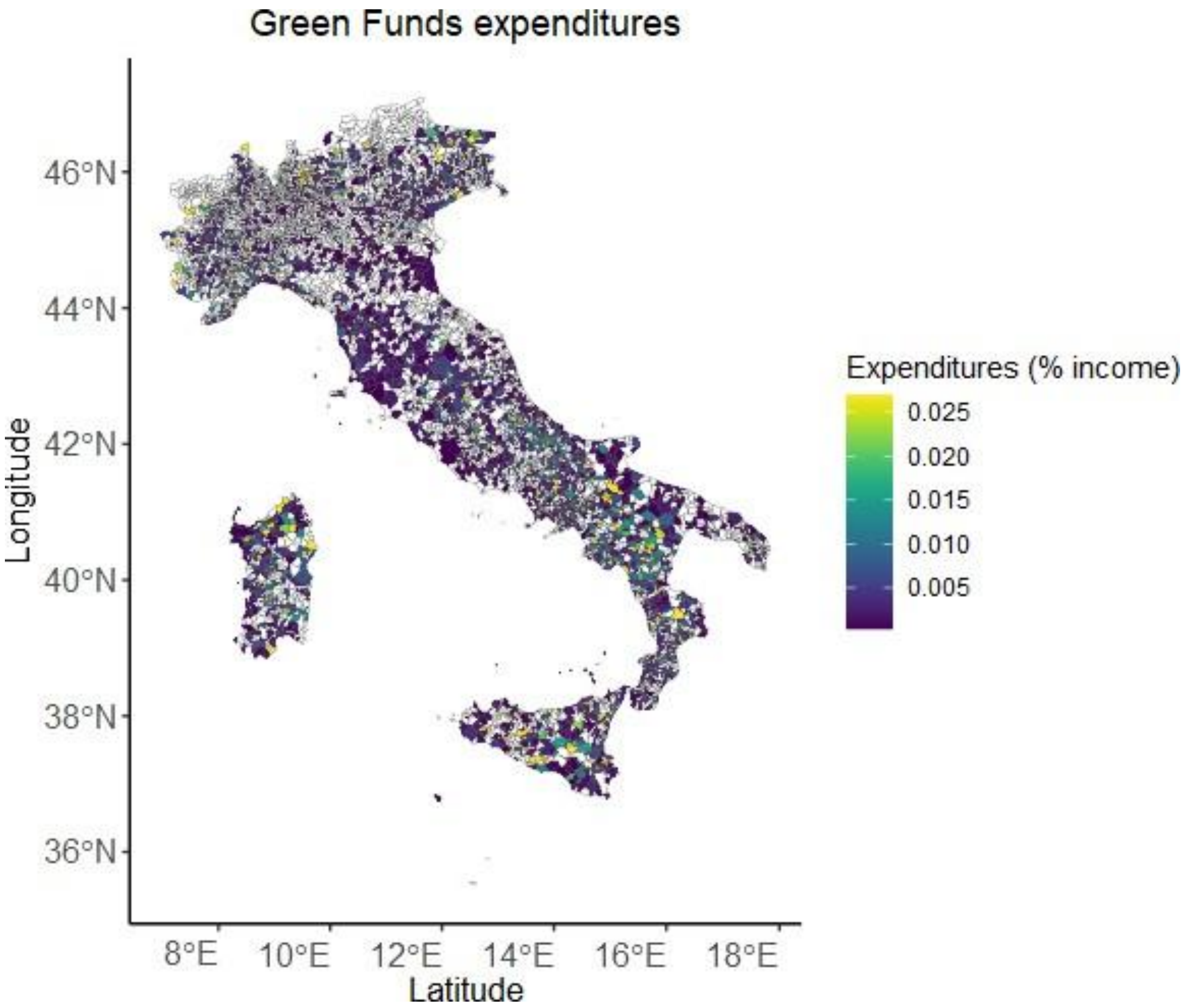


Figure 1: We show the distribution of green funds expenditures across Italian municipalities normalized by the total income of the underlying administrative unit.

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 by the European Environment Agency (EEA) and is a reference pollutant used by the European Commission to establish environmental targets (Tarın-Carrasco et al., 2021; Beloconi and Vounatsou, 2023).[3]

[3] 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-qua lity/eu-air-quality-standards_en.

