June 2024

Fondazione Eni Enrico Mattei

Working Paper

12.2024

Environmental justice gap in Italy: the role of industrial agglomerations and regional pollution dispersion capacity

Alessandra Drigo

Environmental justice gap in Italy: the role of industrial agglomerations and regional pollution dispersion capacity

Alessandra Drigo
(Department of Environmental Science and Policy, University of Milan and Fondazione Eni Enrico Mattei)

Summary

This study is the first to examine the relationship between PM2.5 concentration and per capita income at the municipality level for Italy. The novelty of this work is also to explore the role of agglomerations and morphological factors in influencing the income-pollution correlation in the year 2013, and to assess its persistence to 2019. While there is not an unconditional environmental justice gap in Italy, controlling for land morphology and agglomerations variables weakens the positive correlation between PM2.5 and per capita income to the point of disappearance. Notably, being located in the Padana Valley ecoregion serves as a key indicator of environmental injustice nation-wide. The excess of PM2.5 exposure in the region increased mortality risk by 13.8% in 2013 and 10.88% in 2019 with respect to the WHO threshold (5 mg/m^3 annual average). The largest environmental justice gap in relative measures shows a difference in mortality risk of 9.31% in 2013 and 7.04% in 2019 between the populations of the most polluted ecoregion (Padana Valley) and the least polluted one (Apennines). When attempting to disentangle the pollution variation among municipalities within the same province, the per capita income level of municipalities emerges as a significant indicator. An increase of 10,000 euros in the averagess per capita income of the municipality corresponds to a decrease of 2.01 mg/m^3 in PM2.5 annual average exposure level (-1.6% in mortality risk) in 2013 and 1.05 mg/m^3 (-0.7% in mortality risk) in 2019.

Keywords: Environmental inequality, Environmental justice, Air pollution

JEL classification: Q53, Q56, I14, C21

Corresponding Author:
Alessandra Drigo
Postdoctoral fellow
Department of Environmental Science and Policy, University of Milan
Via Celoria 2, Milan (Italy)
e-mail: alessandra.drigo@unimi.it

Environmental justice gap in Italy: the role of industrial agglomerations and regional pollution dispersion capacity.

A. Drigo[1,2,*]

[1]University of Milan, Department of Environmental Science and Policy, Milan, Italy.
[2]Fondazione Eni Enrico Mattei, Milan, Italy.
[*]alessandra.drigo@unimi.it

Abstract

This study is the first to examine the relationship between PM2.5 concentration and per capita income at the municipality level for Italy. The novelty of this work is also to explore the role of agglomerations and morphological factors in influencing the income-pollution correlation in the year 2013, and to assess its persistence to 2019. While there is not an unconditional environmental justice gap in Italy, controlling for land morphology and agglomerations variables weakens the positive correlation between PM2.5 and per capita income to the point of disappearance. Notably, being located in the Padana Valley ecoregion serves as a key indicator of environmental injustice nation-wide. The excess of PM2.5 exposure in the region increased mortality risk by 13.8% in 2013 and 10.88% in 2019 with respect to the WHO threshold (5 mg/m^3 annual average). The largest environmental justice gap in relative measures shows a difference in mortality risk of 9.31% in 2013 and 7.04% in 2019 between the populations of the most polluted ecoregion (Padana valley) and the least polluted one (Apennines). When attempting to disentangle the pollution variation among municipalities within the same province, the per capita income level of municipalities emerges as a significant indicator. An increase of 10,000 euros in the average per capita income of the municipality corresponds to a decrease of 2.01 mg/m^3 in PM2.5 annual average exposure level (-1.6% in mortality risk) in 2013 and 1.05 mg/m^3 (-0.7% in mortality risk) in 2019.

Keywords: Environmental inequality – Environmental justice – Air pollution

JEL Codes: Q53, Q56, I14, C21.

