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Local environmental gains from green Cohesion Policy: a study of air pollution reduction in Italian municipalities

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ABSTRACT

We investigate how local characteristics influence the impact of Cohesion Policy funds targeting air pollution reduction (PM_{2.5}) between 2014 and 2020. Based on spatial Durbin models, we find significant direct and indirect effects of these financial support programmes in municipalities characterised by high economic capital. Moreover, these funds are associated solely with significant direct effects in the cluster of municipalities characterised by high water availability, extensive land use and a strong tourism infrastructure but dispersed housing. Conversely, we do not find a significant impact in territories with a low economic endowment, but high-quality human capital.

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European Union Cohesion Policy; air pollution; PM_{2.5}; spatial Durbin model; local context

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1. Introduction

Air pollution constitutes a global pressing environmental and public health challenge. Its social costs are substantial, as it causes respiratory and cardiovascular diseases, premature mortality, and increased health-care expenditures (Anderson, 2020; Deryugina et al., 2019; Palma et al., 2022). Beyond the health dimension, air pollution also reduces labour supply and productivity (Chang et al., 2019; Zivin & Neidell, 2012), generating significant economic losses (Di Porto et al., 2021).

As a consequence, governments have adopted a wide range of policies to curb air pollution, differing in both mechanisms and stringency (see Feng et al., 2024, for an extensive review). Some interventions rely on market-based instruments, such as pollution charges or emission trading schemes, which seek to internalise the social cost of emissions by aligning economic incentives with environmental objectives (Flori et al., 2024; Flori & Scotti, 2025). Other policies impose direct requirements, for instance by setting emission limits or mandating the use of cleaner technologies (Chang et al., 2022). Alternatively, policymakers operate through financial support, which encourages firms to voluntarily adopt cleaner practices (Mazzucato & Semieniuk, 2018). Incentive-based mechanisms have gained prominence as they enhance political and social acceptability of these measures (Rodríguez-Pose & Bartalucci, 2024).

Within this framework, the European Union (EU) Cohesion Policy stands as a key instrument to foster long-term economic growth while supporting compliance with international air pollution targets (Barca et al., 2012). Initially designed to promote regional economic convergence, the EU Cohesion Policy has gradually incorporated environmental goals, allocating about €40 billion in the 2014–20 period to support the transition to a low-carbon economy and the reduction of air pollution.

Despite the growing emphasis of the EU Cohesion Policy on sustainability transition, most studies have focused on its socio-economic impacts, typically assessing outcomes such as gross domestic product (GDP)

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per capita and employment (Dall'Erba & Fang, 2017; Scotti et al., 2024). Only a few contributions have examined its environmental effects (Scotti et al., 2025), mainly in areas such as water supply, sanitation, waste management and renewable energy (Agovino et al., 2016; Medeiros, 2014). However, these studies overlook air quality improvements and often adopt aggregate approaches more suited to assessing 'spatially blind' policies, thereby failing to capture territorial heterogeneity. This contrasts with the inherently place-based nature of the EU Cohesion Policy, which provides context-specific interventions shaped by local stocks of tangible and intangible assets that may mediate policy outcomes (Bachtrögl et al., 2020; Fratesi & Perucca, 2014).

Against this background, this paper examines the impact of Cohesion Policy interventions targeting air pollution on concentrations of fine particulate matter (PM_{2.5}). In fact, PM_{2.5} is a relevant pollutant due to its severe health impacts and its predominantly local dispersion. Unlike pollutants that rapidly diffuse across regions (Roostaei et al., 2024), PM_{2.5} tends to remain concentrated near emission sources, allowing us to identify the localised effects of EU-funded projects targeting air pollution reduction.

We rely on a dataset including 2352 projects focused on air pollution reduction, covering €1.04 billion of green EU funds expenditures, corresponding to around 30% of the total budget allocated by the European Commission (EC) to low-carbon economy projects in Italy for the programming period 2014–20. To the best of our knowledge, this study is the first to examine how green EU funds interact with reductions in PM_{2.5} emissions at the municipal level, with particular attention to the role of local contextual factors. In doing so, it unveils how specific territorial characteristics shape the impact of EU Cohesion Policy in promoting PM_{2.5} abatement.

To this scope, we focus on Italy as it serves as an ideal setting for two main reasons. First, the country displays a wide heterogeneity in air quality, with Northern regions frequently exceeding the EC's PM_{2.5} average daily concentration standard of 25 µg/m³, reflecting persistent and severe pollution episodes, while Southern and Insular regions record substantially lower concentrations. Second, Italy, with €3.2 billion allocated to the low-carbon economy, stands out as one of the primary recipients of green EU funds (only behind Spain with €3.3 billion), offering exceptional and comprehensive data on the EU Cohesion Policy framework for our analysis (Atella et al., 2023).

We contribute to the extant literature by analysing how the characteristics of the local context mediate the effect of the Cohesion Policy, thus fuelling the debate on 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 hinder the effectiveness of EU Cohesion policy in urban sustainability (Davies et al., 2021). A careful comprehension of the drivers influencing the impact of the EU Cohesion Policy on the sustainability transition may thus support policymakers to improve the cost-effectiveness of current strategies to comply with environmental goals.

The rest of the paper is organised 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. Section 6 concludes by highlighting the main implications of our study.

2. Theoretical background

The Cohesion Policy establishes explicit and quantified targets for PM_{2.5} reduction. The Thematic Strategy on Air Pollution¹ identifies fine particulate matter as the pollutant responsible for the largest health burden in the EU and sets a concrete long-term objective of reducing PM_{2.5} emissions by 55% by 2020 compared with 2000 levels. This strategic objective was translated into binding legal standards in Directive 2008/50/EC on ambient air quality.² It establishes an annual limit value for PM_{2.5} of 25 µg/m³ (Article 13 and Annex XIV) and National Exposure Reduction Target requiring member states to achieve a percentage reduction in urban PM_{2.5} concentrations ranging from 0% to 20% between 2010 and 2020, depending on initial concentration levels. Regions exceeding PM_{2.5} limits were therefore legally required to adopt air-quality plans specifically addressing PM_{2.5} and could mobilise Cohesion Policy funds to achieve the binding reduction targets. This policy rationale is explicitly reflected in several 2014–20 regional operational programmes (e.g., the European Regional Development Fund – ERDF), where particulate matter, and in particular PM_{2.5}, is identified either as a key environmental challenge (e.g., the Liguria region³) or as a specific policy

objective linked to improving environmental performance and reducing exposure to harmful pollutants (e.g., the Molise region⁴), in line with Directive 2008/50/EC.

Therefore, EU Cohesion Policy may contribute to the shift towards a low-carbon economy for several reasons. First, the transition to sustainable production and consumption systems requires a large-scale reallocation of capital from incumbent technologies to clean and innovative alternatives (Acemoglu et al., 2012). In this context, EU green funds act as a critical lever by supporting private firms in overcoming high entry costs and competitive disadvantages vis-à-vis established polluters, which typically benefit from better access to finance and lower initial investment requirements (Christou et al., 2026).

Second, the financial system often fails to provide sufficient support for low-carbon innovation due to high perceived risks and uncertain returns, particularly in early-stage exploration activities (Mazzucato & Semieniuk, 2018). Incentive-based public policies can address this gap by mitigating risks, thus enabling firms to invest in green technologies that would otherwise remain underfunded (Polzin et al., 2016).

Third, public finance can play a mission-oriented role by not only funding technological development but also fostering legitimacy, coordination and credibility around emerging solutions (Mazzucato & Penna, 2016).