National statistical offices do not provide information related to the air concentration of alternative pollutants with the spatial granularity and temporal frequency required by our analysis. Therefore, we build our dependent variable based on satellite data disclosed by the European Environmental Agency (EEA) covering the timeframe 2014-2020. In particular, we rely on air pollutant concentration grids (1km2 x 1km2) combining monitoring air quality data in a 'regression-interpolation-merging mapping' methodology. We compute the yearly level of PM2.5 in every Italian municipality as a weighted average of the pollutant concentration in each grid based on the portion of the overlapping area between the grid and the considered administrative unit.

Figure 2 shows the geographical distribution of PM2.5 levels across Italian municipalities in 2014. We observe a higher concentration of emissions in the North of Italy especially in Lombardy, Piedmont, Emilia-Romagna, and Veneto regions. PM2.5 levels tend to be lower in the Centre-South of Italy, with Sardinia constituting the cleaner region.

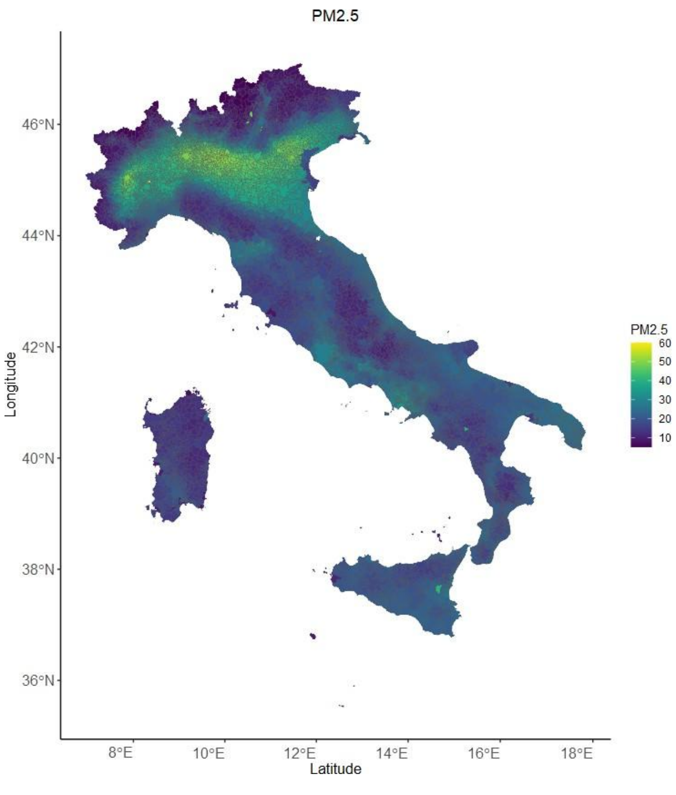


Figure 2: We show the geographical distribution of the level of PM2.5 across Italian municipalities.

4. Methodology

4.1 Cluster analysis

Our analysis aims to disentangle the impact of green EU Cohesion Policy funds across territories based on the local context. In order to distinguish the different characteristics of Italian municipalities, we rely on a cluster analysis. The selection of variables used in the cluster analysis takes as reference the ”Territorial Capital” framework introduced by Camagni et al. (2009). However, we expand the set of variables previously used by Fratesi et al. (2014), Fratesi and Perucca (2016), Fratesi and Perucca (2018), Fratesi and Perucca (2019) and Bachtrogler et al. (2020) mainly focusing on private/public assets and hard/soft infrastructures to account for a complete set of social, economic, environmental and demographic variables.
In particular, in terms of economic variables we consider Income per capita, Bank branches, Bank deposits per capita and Bank loans per capita, and the Percentage of employees in the Manufacturing sector Manufacturing employees. We also include 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 portion of Soil usage as proxies of urban ecology, quality of local environmental services, and of the level of anthropization of the area. We account for additional local services by including the Public mobility index and the number of Accommodation beds. We also plug the heterogeneity in housing and household assets through the Housing dispersion and Building expansion indices. Finally, the percentage of enrolled university students based on the municipality of residence University students and the portion of Active Population allow us to map the human capital of Italian administrative units.
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. We then assess the stability of our results by comparing the output of different hierarchical clustering methods based on alternative agglomeration methods such as ”Single”, ”Complete”, ”Average”, ”Mcquitty”, ”Median”, ”Centroid” (McQuitty, 1966; Hartigan, 1975). 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 on the quality of the clustering method output. We define the silhouette as:

$$Silhouette = \frac{1}{N} s_i \quad (1)$$

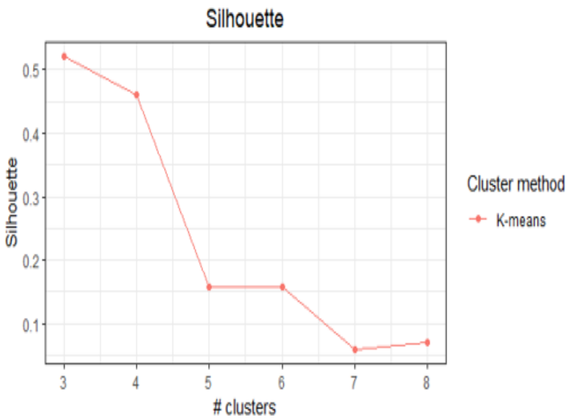
where s_i is the silhouette of observation i and N is the sample size. In particular, s_i can be computed as:

$$s_i = \frac{b_i - a_i}{max(a_i; b_i)} \quad (2)$$

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

$$a_i = \frac{1}{N_{c_i} - 1} \sum_{j \in c_i, j \neq i} (d_{i,j}) \ (3)$$

where N_{c_i} is the size of cluster c_i and $d_{i,j}$ is the euclidean distance between observation i and j.
We obtain the optimal results in terms of silhouette for a number of clusters equal to 3 (see the left panel in Figure 3). Figure 3 (right panel) reports the geographical distribution of municipalities across the three clusters. Figure 4 shows the distribution of the covariates used in the cluster analysis across the 3 groups. In particular, Cluster 1 mainly encompasses municipalities in the Centre-North of Italy, with a high economic capital. Cluster 2 tends to include areas with a high presence of accommodations in the Touristic sector. Finally, Cluster 3 accounts for municipalities in the Centre-South of Italy, with a large portion of university enrolled students, a high usage of public mobility means of transport and a low level of services in terms of waste sorting. Table 1 reports the median values of all the covariates for the 3 clusters.



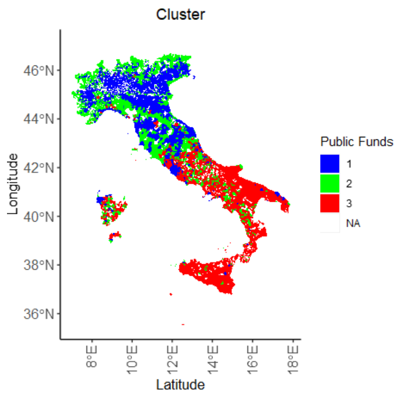


Figure 3: We show the output of our cluster analysis and the silhouette associated with alternative number of clusters.

Table 1: We show the median value of 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