1. Introduction

Particulate matter can penetrate the respiratory and circulatory systems, leading to a range of diseases, including cardiovascular, cancerous, pulmonary, and respiratory conditions, representing the most significant environmental health risk in Europe (EEA, 2022). With the publication of the World Health Organization Air Quality (WHO AQ) guidelines in 2021, the relative risk of dying prematurely was found to increase from 6.2% to 8% for each 10 µg/m^3 increase in PM2.5 concentrations. For PM2.5, the highest absolute numbers of premature deaths in Europe in 2020 were seen in Italy, Poland, Germany, Romania and Spain, in order of decreasing rank (EEA, 2022). More specifically, in Italy, exposure to PM2.5 concentration levels beyond the WHO AQ guidelines threshold of 5 µg/m3 was linked to 52,300 premature deaths in 2020 (EEA, 2022). Despite this alarming data, there is limited knowledge about socioeconomic disparities in PM2.5 exposure in Italy.

This study is the first to examine the relationship between PM2.5 concentration and per capita income, and its related mortality risk, at the municipality level for Italy. To measure pollution, I use 0.01°x0.01° (1kmx1km) gridded PM2.5 concentration data, incorporating factors such as air transportation and the impact of mobile sources of pollution on local air quality. These concentration measures permit an analysis that goes beyond the insights offered by previous studies into the socio-demographics of the residents close to polluting hazardous facilities and their punctual emissions (Rüttenauer 2018; Glatter-Götz, 2019; Neier, 2021), delivering a more precise quantified exposure across all areas. In general, previous European studies on pollution exposure disparities have yielded inconsistent results, and some richer areas have been found to experience more pollution than poorer areas (Forestiere et al. 2007, Deguen and Zmirou-Navier 2010, Richardson et al. 2013, Germani et al. 2014, Hajat et al. 2015). While the variation in the results has been mainly addressed as a consequence of the diversity and heterogeneity of European societies (Padilla et al., 2014; Glatter-Götz, 2019), as well as challenges in getting proper pollution exposure data, this study brings the novelty of exploring the role of agglomerations and morphological factors in affecting environmental inequalities. The presence and development of agglomerations affect both income and pollution. On the one hand, industrial agglomerations affect pollution levels depending on the predominant effect between scale of production and technology. On the other hand, industrial agglomerations act by pooling the labor force, favoring urbanization, which is correlated with higher income. Secondly, while land characteristics have been previously employed to control for variations in pollution sources through the urban/rural differentiation, in this work I adopt the ecoregion morphological classification to focus on the ability of the area to disperse pollution. These land characteristics can influence the relationship between per capita income and exposure to pollution, potentially altering the correlation and making it more persistent despite improvements in cleaning the air through environmental policies.

The analysis exploits a multivariate cross-sectional model for the year 2013, explaining particulate matter exposure with the income pc of the municipalities and adding the agglomeration controls, ecoregion dummies and provincial fixed effects progressively. Ensuring equitable access to clean air is a fundamental aspect of social justice. Persistent inequalities, where certain groups keep bearing a disproportionate burden of pollution, highlight a lack of environmental justice over both space and time. Consequently, specific communities are persistently exposed to elevated pollution levels, which result in adverse health outcomes. To examine the persistence of these correlations, a cross-sectional model was repeated for the year 2019.

The results reveal a positive unconditional correlation between PM2.5 levels and per capita income across municipalities, indicating no unconditional environmental justice gap in Italy.

However, when controlling for agglomerations and morphological features, the positive correlation weakens. Controlling for agglomeration reduces the correlation's magnitude but retains its significance over the years. In contrast, controlling for land characteristics completely nullifies the correlation, with the Padana Valley ecoregion emerging as a significant predictor of environmental injustice nationwide. Within provinces, the per capita income of municipalities is a significant indicator of environmental inequality, illustrating an environmental justice gap conditional on land characteristics and the presence of agglomerations.
The paper is organized as follows: section 2 shows the literature review, section 3 introduces the conceptual framework, section 4 illustrates the data and the descriptive evidence, section 5 shows the empirical strategy, section 6 shows the results, section 7 discusses the conclusions.