Since the transition towards a low-carbon economy emerged as a key priority in the programming period 2014–20 of the EU Cohesion Policy, the impact of green EU funds on air pollution reduction has garnered increasing scholarly attention. Previous studies show that the EU Cohesion Policy may have a strong potential to drive the sustainability transition especially in terms of convergence of carbon emissions across EU member states, and improvement of air quality reducing morbidity and premature mortality (Liobikienė & Mandravickaitė, 2016; Nilsson & Nilsson, 2013; Pisoni et al., 2023). However, we still lack robust studies clarifying the EU funds' impact on PM_{2.5} targets. In this study, we integrate data on EU green fund expenditures with municipal-level measurements of PM_{2.5} concentrations for the most recently completed programming period (2014–20). This approach addresses a notable gap in the literature by empirically assessing the extent to which EU Cohesion Policy interventions targeting the environmental sector have contributed to the reduction of PM_{2.5} emissions across territories characterised by heterogeneous local conditions.

3. Data

3.1. Beneficiaries identification

This study examines the impact of EU Cohesion Policy funds on PM_{2.5} reduction. To this end, we construct a comprehensive database of EU-financed projects across Italian regions that explicitly target PM_{2.5} abatement, drawing on data from the OpenCoesione platform.⁵ In particular, we consider the European Regional Development Fund (ERDF) and the European Social Fund (ESF), since they represent the main programmes of financial support within the EU Cohesion Policy, covering 58.0% and 26.4% of the total available budget for the time frame 2014–20, respectively.

In the first stage, we select projects classified under Thematic Objective 4, 'Low-carbon economy and energy efficiency', based on the thematic codes assigned by the EC.

PM_{2.5} originates from a heterogeneous set of anthropogenic activities and atmospheric chemical processes (Dai et al., 2018). To ensure that our analysis captures only those interventions plausibly affecting local PM_{2.5} concentrations, we refine our sample by leveraging detailed project-level information available in the OpenCoesione dataset. Specifically, we rely on the official descriptions of investment priorities and expenditure categories to identify projects explicitly targeting PM_{2.5} reduction. This selection process is guided by a systematic review of the primary anthropogenic sources of PM_{2.5} emissions, which informs the identification of relevant interventions within the broader thematic objective 'low-carbon economy and energy efficiency'. Only projects directly addressing emission sources known to contribute to PM_{2.5} concentrations are retained for the final analysis. We consider both projects aimed at reducing primary PM_{2.5}, directly emitted into the atmosphere from specific sources, as well as secondary PM_{2.5}, which is generated through atmospheric chemical reactions involving precursor gases.

Figure 1 provides a conceptual framework outlining the main anthropogenic drivers of PM_{2.5} pollution and the physical–chemical mechanisms responsible for its formation.⁶ Moreover, it reports a synthesis of

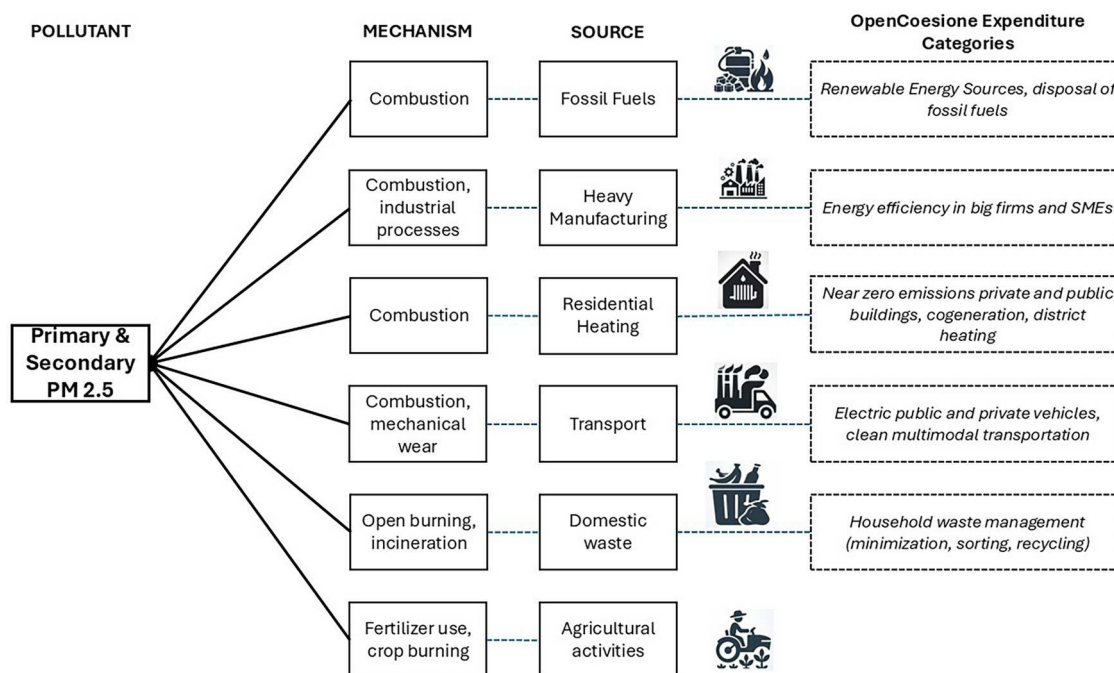


Figure 1. Conceptual framework for understanding the major anthropogenic sources of $PM_{2.5}$, as well as the physical and chemical mechanisms underlying its formation. We also show a synthesis of the expenditure category of projects disclosed in the OpenCoesione dataset that we use to select projects linked to improvement in primary sources of $PM_{2.5}$ emissions.

the expenditure category of projects disclosed in the OpenCoesione dataset that we use to select projects linked to a reduction of primary sources of $PM_{2.5}$ emissions.

In particular, we focus on the following key anthropogenic sources of $PM_{2.5}$ targeted by EU Cohesion Policy projects. These include: (1) fossil fuel combustion, primarily from coal-, oil- and gas-fired power plants and industrial facilities, which emit both primary and secondary fine particles (Shi et al., 2021; Wang et al., 2015); (2) heavy manufacturing, such as cement, iron, steel and glass production, where high-temperature processes and fuel use generate substantial particulate emissions and precursor gases (Yang et al., 2018); (3) residential heating with solid fuels (wood, coal, biomass), producing unburned carbonaceous particles and secondary aerosols (Olszowski, 2019); (4) transportation, where both exhaust (especially from diesel engines) and non-exhaust sources (brake, tire and road dust) contribute to urban $PM_{2.5}$ (Tong et al., 2020); and (5) waste combustion, involving heterogeneous materials such as plastics and organic residues, which emit complex particulate mixtures and secondary precursors (Yan et al., 2016). While agriculture also generates $PM_{2.5}$ through ammonia volatilisation and residue burning (Cheng et al., 2021), it is excluded from our analysis as it falls under the Common Agricultural Policy.

Further justification for the selection of these anthropogenic $PM_{2.5}$ sources is provided in Appendix A in the supplemental data online. Additional information about the investment priority, expenditure categories and number of projects associated with each anthropogenic source of $PM_{2.5}$ is available in Table A1 online. Moreover, Tables A2–A6 online show for each source of emission and expenditure category illustrative projects that explicitly target reduction in $PM_{2.5}$ concentration. Such examples aim to strengthen the identification of projects that were strategically designed to affect $PM_{2.5}$.