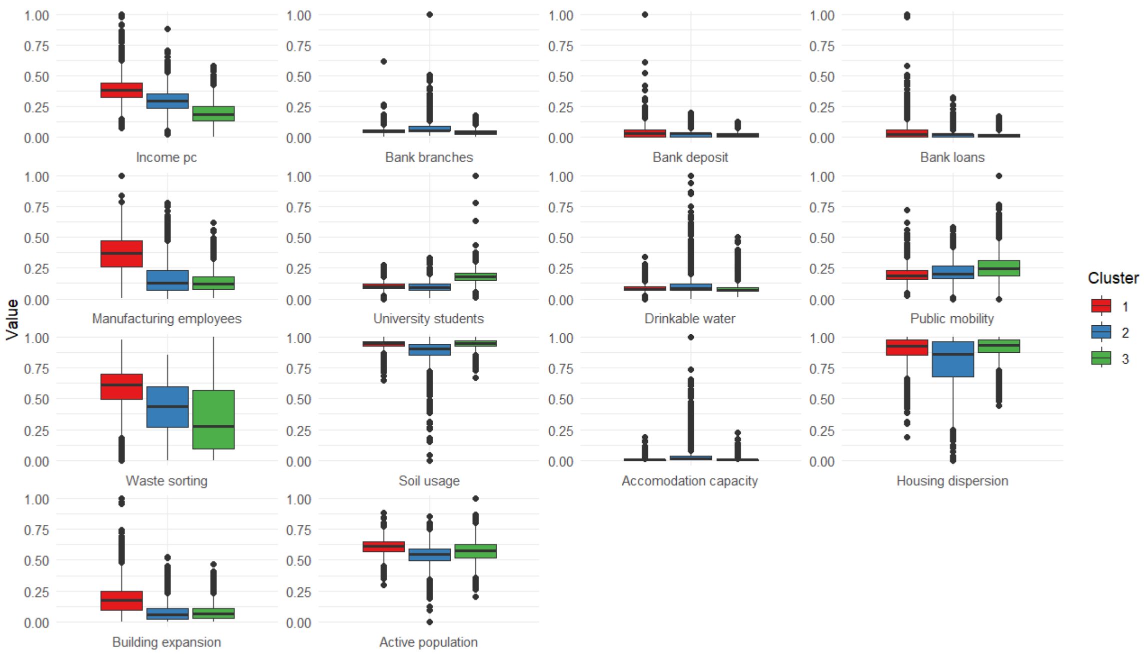


Figure 4: We show the distribution of the normalized covariates used in the cluster analysis across the 3 groups.

4.2 Spatial analysis

To investigate our research question, we implement a panel Spatial Durbin Model (SDM), based on the following equation:

$$Y_{i,t} = \lambda \sum_j w_{i,j} * Y_{i,t} + \beta_0 + \beta_1 * Environmental\ Funds_{i,t} + \beta_2 * \sum_j w_{i,j} * Environmental\ Funds_{i,t} + \gamma * X_{i,t} + \varepsilon_{i,t} \quad (4)$$

where $Y_{i,t}$ is our dependent variable computed as the percentage variation of PM2.5 concentration in municipality i in year t (see Section 1.3.2 for further details). We include the spatial autoregressive component $\sum_j w_{i,j} * Y_{i,t}$ to account for potential similar pollutant concentration dynamics in close municipalities. Moreover as explained in Section 1.3.1, $Environmental\ Funds_{i,t}$ is the expenditure of green funds 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 $\sum_j w_{i,j} * Environmental\ Funds_{i,t}$ is rather responsible for spillover effects (indirect effect) since the expenditures of green funds in a municipality may also have an impact in terms of PM2.5

reduction in neighbour municipalities. Finally, $X_{i,t}$ is a vector of control variables including meteorological factors that could affect the pollutants concentration such as the wind speed, precipitation level, temperature and humidity (Zhou and Levy, 2007; Zhang et al., 2015; He et al., 2017). We test the robustness of our results through alternative specifications of the spatial matrix W.

First, we model traditional weight matrices based on the great circle distance between the centroids of different regions. Based on the application of the K-Nearest Neighbours (KNN) algorithm, we thus define this spatial matrix W as:

$$W = \left\{ \begin{array}{l} w_{ij}^{*}(k) = 0 \; if \; i = j \\ w_{ij}^{*}(k) = 1 \; if \; d_{ij} \leq d_i(k) \; and \; w_{ij}(k) = \dfrac{w_{ij}^{*}(k)}{\sum_j w_{ij}^{*}(k)} \\ w_{ij}^{*} = 0 \; if \; d_{ij} > d_i(k) \end{array} \right\}$$

where $d_i(k)$ is the cutoff threshold, representing the distance of the kth closest administrative unit to municipality i, such that each administrative unit has exactly k neighbours. We set k = 10 and then we perform robustness checks considering also alternative specifications (e.g., k = 10, 20, 30, 40, 50). Hence, $w_{ij}^{*}$is an element of the unstandardized weight matrix W, while $w_{i,j}$ is an element of the standardized weight matrix in which the sum of each element of a row equals to 1.

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 4. 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.

5. Findings

5.1 Results across clusters

In this section, we analyse the impact of green EU Cohesion Policy funds across different clusters of municipalities displaying heterogeneous social, economic, environmental and demographic characteristics as shown in Section 1.4.1.

In particular, in Table 2 we separately estimate the panel-spatial models by restricting the sample to municipalities included in one single cluster. In Cluster 1, we observe a significant direct and indirect impact of funds targeting carbon abatement. In particular, these programs of financial support reduce by 1.1% the level of PM2.5 emissions in the municipality implementing the project and by 2.2% in the neighbour administrative areas. On the other hand, we only find statistically significant spillovers for municipalities in Cluster 2. However, notice how the magnitude of β_2 (0.012) is lower than in Cluster 1. Finally, we do not obtain relevant effects of green funds for municipalities located in Cluster 3.