2. Background

The US provides the widest literature on environmental inequalities, funding them existing along both income and racial dimensions. Over several decades, researchers have delved into the race vs. class debate (Anderton et al., 1994; Been, 1994; Downey, 1998; Downey, 2006; Banzhaf et al., 2019), and empirical studies have attempted to investigate to what degree the observed associations between pollution and race actually depend on the presence of a deeper and more complex issue of income inequality (Mohai, 2009; Wolverton 2009; Banzhaf et al., 2019). However, while the underlying mechanisms are being tested, the evidence of injustice towards disadvantaged communities based on income and ethnicity in the United States is undeniable.
In Europe, evidence of environmental inequalities is generally less clear (Glatter glotz, 2019). Previous European studies have found inconsistent results regarding pollution in richer and poorer areas under the American framework, with richer areas in European countries experiencing more pollution than poorer areas (Forestiere et al. 2007, Deguen and Zmirou-Navier 2010, Richardson et al. 2013, Germani et al. 2014, Hajat et al. 2015). The variation in the results may be influenced by the diversity and heterogeneity of European societies as a product of distinct historical socioeconomic processes (Agyeman, 2002; Diekmann and Meyer, 2010; Padilla et al., 2014; Glatter-Götz, 2019), aside from the specific characteristics of the countries/regions/cities selected in each European study.
Latest nation-wide analysis on inequalities in pollution exposure in Europe have investigated the demographic characteristics of the population living close to polluting facilities recorded in the European Pollutant Release and Transfer Register (E-PRTR) (Rüttenauer 2018; Neier 2021).
Rüttenauer (2018) investigates environmental inequality in Germany using the 2011 census data and emissions from 4971 industrial facilities recorded in the E-PRTR, with living space per inhabitant as a proxy for socio-economic status. The study finds that areas with a high minority population are closer to industrial facilities, particularly in urban regions. In contrast, Neier (2021) examines similar issues in Austria by analyzing emissions from 316 E-PRTR facilities and gridded census data of the facilities' surrounding areas. The results reveal that lower-income neighborhoods are concentrated near polluted areas in urban settings, with the exception of Vienna. Interestingly, rural areas show a positive correlation between income and pollution, deviating from previous European studies. While the study highlights the existence of an environmental justice issue, it solely focuses on industrial air pollution and disregards other potential sources, such as mobile sources. In these works, and more in general previous literature, there has been extensive use of distance-based methods to investigate the socioeconomic and ethnic attributes of individuals living in proximity to polluting facilities. Currie et al. (2023) have, however, pointed out certain limitations connected with this approach: these

methods fail to consider factors like air transportation and the impact of mobile sources of pollution on local air quality. As a result, while they offer insights into socio-economic/racial disparities concerning residents in proximity to hazardous facilities and toxic waste sites, the precise degree to which these disparities translate into variations in quantified exposures remains uncertain.

Zwickl et al. (2024) provide a comparable municipality-level environmental justice study on Austria, exploiting 0.01°x0.01° (1kmx1km) gridded PM2.5 concentration data. Their study provides a disaggregated environmental justice analysis comparable to previous studies in the US and this work, finding that foreign nationals are significantly more exposed to particulate matter. However, they do not address the persistence of these correlations over time and overlook a quantification of the associated health-risks outcomes. As for Italy, it has been the subject of the cross-sectional environmental justice study at provincial level carried out by Germani et al. (2014), whose findings indicate that a rise in income is likely to lead to an increase in air pollution emissions. Although their results provide a substantial starting-point, they may be biased by the provincial dimension of the available data. The province's larger area can obscure variations in socio-demographics and pollution levels that are noticeable at smaller units, such as the municipality (Banzhaf et al., 2019). Overall, while the majority of environmental justice recognizes that communities located nearby specific E-PRTR polluting facilities face higher pollution exposure, controlling for the cumulative pollution effects of the clustering of polluting industries has received much less attention.

Agglomerations are complexly associated with emissions and income. Zhu and Xia (2018) suggest that economic development drives industrial restructuring, leading to a decline in secondary industries and a rise in tertiary industries. In advanced industrial stages, the expanding tertiary sector absorbs more labor and fuels urbanization. As living standards improve, there is a growing demand for a healthy environment, prompting governments to enforce environmental policies aimed at reducing pollution. Conversely, Dong et al. (2020) argue that industrial clustering enhances resource allocation and energy efficiency but also caution that it may increase overall energy consumption and pollution, thereby making the environmental impact of agglomeration uncertain.