Overall, we select 2513 projects. In this way, we expect to provide a complete overview of the set of projects targeting air pollution reduction with a specific focus on $PM_{2.5}$ abatement. From this sample, we exclude projects with a realised cost equal to zero, as they have not started yet. Our final sample consists of 2352 projects and €1.04 billion of realised expenditures corresponding to about 30% of total EU Cohesion Policy funds allocated to Italy for the Thematic Objective 4, ‘Low-carbon economy and energy efficiency’.

Since our geographical unit of analysis is represented by municipalities, we aggregate our data at the municipal level. Overall, our dataset covers 1152 Italian municipalities spending public funds from the Cohesion Policy with a specific target on air pollution reduction over the time frame 2014–20. Figure A1

in Appendix A in the supplemental data online shows the geographical distribution of green EU funds expenditures across Italian municipalities normalised by the total income of the underlying administrative unit. In line 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 (0.49% and 0.36% of total households' income, respectively), receiving €312 and €122 million, respectively (see Table A9 in Appendix A online). Conversely, North-East and North-West macro-areas displayed the lowest treatment intensity (0.14% and 0.21% of total income corresponding to €156 and €231 million, respectively).

3.2. Dependent variable

We consider the concentration of $PM_{2.5}$ emissions at the municipal level for the time frame 2014–20 as our dependent variable. We focus on $PM_{2.5}$ since it is a primary cause of death monitored by the European Environment Agency (EEA) and is a reference pollutant used by the EC to establish air pollution targets (Beloconi & Vounatsou, 2023). Epidemiological evidence consistently indicates that exposure to $PM_{2.5}$ is associated with increased incidence and mortality (Anderson, 2020; Deryugina et al., 2019; Heutel & Ruhm, 2016) from a range of diseases, including diabetes (Bowe et al., 2018), respiratory illnesses (Xing et al., 2016), cardiovascular conditions (Hayes et al., 2020) and neurological disorders (Shi et al., 2020). International assessments, such as the air quality life index, have identified $PM_{2.5}$ as a major global risk factor for reduced life expectancy (Chen et al., 2017). Consistently, the World Health Organization (WHO) reports substantial global mortality burdens attributable to $PM_{2.5}$, especially in areas with high ambient air pollution exposure (WHO, 2021).

Due to its significant implications for public health and its sensitivity to local environmental and socio-economic conditions, it has become a widely adopted indicator in urban and environmental research, particularly in studies designed to guide place-based policy interventions.

Furthermore, focusing on $PM_{2.5}$ is particularly suitable for analyses conducted at the municipal level, as it is a pollutant with predominantly local dispersion characteristics. Unlike more volatile substances such as CO_2 , SO_x and NO_x , which are subject to long-range atmospheric transport and broader climatic dynamics, $PM_{2.5}$ concentrations are primarily influenced by proximate emission sources and localised meteorological conditions (Roostaei et al., 2024). As a result, $PM_{2.5}$ provides a geographically precise indicator of air quality, making it well-suited to assess the effects of socio-economic, demographic and environmental factors at fine spatial scales. This analytical focus is consistent with a growing literature that employs $PM_{2.5}$ as the primary outcome variable to explore the determinants of air pollution. Prior studies have examined the influence of urban expansion and population distribution (Shi et al., 2021), the effectiveness of industrial regulation, and the interplay between human activity and natural processes (Wang et al., 2018). Collectively, these contributions underscore the relevance of $PM_{2.5}$ as a key environmental indicator for investigating the complex interactions between pollution and broader socio-economic dynamics.

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. Therefore, we compute our dependent variable using raster data disclosed by the EEA covering the time frame 2014–20 (spatial resolution: 1×1 km) that were derived by combining monitoring air quality data with external covariates in a 'regression-interpolation-merging mapping' methodology (Horálek et al., 2024).

Appendix B in the supplemental data online provides additional details on the computation of $PM_{2.5}$ concentration at the municipal level over the period 2014–20. Tables B1 and B2 online summarise the average concentrations at the province level. They clearly show that the North of Italy displays a lower air quality due to the high values of $PM_{2.5}$. In particular, areas located in Lombardy and Veneto regions tend to exceed the air quality standard set to $25 \mu g/m^3$ of $PM_{2.5}$ by the EC. Conversely, lower pollution levels are observed in the South and Insular Italy with average $PM_{2.5}$ levels equal to 20.89 and $18.32 \mu g/m^3$, respectively. 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).

Figure B1 in Appendix B in the supplemental data online shows that our dependent variable exhibits a high degree of spatial dependence. Such evidence is corroborated by Moran's I test (Bivand

& Wong, 2018) (see Table E1 in Appendix E online). The Moran statistic is statistically significant, indicating that municipalities with similar $PM_{2.5}$ levels tend to be geographically proximate rather than spatially independent. The Moran's I test is based on a spatial exponential decay matrix, as explained in Section 4.2.

4. Methods

4.1. Cluster analysis

Our analysis investigates how territorial characteristics influence the impact of green EU Cohesion Policy funds. To this end, we perform a cluster analysis to group municipalities according to their territorial conditions.

To identify relevant features for characterising territories, we adopt a classification framework structured around three domains: economic, human and physical territorial characteristics. Our approach builds on the concept of territorial capital developed by Camagni et al. (2009). Within this framework, territorial capital includes natural resources, infrastructure, human capital, agglomeration economies, relational services, institutions and social capital.

Departing from the original structure, we reorganise these elements into three analytically coherent dimensions, as also proposed in Amaddeo et al. (2024). The human dimension includes human capital, defined as the stock of knowledge, skills, competencies and attributes embodied in individuals (Brain, 2007), corresponding to the private and intangible components of territorial capital in Camagni's framework. The physical dimension comprises both environmental and infrastructural assets. The environmental component refers to the stock of natural and ecological resources available within a territory (Jabareen, 2008; Pearce & Turner, 1989), consistent with the public and tangible resources identified in the territorial capital literature. The infrastructural component encompasses material infrastructures and facilities embedded in the local context (Servillo et al., 2012), which support economic development and foster social cohesion (Castelnovo et al., 2020; Clifton et al., 2016). Finally, the economic dimension captures productive structures, agglomeration economies, relational services, and institutional assets that shape local competitiveness and collective efficiency, thus encompassing both tangible and intangible elements highlighted in the territorial capital framework.

This reorganisation does not alter the substantive components identified in the literature; rather, it provides a simplified structure better suited to the empirical strategy adopted in this study.

Table C1 in Appendix C in the supplemental data online presents a comprehensive breakdown of the dimensions, subdimensions and corresponding indicators utilised in our study, categorising them into human, physical and economic domains.

We perform a hierarchical cluster analysis based on these variables using the Ward's D2 linkage criterion, which at each step merges clusters so as to minimise within-cluster variance (Ward, 1963) (see Appendix C in the supplemental data online for further details).

From the clustering analysis, we obtain the optimal results for a number of clusters equal to 3; this number is confirmed across the different clustering methods applied. Figure 2 reports the geographical distribution of municipalities across the three clusters.⁷ Figure C1 in Appendix C in the supplemental data online shows the distribution of the variables used in the cluster analysis across the three groups. Finally, to assess the robustness of the clusters in terms of differences across each variable, a pairwise t -test with Bonferroni correction was conducted (see Appendix C online).

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 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.