Table 3: We show the estimates of a Spatial Durbin Models analysing the impact of funds targeting carbon abatement on the variation of pollutants intensity in terms of PM2.5 across clusters.

	Dependent variable: Variation of PM2.5 concentration		
	Cluster 1	*Cluster 2*	*Cluster 3*
Lambda	0.944***	0.922***	0.931***
	(0.003)	(0.005)	(0.004)
Environmental funds	-0.011**	-0.004	0.000
	(0.004)	(0.003)	(0.001)
Environmental funds spillovers	-0.016***	-0.012***	-0.003
	(0.005)	(0.004)	(0.002)
Temperature	0.000	0.000	-0.001
	(0.002)	(0.002)	(0.001)
Precipitation	-0.002*	-0.002	-0.001
	(0.001)	(0.002)	(0.001)
Wind speed	0.002	0.000	0.000
	(0.002)	(0.002)	(0.001)
Humidity	-0.003***	-0.002	-0.002*
	(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

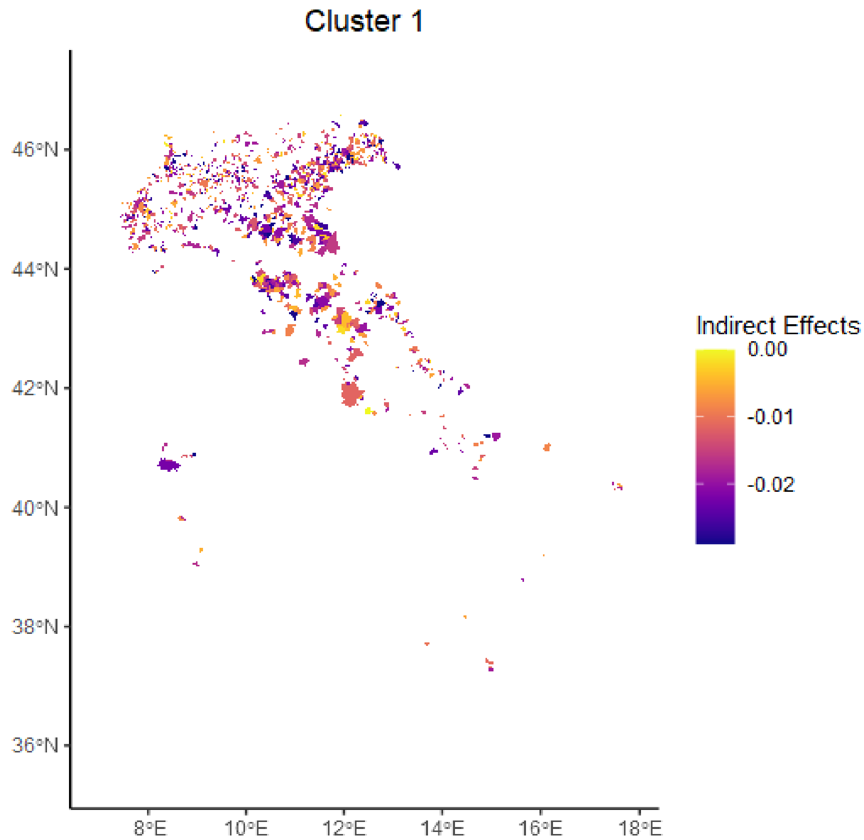


Figure 5: Geographical distribution of indirect effects in municipalities in Cluster 1.