With regard to the influence of land morphology on pollution concentration levels, several studies have been conducted. Zhang et al. (2018) identify that the surrounding mountains of Beijing and its wind systems contribute to haze pollution in downtown Beijing. The mountains create southerly winds, high humidity, low boundary layer heights, and sinking motion, which foster haze formation. Similarly, Carvalho et al. (2006) find that topography on the Atlantic Coast of the Iberian Peninsula drives air pollutants into higher tropospheric levels. Weger and Heinold (2023) study the Dresden Basin and discover that surface orography influences black carbon distribution, with traffic emissions causing higher concentrations in the basin and its slopes during late winter, and elevated levels in the central urban section during late summer. Despite the significant role of morphological characteristics in shaping pollution distribution, they are often excluded from control variables in environmental inequality studies, potentially underestimating their impact on the relationship between pollution and socioeconomic factors. Overall, factors such as industrial agglomerations and land morphology, which can significantly affect the correlation between pollution and income (and/or other sociodemographics variables), have been largely overlooked in environmental inequalities studies, highlighting a critical gap in the existing research. Concurrently, the majority of studies are cross-sectional, which precludes confirmation of the persistence of these correlations over time.

3. Conceptual Framework

3.1. Environmental Justice

The unequal distribution of pollution exposure is a complex issue influenced by multiple mechanisms, with firm siting and residential sorting standing out as significant ones (Banzhaf et al., 2019). Socioeconomic disadvantages, such as being part of non-white minorities and lower-income groups, have been found to be correlated with higher pollution levels. At the core, it is debated if environmental inequalities along the racial dimension depend on the more complex issue of income inequality. The pivotal work of Wolverton et al. (2009) addresses the role of community socioeconomic characteristics, both at the time of siting and at present, in the location decisions of manufacturing plants. When examining the relationship between current socioeconomic characteristics and plant location, the findings align with environmental justice predictions: being part of the non-white minority positively relates to plant location. However, when considering socioeconomic characteristics at the time of siting, race no longer appears significant, while income remains negatively related to plant location. Variables traditionally examined in firm location literature, such as land and labor costs, labor quality, distance to rail, the presence of pre-existing polluting plants in a neighborhood, and average plant size, all display significant influences on plant location decisions. The findings suggest that firm siting decision are often driven by local market conditions and the pursuit of cost-minimization strategies, both of which tend to be correlated with the location of lower-income neighborhoods. This correlation can exacerbate environmental injustice as it concentrates pollution in areas already vulnerable due to economic disparities.

Residential sorting plays a complementary role in perpetuating pollution exposure disparities. Areas with higher pollution levels frequently offer lower housing prices (Banzhaf et al., 2019), making these areas more attractive to individuals with financial constraints, including lower-income households. As a result, residents in these neighborhoods may face a double burden - not only dealing with economic challenges but also experiencing heightened exposure to pollution (Banzhaf et al., 2019). Building on this mechanism, I expect that wealthier areas tend to be situated at a distance from pollution sources, resulting in a correlation where municipalities experiencing higher pollution levels are associated with lower income.

H1: Higher income households will sort in less-polluted areas, leading higher income municipalities to be less correlated with pollution levels.

3.2. Agglomeration, Income and Pollution

The presence and the development of agglomerations affect both income and pollution. Agglomerations rise since there are significant economic incentives for populations and production to concentrate in a small number of densely populated areas (Krugman, 1991). Ottaviano and Thisse (2004) discuss that the geographical concentration of firms and workers within clusters may be explained by mutually reinforcing external effects, in an egg-and-chicken dynamic, raising externalities. Identifying the direction of these mutually reinforcing effects is beyond the scope of this paper. However, it is of interest to discuss the externalities and their influence on income and pollution. Agglomerations' externalities arise because of:

(i) mass-production (or, equivalently, increasing returns at the firm level);

(ii) the formation of a highly specialized labor force and the production of new ideas, both based on the accumulation of human capital and face-to-face communications;

(iii) the availability of specialized input services;

(iv) the existence of modern infrastructures.