The second cluster is characterised by many bank branches in economic terms. From an environmental perspective, it is marked by a high availability of drinkable water and high soil usage. In terms of infrastructure and services, it is notable for its high tourist accommodation capacity, while in housing, it shows high

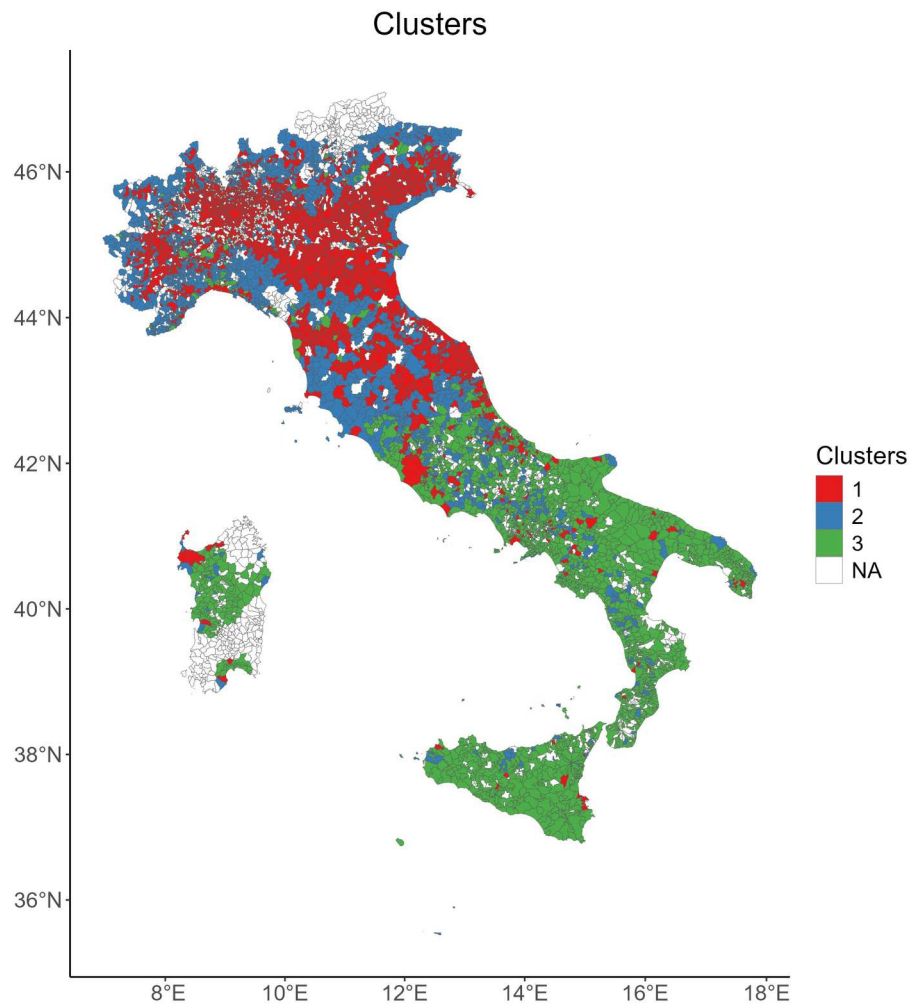


Figure 2. Geographical map of the output of our cluster analysis. Municipalities left blank (NA) are administrative units with missing values on one or more covariates employed in the cluster analysis.

housing dispersion. Regarding human resources, it is characterised by a low active population. 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 characterised 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 characterised by low housing dispersion.

Table C3 in Appendix C in the supplemental data online reports the median values of all the covariates for the three clusters.

4.2. Spatial panel models

To investigate our research question, we employ a panel spatial Durbin model (SDM). The model choice is justified by the high degree of spatial dependence of the dependent variable, as discussed in Section 3.2. This approach enables us to decompose the estimated impacts of green EU Cohesion Policy Funds into direct effects, capturing the influence of green investments on $PM_{2.5}$ concentrations within the same municipality, and indirect effects (spatial spillovers), which measure the extent to which funding in one municipality

affects PM_{2.5} levels in neighbouring areas through spatial interdependencies (Elhorst, 2014). In formula:

$$Y_{i,t} = \lambda \sum_j w_{ij} * Y_{j,t} + \beta_0 + \beta_1 \text{Environmental Funds}_{i,t} + \beta_2 \sum_j w_{ij} * \text{Environmental Funds}_{j,t} + \gamma X_{i,t} + \epsilon_{i,t} \quad (1)$$

where $Y_{i,t}$ is our dependent variable computed as the annual percentage variation of PM_{2.5} concentration in municipality i in year t (see Section 3.2 for further details). We include the spatial autoregressive component $\sum_j w_{ij} * Y_{j,t}$ 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 programmes of financial support to the reduction of pollution in the municipality where projects are implemented (direct effect). Due to the Moran's I test highlighting significant spillovers in air pollution, the term $\sum_j w_{ij} * \text{Environmental Funds}_{j,t}$ is responsible for indirect effects since the expenditures of green EU funds in a municipality may also have an impact in terms of PM_{2.5} reduction in neighbour municipalities. For example, Jia et al. (2021) employ a similar approach relying on an SDM model to investigate the impact of high-speed rail investments and CO₂ emissions in China.

Finally, $X_{i,t}$ is a vector of control variables including meteorological (temperature, rainfall, wind speed, humidity) and socio-economic factors (income pc, employment rate, vehicles, the municipal administrative quality index (Maqi), population density) that could affect the concentration of the pollutant.

Table D1 in Appendix D in the supplemental data online reports information related to the descriptive statistics, sources and units of measure of our control variables.

We test the robustness of our results through alternative specifications of the spatial matrix $W = \{w_{ij}\}_{i,j=1}^n$, where n is the number of municipalities in our model. First, we rely on the spatial exponential decay matrix:

$$w_{ij} = \exp(-\alpha d_{ij})$$

where d_{ij} is the distance (km) between municipalities i and j and α is the spatial decay parameter. We use a value of 2 in our main analysis since it is the value minimising the Akaike information criterion (AIC) and the Bayesian information criterion (BIC). We then 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 (e.g., Bergantino et al., 2020). Consistently with other studies relying on spatial models to investigate the impact of the EU Cohesion Policy (Scotti et al., 2022), we consider different spatial weight matrices based on the application of the K -nearest neighbours (KNN) algorithm (see Appendix F in the supplemental data online for further details).

Moreover, in line with the terminology in Elhorst (2014), we define direct, indirect and total effects based on our equation (1). In formula:

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

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

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

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

5. Empirical evidence

5.1. Impact across clusters

In this section, we analyse 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 1, we separately estimate the panel-spatial model defined in equation (1) by restricting the sample to municipalities included in a single cluster. We examine the impact of EU green funds on reductions in $PM_{2.5}$ concentrations allowing for up to three years of lag from project implementation to assess how their impact unfolds over time. This choice reflects evidence from the environmental innovation and air pollution control literature, indicating that the implementation of green technologies and related infrastructure often requires several years before producing measurable air pollution benefits (Prettner & Werner, 2016; Scotti et al., 2024). By incorporating lags of up to three years, we aim to capture these delayed effects while maintaining sufficient data coverage for robust estimation.

When considering the total amount of green EU funds related to projects concluded in the underlying year (lag 0), we observe an immediate significant direct and indirect impact in cluster 1. In particular, these programmes of financial support reduce the level of $PM_{2.5}$ emissions in the municipality implementing the project ($\beta_1 = -0.067$) as well as in the neighbour administrative areas ($\beta_2 = -0.022$).⁸ Interestingly, these effects hold also at different lags, even if with a smaller magnitude (β_1 between -0.026 and -0.011 and β_2 between -0.010 and -0.008). We do not find significant spillovers at lag 1.