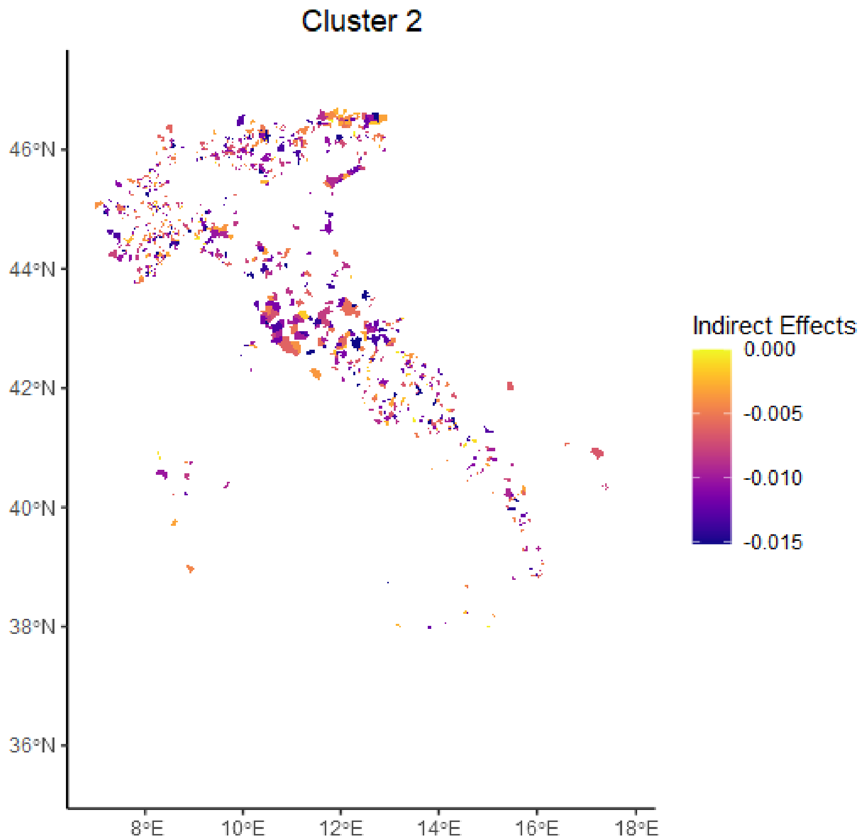


Figure 6: Geographical distribution of indirect effects in municipalities in Cluster 2.

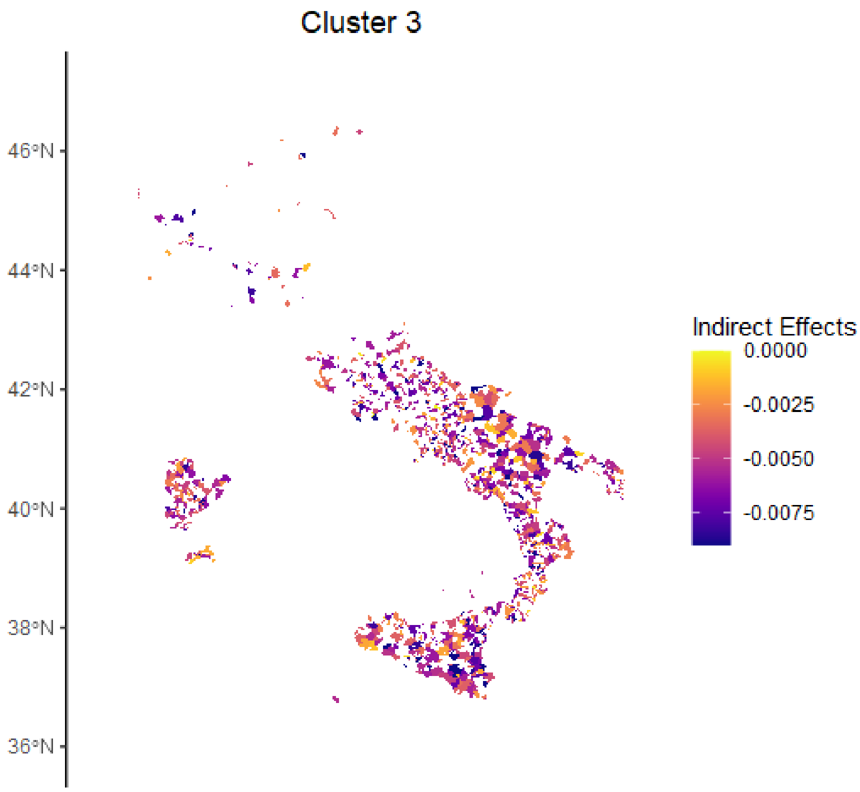


Figure 7: Geographical distribution of indirect effects in municipalities in Cluster 3.

In line with LeSage and Pace (2009), we also estimate indirect effects to assess the spillovers generated by the green EU funds. For Cluster 1, we find that a 1% growth of EU funds, expressed as a portion of local total income, generates a decrease in emissions by 1.6% in neighbouring municipalities. A similar impact in terms of spillovers is observed in municipalities of Cluster 2 where the green funds reduce PM2.5 levels by 0.9%. We confirm the absence of indirect effects in Cluster 3. Figure 2 highlights the geographical distribution of spillovers across municipalities.
We find 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 −2.0% and −1.4%). Conversely, significantly lower indirect effects are generated in municipalities of Cluster 3 with values below −0.5%.