Ottaviano and Thisse (2004) relate these externalities to Hoover's (1936) classification of agglomeration economies, distinguishing between two types: (a) urbanization economies, which are external to industries and depend on the overall scale and scope of economic activity in a given location; and (b) localization economies, which are external to firms but internal to an industry. Urbanization economies encompass externalities (ii), (iii), and (iv) (Ottaviano and Thisse, 2004) and provide larger, diversified labor pools in close proximity to customers and suppliers (Bloom et al., 2008). Cities enable firms to respond quickly and effectively to market demand changes and facilitate efficient growth by maximizing social returns from increased human capital (Bloom et al., 2008). The variety of services available in urban settings drives agglomeration through a consumption motive, as individuals derive higher utility from spending their income in cities (Ottaviano and Thisse, 2004). Urban agglomeration involves the simultaneity of production and consumption processes: workers consume most of what they earn where they earn it. These factors lead to a strong correlation between the proportion of a country's population living in urban areas and its income level, as observed in the literature (Bloom et al., 2008).
Localization economies, or industrial agglomerations, directly impact the environment based on the emission intensity of their industry. The degree of emission intensity within an industry determines how much the technological effect can offset the scale effect. The scale effect occurs when firm-level increasing returns lead to industry-level concentration due to specialization and large-scale production, resulting in technological spillovers that enhance operational efficiency and reduce production's pollution impact. While the technological effect mitigates pollution, the scale effect's impact can vary. Dong et al. (2020) argue that clustering improves resource allocation and energy efficiency but also highlight the potential for increased energy consumption and pollution, making the environmental impact of agglomeration uncertain.
Considering the underlying mechanisms, industrial agglomerations impact on pollution levels depending on the predominant effect between scale and technology, while high-emission-intensity industries negatively impact on the environment. Industrial agglomerations act by pooling labor force, favoring urbanization, in a mutually reinforcing dynamic. Urbanization, in turn, is correlated with higher income. Taking into account agglomerations and their environmental impacts as outlined, the following hypothesis is derived:

H2: Municipalities with higher levels of industrial agglomeration might show higher income pc and higher pollution levels.

3.3. Land Morphology and Pollution Dispersion

Regional land characteristics affect the capacity of pollutants dispersion across regions. In general, the temporal variability of air-pollution concentrations from local sources is governed by two main factors: a) the variability in the emission intensity at the source and b) the variability in mixing/ventilation efficiency of the atmospheric flow constrained by the land morphology (Weger and Heinold, 2023).
The Padana plain, located in northern Italy, is widely recognized as a heavily polluted area

in terms of the concentration of particulate matter (PMs) (Raffaelli et al. 2020). The area's meteorological conditions and the efficiency of pollutant transport and dispersion are significantly influenced by the morphological characteristics of the plain and the Northern Adriatic Basin. The transport of pollutants is constrained by geographical features such as the Alps, the Apennines, and the Dinaric Alps (Raffaelli et al., 2020). The region experiences relatively low wind speeds compared to other parts of Europe, which results in the formation of a single layer of diffuse and uniform pollution in the lowermost part of the atmosphere (Raffaelli et al., 2020). Consequently, high pollutant concentrations are evenly distributed throughout the basin, extending even to rural areas far from the emission sources (Raffaelli et al., 2020). The homogeneity of pollutant levels across the Padana plain poses significant challenges for mitigating air pollution in the region, compared to the other morphological region of Italy (Apennines, coastlines, islands etc.). Taking into consideration the effects of morphological characteristics of the areas on limiting/facilitating pollution dispersion, the following hypothesis is derived:

H3: If the morphological characteristics of the land limit the dispersion of pollution, the persistence of pollutants in the area makes the differences in pollution exposure less clear. Consequently, richer and poorer areas may face similar levels of pollution. Hence, the correlation between income per capita and pollution may result in a weak or non-existent relationship.