Our findings are consistent with a growing body of European evidence documenting measurable air-quality improvements associated with EU funds interventions. First, Czyżewski et al. (2019) show that a higher concentration of EU funds allocated to carbon abatement and low-carbon transition is significantly associated with reductions in $PM_{2.5}$ concentrations across European regions, suggesting that Cohesion-related investments can translate into tangible improvements in air quality at the territorial level. Second, complementary simulation-based evidence demonstrates that removing anthropogenic sources of $PM_{2.5}$ leads to substantial improvements in ambient air quality, particularly in urban and industrial areas (Pisoni et al., 2022). At the firm level, Scotti et al. (2024) provide evidence that the interaction between the European Union Emissions Trading System (EU ETS) and Cohesion Policy financial support reduces emissions intensity, with relevant effects in the energy and manufacturing sectors. These sectors overlap closely with those targeted by the projects identified in our analysis.

On the other hand, only statistically significant direct effects of green EU funds are observed for municipalities in cluster 2 ($\beta_1 = -0.014$) when considering their immediate impact. This effect remains statistically significant even several years after project completion, with the estimated coefficients ranging between -0.009 and -0.005 , indicating a reduced magnitude over time. In contrast, the spillover effects are statistically significant only in model specifications that account for green EU fund expenditures with a two- or three-year lag, with β_2 ranging from -0.009 to -0.005 . In municipalities belonging to cluster 3, we do not detect any significant direct or indirect effects of green EU funds. The only exception is the contemporaneous coefficient of Environmental funds, which shows a weakly negative and marginally significant estimate ($\beta_1 = -0.003$).

Table 2 reports our complete estimates for direct, indirect and total effects generated by green EU Cohesion Policy funds as explained in Section 4.2. They refer to the model specification where we consider the immediate impact of green EU funds (lag 0).

For cluster 1 we find that a 1% growth of EU funds, expressed as a portion of local total income, contributes to reducing $PM_{2.5}$ levels by about 0.9% in the same municipality. Moreover, it generates a decrease in emissions by 1.0% in neighbouring municipalities. In municipalities of cluster 2, direct effects are still significant, even if with a lower magnitude, since the green funds reduce $PM_{2.5}$ levels by 0.2%, while we do not obtain evidence of significant spillovers. We obtain the absence of both direct and indirect effects in cluster 3. A possible explanation for these heterogeneous effects may lie in the different composition of green expenditures across clusters. As shown in Table A12 in Appendix A in the supplemental data online, cluster 1 allocates a relatively larger share of its total green budget to residential heating (12.9%) and transport (5.3%), compared with cluster 3 (9.0% and 2.6%, respectively) and cluster 2 (9.1% and

Table 1. Estimates of a spatial Durbin model (SDM) analysing the impact of funds targeting air pollution reduction on the variation of pollutant intensity in terms of $PM_{2.5}$ across clusters.

	Cluster 1				Cluster 2				Cluster 3			
	(lag 0)	(lag 1)	(lag 2)	(lag 3)	(lag 0)	(lag 1)	(lag 2)	(lag 3)	(lag 0)	(lag 1)	(lag 2)	(lag 3)
Lambda	0.554*** (0.014)	0.550*** (0.014)	0.563*** (0.015)	0.643*** (0.017)	0.693*** (0.008)	0.710*** (0.008)	0.719*** (0.008)	0.707*** (0.010)	0.694*** (0.007)	0.681*** (0.008)	0.724*** (0.008)	0.723*** (0.009)
Environmental funds	-0.067*** (0.005)	-0.011** (0.005)	-0.020*** (0.006)	-0.026*** (0.006)	-0.014*** (0.002)	-0.009*** (0.003)	-0.005** (0.002)	-0.006** (0.002)	-0.003* (0.002)	-0.002 (0.002)	-0.001 (0.002)	-0.002 (0.002)
Environmental funds spillovers	-0.022*** (0.006)	-0.001 (0.006)	-0.008*** (0.003)	-0.010*** (0.003)	-0.002 (0.002)	-0.003 (0.003)	-0.009*** (0.002)	-0.005** (0.002)	0.002 (0.001)	0.002 (0.002)	0.001 (0.001)	0.002 (0.001)
Temperature	0.012** (0.006)	0.022*** (0.008)	0.018** (0.008)	0.023*** (0.006)	-0.003 (0.002)	0.000 (0.003)	0.002 (0.003)	-0.003 (0.003)	-0.002 (0.002)	-0.002 (0.002)	-0.001 (0.002)	-0.003 (0.002)
Rainfall	-0.018*** (0.005)	-0.030*** (0.006)	-0.031*** (0.006)	-0.021*** (0.005)	-0.012*** (0.002)	-0.018*** (0.003)	-0.017*** (0.002)	-0.017*** (0.003)	0.000 (0.002)	-0.001 (0.002)	0.001 (0.002)	0.000 (0.002)
Wind speed	-0.016*** (0.006)	-0.019*** (0.008)	-0.022*** (0.008)	-0.022*** (0.006)	0.002 (0.002)	0.007** (0.003)	-0.002 (0.003)	0.000 (0.003)	0.002 (0.002)	0.002 (0.002)	0.002 (0.002)	0.003 (0.002)
Humidity	0.001 (0.005)	-0.029*** (0.006)	-0.026*** (0.006)	-0.008 (0.005)	-0.007*** (0.002)	-0.018*** (0.003)	-0.016*** (0.002)	-0.019*** (0.003)	-0.002 (0.002)	-0.007*** (0.002)	0.000 (0.002)	-0.003 (0.002)
Income pc	-0.056 (0.047)	-0.049 (0.049)	-0.051 (0.046)	-0.047 (0.045)	0.025* (0.013)	0.019* (0.011)	0.021** (0.011)	0.024** (0.010)	-0.033 (0.020)	-0.035 (0.022)	-0.036 (0.025)	-0.029 (0.026)
Employment rate	0.007 (0.015)	-0.009 (0.018)	-0.011 (0.016)	-0.007 (0.015)	-0.012 (0.016)	-0.009 (0.015)	0.002 (0.015)	0.004 (0.016)	-0.003 (0.018)	0.005 (0.017)	-0.007 (0.017)	-0.005 (0.016)
Maqi	-0.007 (0.005)	-0.001 (0.006)	0.001 (0.006)	0.006 (0.006)	-0.005** (0.002)	-0.003 (0.003)	0.001 (0.002)	0.002 (0.003)	-0.006*** (0.002)	-0.003 (0.002)	0.000 (0.002)	0.001 (0.002)
Vehicles	0.003 (0.005)	0.008 (0.008)	0.003 (0.007)	0.005 (0.006)	0.005*** (0.002)	0.006*** (0.002)	0.007*** (0.003)	0.008*** (0.002)	0.002 (0.002)	0.003 (0.002)	0.001 (0.002)	-0.001 (0.002)
Population density	0.015 (0.021)	0.018 (0.020)	0.021 (0.020)	0.016 (0.022)	0.014 (0.024)	0.017 (0.023)	0.012 (0.025)	0.013 (0.025)	0.023 (0.038)	0.021 (0.038)	0.019 (0.038)	0.022 (0.040)
N	1890	1620	1350	1080	3241	2778	2315	1852	3213	2754	2295	1836
Akaike information criterion (AIC)	-4375.62	-4180.14	-3956.42	-3735.60	-8893.45	-8677.32	-8537.34	-8355.90	-11,235.75	-10,171.32	-8915.18	-7820.40
Bayesian information criterion (BIC)	-4327.30	-4167.45	-3944.15	-3724.08	-8845.17	-8664.77	-8525.38	-8344.70	-11,187.95	-10,158.70	-8903.55	-7809.70

Note: We report alternative different specifications of our model, considering alternative lags (years 0–3) for environmental funds and related spillovers. Results are obtained using a spatial exponential decay matrix with $\alpha = 2$.
 * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2. Direct, indirect and total effects generated by green funds across the three analysed clusters.