5.2 Spatial matrices robustness check

Our results might be driven by the definition of the concept of ”neighbour” municipalities. In previous sections, neighbour municipalities were the 10 closest municipalities based on the distance between centroids of considered administrative units. 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 5 shows a sensitivity analysis in case we use the KNN method with k = 20, 30, 40, 50 to identify neighbour municipalities.
Table 5 tends to confirm our previous findings. Indeed, in all cases we confirm that green funds allocated to Cluster 1 generate a significant reduction of PM2.5 levels in the administrative unit spending these financial resources and in the neighbour municipalities. We obtain only relevant spillovers for Cluster 2 municipalities and no significant effects in Cluster 3 areas. Notice how limited exceptions arise only in the case of a larger number of neighbour municipalities (e.g., k = 40 or k = 50).

Table 5: We show the estimates of a Spatial Durbin Models analysing 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 number of K-Nearest Neighbours.

	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***	0.942***	0.951***	0.959***	0.964***	0.950***	0.956***	0.962***	0.966***
	(0.004)	(0.004)	(0.004)	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)	(0.004)	(0.005)	(0.005)	(0.005)
Environmental funds	-0.016***	-0.019***	-0.021***	-0.023***	-0.006	-0.006	-0.006	-0.006	-0.001	-0.001	-0.001	-0.001
	(0.005)	(0.005)	(0.006)	(0.006)	(0.005)	(0.005)	(0.004)	(0.004)	(0.001)	(0.001)	(0.001)	(0.001)
Environmental spillovers	-0.040***	-0.060***	-0.073***	-0.072***	-0.017**	-0.015*	-0.012	-0.005	-0.004	-0.006	-0.007	-0.009*
	(0.012)	(0.015)	(0.017)	(0.018)	(0.007)	(0.008)	(0.009)	(0.010)	(0.003)	(0.004)	(0.005)	(0.004)
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

	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)
Precipitation	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002	-0.002	-0.003*	-0.002
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)
Wind.speed	0.002	0.002	0.002	0.002	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)	(0.003)	(0.003)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)
Humidity	-0.003**	-0.002	0.000	0.001	-0.003	-0.003	-0.003	-0.003	-0.003***	-0.004***	-0.005***	-0.005***
	(0.001)	(0.002)	(0.002)	(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

6. Policy Implications

This study highlights how the relationship between funds with a carbon abatement objective and the reduction of the concentration of PM2.5 levels is heterogeneous with respect to the local territorial capital.

In particular, Cluster 1 municipalities, including territories with a high economic capital, we observe both a direct and indirect effect of these funds. This means that the spending of low-carbon economy funds is associated with a reduction in the concentration of PM2.5 in the municipalities where these projects are implemented. Furthermore, this expenditure also contributes to a reduction of pollutants in neighbour municipalities.

The municipalities of Cluster 2 tend to experience a direct effect that is not statistically significant, while the spillovers are significant. We show how these indirect effects might be generated by close Cluster 1 administrative units. 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 a number of alternative definitions of clusters and spatial matrices. Although this paper does not aim to explain the mechanism of this heterogeneity in the effect of funds with respect to the local territorial capital, the different levels of institutional capacity and efficiency of the Cluster 1 municipalities in implementing effective projects may be the main determinants of the observed significant reduction of pollution in these areas.

Our study has relevant implications for different economic actors (e.g., regulators at the national and international levels) since we highlight the main determinants of a successful implementation of projects fostering the sustainability transition in Italian municipalities. This analysis may thus support policy makers in a proper comprehension of the key factors contributing to decreasing PM2.5 levels and to designing a more cost-effective allocation of 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 understand how to coordinate and integrate alternative policy packages aiming to achieve carbon abatement and comply with EU targets (Stojcic, 2021; Van den Bergh et al., 2021; Greco et al., 2022).

Furthermore, our 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, our findings enrich the literature discussing the key local characteristics that may contribute to increasing the effectiveness of EU funds such as the quality of institutions and government processes (Crescenzi and Giua, 2016; Allain-Dupre, 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.

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