4. Data and Descriptive Statistics

To study the correlations between PM2.5 and income levels among municipalities, I calculated the average annual particulate matter exposure aggregated at the municipality level and merged it with income and agglomeration data at the same level, lagged by one year. This approach was taken in order to obviate simultaneity problems (see section 5). The dataset comprises two cross-sectional samples: one for 2013 with 7,791 observations and one for 2019 with 7,507 observations. Table 1 shows the descriptive statistics.

PM2.5 Concentrations

The study utilizes annual concentration data of PM2.5 mg/m^3 gridded at a spatial dimension of 1km x 1km, sourced from Staffoggia et al. (2019). These values are estimated using a comprehensive approach that integrates PM monitored data, Aerosol Optical Depth (AOD) data, meteorological parameters, and spatial predictors. PM monitored data, obtained from the Italian Institute for Environmental Protection and Research (ISPRA), provided daily measurements of 24-hour mean PM2.5 concentrations. AOD data, crucial for assessing suspended particle levels, were obtained from the Monitoring Atmospheric Composition and Climate - Interim Implementation (MACC-II) project, developed within the Copernicus Atmosphere Monitoring Service (CAMS). Meteorological parameters, including daily mean air temperature, sea-level barometric pressure, and wind speed, were retrieved from the ERA-Interim reanalysis project. Additionally, spatial predictors such as geo-climatic zones, resident population, and land cover data were collected at the grid cell level to provide context for environmental assessments (for further details see Staffoggia et al. 2019).
This comprehensive methodology aimed to provide accurate predictions of PM concentrations at a fine spatial resolution for Italy, making them reliable exposure estimates for nation-wide environmental justice and health outcomes studies.
Figure 1 and 2 display the persistence of high PM2.5 concentrations.
The World Health Organization (WHO) recommends a threshold of 5 µg/m^3 for long-term exposure to air pollution. The data suggests that despite efforts to reduce pollution, high levels

well above WHO limits of PM2.5 persist especially in Padana valley region, exposing residents to prolonged periods of harmful air quality. This prolonged exposure to high concentrations of PM2.5 is significantly associated with inflammation, which is directly linked to subsequent cardiovascular disease (Ostro et al., 2014), as well as increased mortality from respiratory disease and lung cancer (Pun et al., 2017).

Ecoregions

Italy has a total land area of 307,635 square kilometers and diverse geoclimatic regions. All Italian municipalities have been classified into distinctive Ecoregions as per the Istat Ecological Region Classification (2020). The Ecological Regions, or ecoregions, are ecologically homogeneous areas of varying sizes, representing zones with similar ecosystem potential. The classification approach involves a classification of the territory into units of increasing homogeneity, based on specific combinations of climatic, biogeographic, physiographic, and hydrographic factors that determine the presence and distribution of different species, communities, and ecosystems. Since these determinants also influence the types and intensity of human activities, these units can be considered representative of more general landscape characteristics. This approach complements the traditional administrative boundaries and provides a complementary framework for understanding the environmental features and land use patterns that characterize Italy.
Figure 3 presents Istat's ecological region categorization. Table 2 displays the descriptive statistics relevant to the Ecoregions. The Temperate ecoregions comprise over half of the Italian population, and the Padana plain is the most populous of these regions (32.4% of the Italian population). The most populous ecoregion in the Mediterranean group is the Tyrrhenian, accounting for 1.8% more of the national population than the Padana plain. The 19.497 million residents of the Padana plain are exposed to the highest pollution levels in the country.

Income and Socio-economic Variables

Income data are referred to the declared income categories, to which IRPEF tax (Personal income tax) is applicable according to the Italian tax legislation. The total income suitable for the IRPEF tax in the released data is the sum of: i) Rental income from real estate; ii) Income from employment and similar sources; iii) Retirement income; iv) Income from self-employment; v) Income from employment and assimilated; vi) Income attributable to entrepreneur; vii) Income from business investments. Data are provided by the Ministry of Economics and Finance (MEF), they refer to the amount of income in each Italian municipality, classified by source of income, as defined by the Italian Income Agency (Agenzia delle Entrate).
Data on population, the presence of industries and their respective workforces, classified by NACE 2-digit sectors, are provided by Istat. The change in the number of municipalities over time (Table 1) is a result of administrative changes.