	Cluster 1	Cluster 2	Cluster 3
Direct effect	−0.0094*** (0.0005)	−0.0022** (0.0010)	−0.00010 (0.0008)
Indirect effect	−0.0104*** (0.0008)	−0.0029 (0.0025)	−0.00014 (0.0011)
Total effect	−0.0199*** (0.0012)	−0.0052** (0.0025)	−0.00024 (0.0018)

Note: Results refer to the model specification where we consider the immediate impact of green European Union funds (lag 0).

2.7%, respectively). Conversely, cluster 3 devotes a comparatively higher proportion of resources to heavy manufacturing (32.4%) and domestic waste (11.5%), relative to cluster 1 (25.9% and 4.6%), while cluster 2 lies between the two (31.9% and 7.1%, respectively). Since residential heating, particularly through the combustion of fuels such as wood, coal and biomass (Karagulian et al., 2017; Olszowski, 2019; Stanojević et al., 2024), is typically identified as the main anthropogenic contributor to local PM_{2.5} concentrations, these differences in expenditure composition may appear consistent with the stronger direct and spillover effects observed in cluster 1, the more limited direct effects in cluster 2, and the absence of statistically significant effects in cluster 3. However, this evidence reflects an association between the composition of EU green expenditures across anthropogenic sources of PM_{2.5} and the estimated pollution outcomes, rather than a causal identification. Further research would be needed to provide more robust evidence on the underlying mechanisms.

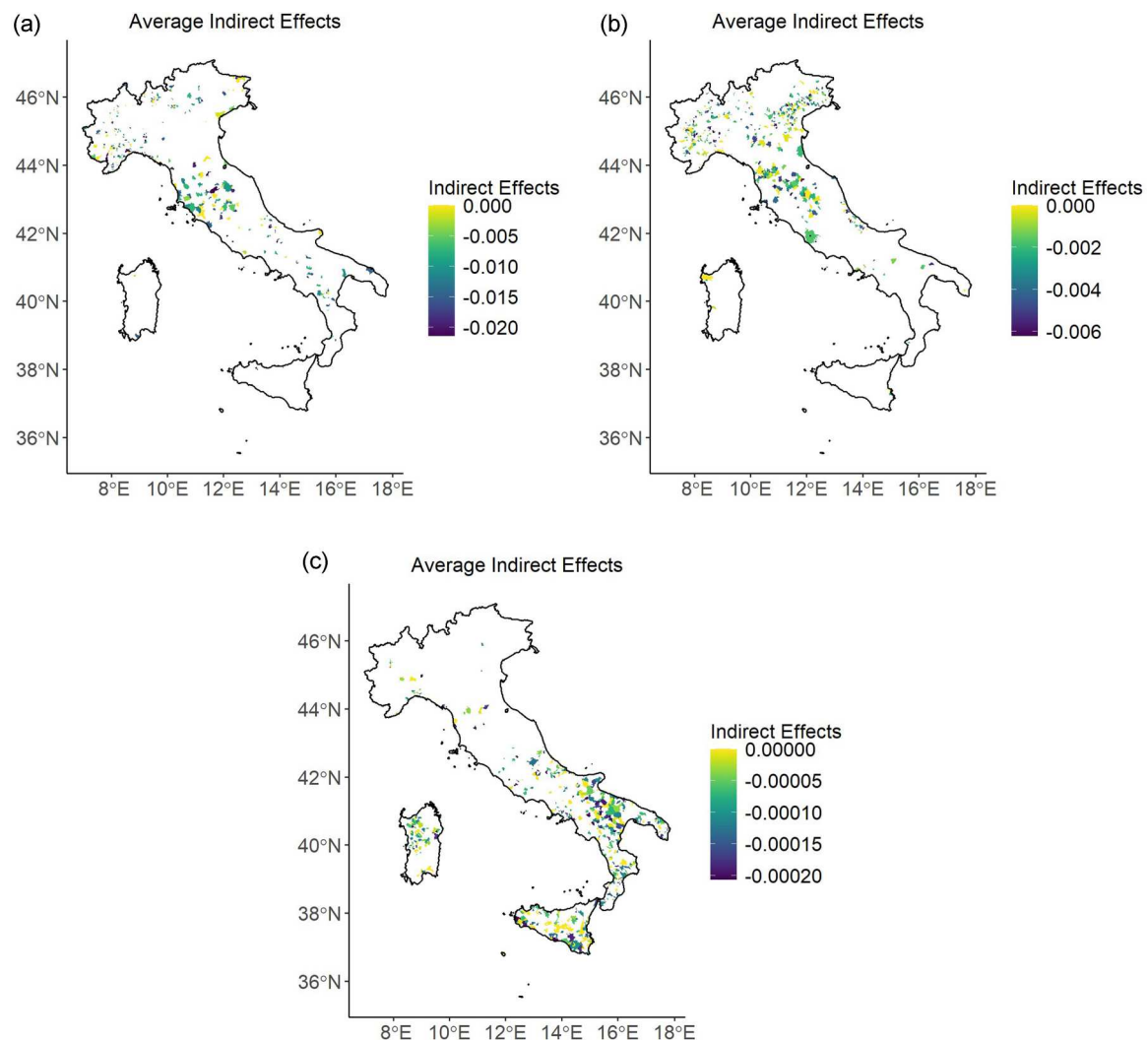
**Figure 3.** Spillovers generated by green funds across the municipalities in the three analysed clusters.

Figure 3 highlights the geographical distribution of spillovers across municipalities. We confirm that on average higher indirect effects are generated in municipalities of cluster 1. Conversely, significantly lower indirect effects are generated in municipalities of cluster 3.

These findings carry important implications for policymakers tasked with designing and implementing Cohesion Policy and broader air pollution governance frameworks. By showing that the impact of green EU funds in reducing PM_{2.5} emissions varies significantly according to the local context, this analysis underscores the necessity of moving beyond a ‘one-size-fits-all’ approach to environmental funding.

First, the evidence that municipalities endowed with higher levels of economic and financial capital achieve both direct and indirect reductions in air pollution suggests that local socio-economic capacities constitute relevant factors in determining policy effectiveness. Policymakers should therefore recognise that institutional quality and financial resources are not neutral background conditions, but rather critical enablers of policy impact. Strengthening local capacities may thus be treated as a complementary policy priority alongside the provision of financial resources.

Second, the results on spillover effects have direct implications for the spatial allocation of funds. Projects implemented in certain municipalities produce measurable benefits in neighbouring areas, highlighting the importance of considering inter-municipal dynamics in allocation strategies (Dall’Erba, 2005). Rather than dispersing funds thinly across territories, a more concentrated investment approach, particularly in pollution-intensive regions where spillovers are strongest, may maximise aggregate environmental gains. This finding adds nuance to the long-standing debate on whether Cohesion Policy should pursue broad territorial coverage or more selective, concentrated interventions (Crescenzi, 2009).

Finally, these findings contribute to broader European and international debates on the cost-effectiveness of climate action. A more precise understanding of the conditions under which green funds deliver tangible air quality improvements can support the design of more efficient budget allocation strategies in future programming periods (2021–27 and beyond). Furthermore, international institutions can draw on these results to better coordinate EU Cohesion Policy with other climate instruments, such as emissions trading, regulatory standards and mission-oriented innovation policies, ensuring that financial support is integrated within a coherent and place-sensitive policy mix (Scotti et al., 2024).

Overall, our model also captures a significant spatial autoregressive spillover (λ between 0.55 and 0.72), meaning that neighbour municipalities tend to experience a variation of PM_{2.5} in the same direction and with a similar intensity. Such estimated values are in line with those obtained by Jia et al. (2021) in an SDM assessing the contribution of high-speed rail investments to CO₂ emissions reduction in China. The magnitude of this coefficient is also consistent with other studies analysing the contribution of the EU Cohesion Policy on economic growth (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 PM_{2.5} exhibits a high degree of spatial correlation (see Table E1 in Appendix E in the supplemental data online).

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 (clusters 1 and 2) tend to be associated with lower PM_{2.5} levels, as they may favour a dispersion of alternative pollutant agents (He et al., 2017). We also highlight that higher humidity levels improve air quality across all analysed clusters, while temperature shows a statistically significant positive association with PM_{2.5} variation only in cluster 1.

The analysis of socio-economic determinants of PM_{2.5} variation reveals that income per capita exerts a weak but statistically significant positive effect exclusively in municipalities belonging to cluster 2. This finding suggests that, within these areas, wealthier territories tend to experience a more unfavourable change in air quality, potentially reflecting higher levels of economic activity and associated emissions. Similarly, the number of vehicles per capita displays a positive association with air quality variation in cluster 2 municipalities, indicating that greater traffic volumes may contribute to more pronounced deterioration in pollution levels. In contrast, for most of our model specifications, no statistically significant effects are identified for the employment rate, population density or Maqi index, suggesting that these factors do not play a systematic role in explaining spatial heterogeneity in PM_{2.5} variation within the framework of our analysis.

To address the potential bias arising from other policy interventions external to the EU Cohesion Policy, particularly those aimed at improving air quality, we perform a robustness check by re-estimating the SDM with an interaction of region–year fixed effects. This specification allows us to account for unobserved heterogeneity that varies both across regions and over time, thereby controlling for the influence of national or regional policies that may overlap with the green EU Cohesion Policy funds. The rationale is that such interventions are typically designed and managed at higher administrative tiers, and their effects would be absorbed by the region–year fixed effects. The results from this robustness analysis, shown in Table E2 in Appendix E in the supplemental data online, are consistent with our baseline findings, indicating that our main conclusions should not be driven by omitted variables related to other green policies. Indeed, we confirm that municipalities in cluster 1 experience both direct effects and spillover effects. In contrast, only a direct impact of green EU funds is observed in territories within cluster 2, while no significant effects are found in areas belonging to cluster 3.

However, while the inclusion of region–year fixed effects strengthens the empirical design, it cannot fully eliminate all sources of confounding. In particular, municipality-specific time-varying factors such as local regulatory changes, private green investments or differential enforcement intensity may not be entirely absorbed. In addition, this specification reduces cross-regional variation and may partially attenuate the estimated effects if EU-funded interventions are systematically aligned with broader regional environmental strategies. Accordingly, our findings should be interpreted as conditional associations within a spatial panel framework.

We complement our baseline SDM estimates with a specification explicitly modelling the interaction between project timing and funding intensity. Specifically, we estimate a model in which the amount of funds spent is interacted with the year in which each project was concluded, thereby capturing potential variations in effectiveness associated with different completion periods. This approach allows us to address the static nature of the SDM framework by incorporating the staggered adoption of projects into the analysis. The results indicate that the largest reductions in $PM_{2.5}$ concentrations are observed for projects completed between 2017 and 2019 (see Table E3 in Appendix E in the supplemental data online). This aligns with the fact that 69% of the funds were disbursed during these years (see Table A11 in Appendix A online), since it usually takes several years from the beginning of a programming period for projects to be completed and their environmental impacts to become evident.

Importantly, our results remain similar when we estimate a dynamic SDM, which augments the baseline specification by explicitly incorporating temporal dependence through a lagged dependent variable while retaining spatial lags of both the dependent and explanatory variables (see Table E4 in Appendix E in the supplemental data online). This dynamic framework allows us to account for path dependence and adjustment dynamics in pollution outcomes, thereby addressing concerns related to the fully static nature of the baseline model.

Our results also hold in case we rely on different spatial matrices. In particular, Table F1 in Appendix F in the supplemental data online 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 F2 online shows a sensitivity analysis in case we use the KNN method with $k = 20, 30, 40$ and 50 to identify neighbour municipalities.

5.2. 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 2014–20, whereas transition and more developed territories benefited from €1.3 and €7.6 billion. The majority of municipalities in less developed regions fall within cluster 3, where we observe only a marginally significant negative coefficient for the variable *Environmental Fund* at lag zero. Moreover, neither the direct nor the indirect effects are statistically significant when estimated following the approach of Elhorst (2014), as described in Section 4.2 and reported in Table 2. Following the EU Cohesion Policy principles, municipalities in cluster 3 received a higher relative allocation of green EU funds, amounting to 0.9% (equivalent to €416.7 million) of their total local income (see Table A10 in Appendix A in the supplemental data online). This share is significantly greater than that of municipalities in cluster 1 and cluster 2, which received 0.6%

(€123.7 million) and 0.3% (€501.7 million), respectively. Considering that such territories will receive the highest portion of financial support also for the next programming period (2021–27), we perform an additional analysis on this set of municipalities, to understand whether we can find some subgroups of administrative units where these green EU funds display more relevant results in terms of $PM_{2.5}$ 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.

First, we divide the municipalities in cluster 3 into four groups (quartiles) based on how much their $PM_{2.5}$ levels changed during the study period. The first quartile includes municipalities with the largest reductions in $PM_{2.5}$, meaning they showed the highest improvement in air quality. Next, we estimate our panel SDM using different subsamples. Each subsample contains municipalities where the average $PM_{2.5}$ change between 2014 and 2020 falls below a certain percentile (quantile) within the quartile. We gradually increase this cutoff by 5% increments, starting from the lowest value of the quartile.

For example, in the first quartile, we analyse municipalities with average $PM_{2.5}$ changes below the 5th, 10th, 15th, 20th and 25th percentiles. For the second quartile, we analyse municipalities with $PM_{2.5}$ changes between the 25th percentile and increasing upper bounds: less than 30th percentile, less than 35th, up to the 50th percentile.⁹ This stepwise subsampling strategy allows us to test the robustness of our results and to detect potential bias in the relationship between $PM_{2.5}$ changes and the estimated effects across different segments of the distribution.

Interestingly, we observe that over the majority of the distribution, the relationship between green EU Cohesion Policy funds and $PM_{2.5}$ variation is negative but not significant in line with our main analysis (Figure 4). However, we find evidence of significant direct and indirect effects of green EU funds on air pollution reduction when focusing on the lower tail of the distribution of $PM_{2.5}$ level variation. Indeed, for municipalities experiencing the best outcome in terms of air quality patterns, these programmes of financial support seem to exhibit a relevant contribution to pollution contraction with direct effects between -1.5% and -1.8% and spillovers in around -1.5% . Notice how such a result is robust only for the set of

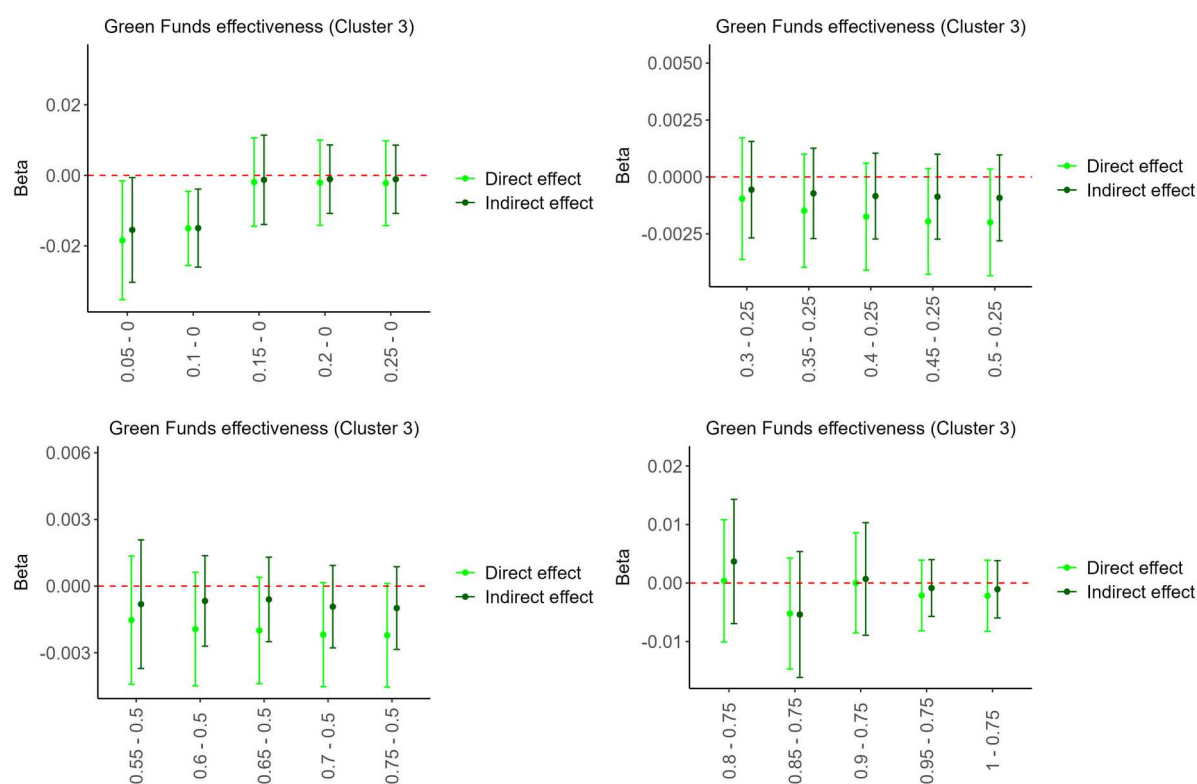


Figure 4. Direct and indirect effects estimated through a spatial Durbin model (SDM) where we restrict the analysis to alternative subsamples of cluster 3 municipalities.

municipalities where the average $PM_{2.5}$ variation is below a Q equal to 0.10, 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 air pollution reduction. Table G1 in Appendix G in the supplemental data online reports the p -values of t -tests comparing the distribution of municipalities where this programme of financial support seems effective in terms of $PM_{2.5}$ 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 0.10), with municipalities characterised by relevant direct effects and spillovers exhibiting higher income per capita and lower levels of employment in the Manufacturing sector. Furthermore, they display lower 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 programme 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 $PM_{2.5}$ 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 poor development strategies, often resulting in ineffective use of the available financial resources (Crescenzi & 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 (Charron et al., 2014; Milio, 2007).

6. Conclusions

This study examines the relationship between EU Cohesion Policy funds aimed at promoting sustainability transition and the resulting air pollution reduction outcome at the municipality level. 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 programmes of financial support (Bachtrögler et al., 2020; Fratesi & Perucca, 2014). 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 0.9% reduction of $PM_{2.5}$ in the municipalities where these projects are implemented. Furthermore, these expenditures also reduce pollutants in neighbour municipalities with spillovers equal to -1.0% . In municipalities of cluster 2, we observe relevant direct effects (equal to -0.2%), whereas spillovers are not statistically significant. Finally, a null relationship between green funds and $PM_{2.5}$ variation is obtained with regard to the municipalities of cluster 3. The results are robust to several alternative definitions of clusters and spatial matrices.

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 policy-makers in gaining a thorough comprehension of the key factors contributing to the reduction of $PM_{2.5}$ 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 air pollution reduction and comply with EU targets (Rausch & Yonezawa, 2023). Moreover, our findings on spillovers 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 indirect effects. In particular, Crescenzi (2009) critiques on the allocation criterion of Cohesion Policy funds, as an insufficient territorial concentration of the expenditure may explain weak spillover effects across territories (Dall'Erba, 2005).

Finally, we investigate the main characteristics of municipalities belonging to cluster 3 that are associated with significant direct and indirect effects of green EU funds. Interestingly, we observe that areas with higher levels of wealth as well as public mobility and tourism-related services, are associated with a more effective contribution of EU Cohesion Policy funds to air pollution reduction. 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 & Giua, 2016). Furthermore, as less developed regions will be allocated the largest portion of EU Cohesion Policy funds also in the next programming period (2021–27), our analysis might be informative for policy makers aiming to distribute the available budget across territories based on robust empirical evidence.

Notes

1. For Directive 2008/50/EC on ambient air quality (OJ L 152, 11.6.2008), see <https://eur-lex.europa.eu/eli/dir/2008/50/oj/eng>.
2. Regione Liguria, *Programma Operativo Regionale FESR 2014–2020*, https://opencoesione.gov.it/media/files/programma-2014it16rfop011/2014IT16RFOP011_6_0.pdf.
3. For the Thematic Strategy on Air Pollution (COM(2005) 446 final; CELEX: 52005DC0446), see <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52005DC0446>.
4. Regione Molise, *Programma Operativo Regionale FESR 2014–2020*, https://opencoesione.gov.it/media/files/programma-2014it16m2op001/2014IT16M2OP001_9_0.pdf.
5. See https://opencoesione.gov.it/it/opensdata/#!progetti_regione_section.
6. Our framework is consistent with previous evidence about the main anthropogenic sources of PM_{2.5}, as outlined by a technical report by the Joint Research Centre (JRC), the EC's science and knowledge service (Karagulian et al., 2017).
7. The clustering analysis covers a total of 6242 municipalities, with a municipalities left blank (NA) percentage of 21% relative to the total number of Italian municipalities.
8. We acknowledge that our analysis is primarily descriptive and does not establish causal relationships between the factors and the reduction of PM_{2.5}. Therefore, these coefficients should be interpreted as the interplay between green EU funds, other socio-economic and meteorological variables with PM_{2.5} variation.
9. For instance, considering the first quartile, the analysed samples are municipalities whose average PM_{2.5} variation over the time frame 2014–20 is below the 5th, 10th, 15th, 20th and 25th quantiles. Concerning the second quartile we analyse municipalities in the following ranges: 25th ≤ Q < 30th; 25th ≤ Q < 35th; 25th ≤ Q < 40th; 25th ≤ Q < 45th; and 25th ≤ Q < 50th.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Data availability statement

Data are available upon request due to third-party restrictions.

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