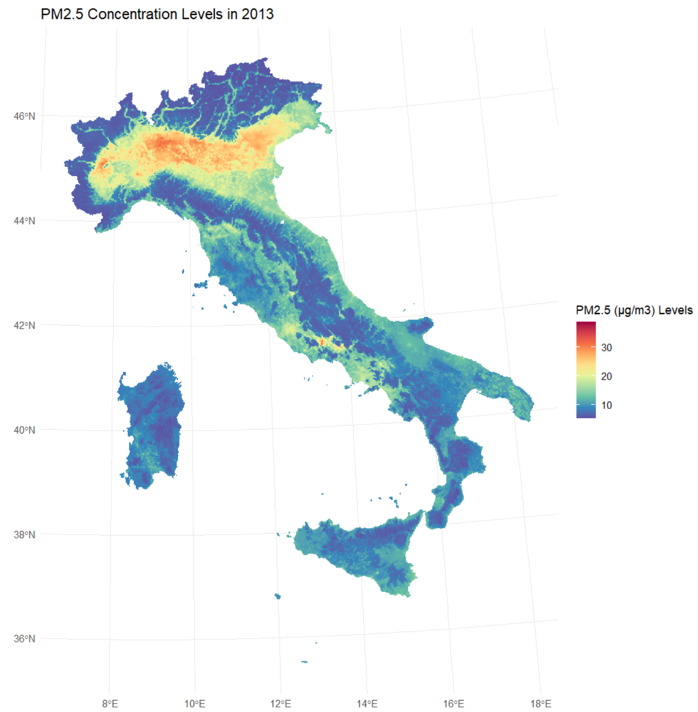

Figure 1: Map of PM2.5 [mg/m^3] concentration in Italy in 2013

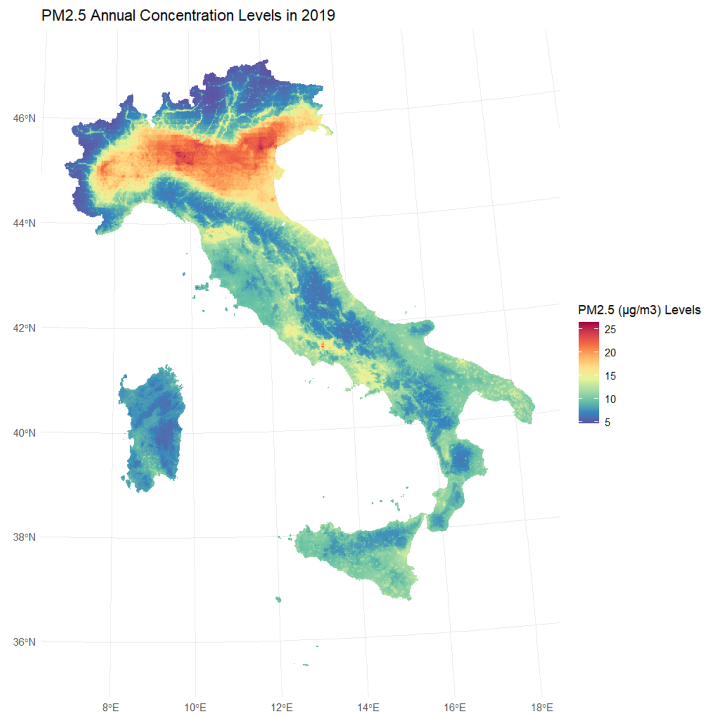

Figure 2: Map of PM2.5 mg/m^3 concentration in Italy in 2019

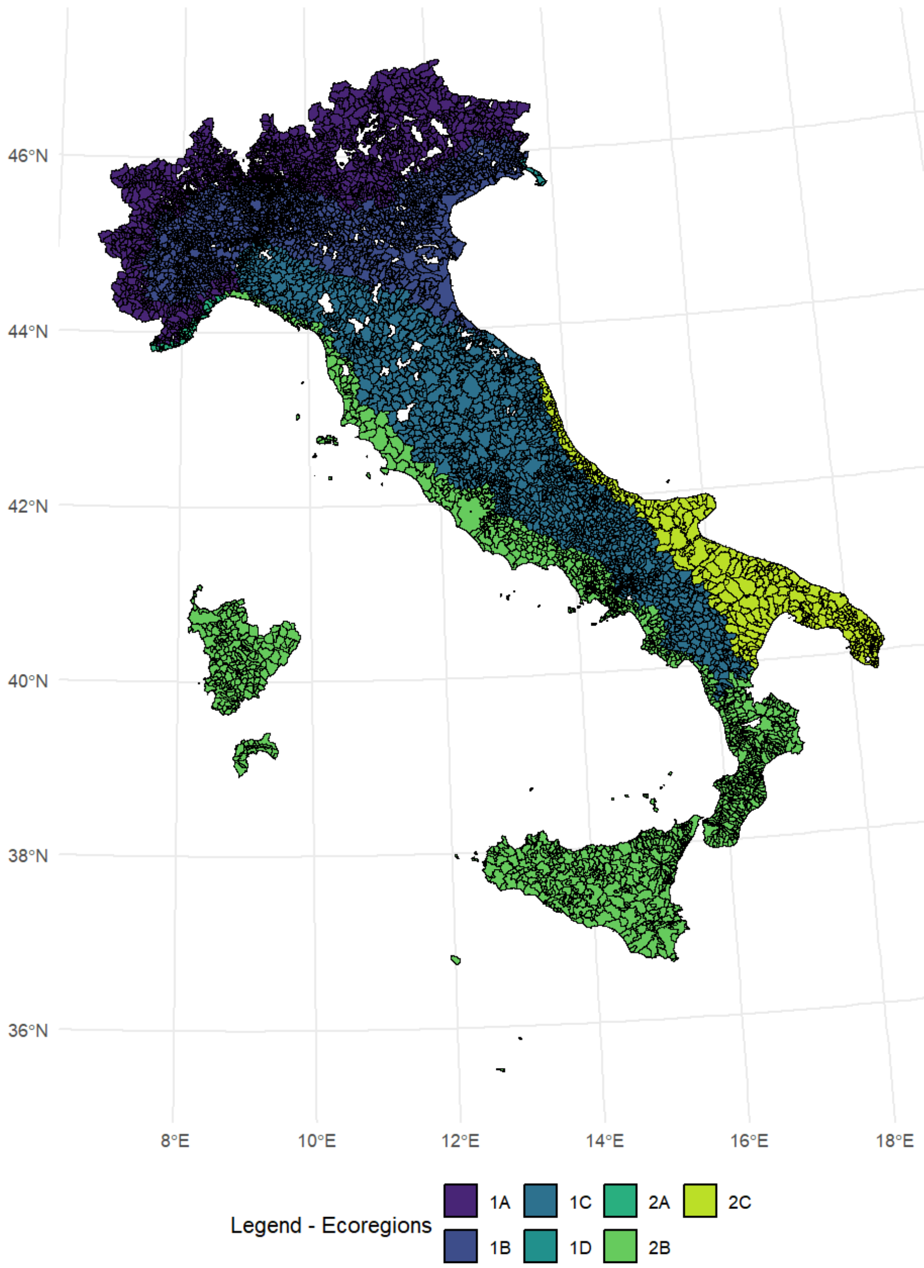

Figure 3: Maps of Ecoregions
Note: 1A Alps ecoregion, 1B Padana ecoregion, 1C Apennines Ecoregion, 1D Illiric ecoregion, 2A Provenzale Ligure ecoregion, 2B Tyrrhenian ecoregion, 2C Adriatic ecoregion. The map does not show the municipalities that were excluded from the analysis.

Table 1: Descriptive Statistics

Socioeconomic variables – 2012

Variable	Obs	Mean	Std. Dev.	Min	Max
Income pc	7791	11736.382	2971.414	3042.497	33183.398
Population	7791	7515.138	40483.159	30	2617175
Area (km2)	7791	36.83847	49.74502	.1206	1287.359
Total Industries Employment	7791	2121.251	15844.574	1	943079.38
Total Polluting Industries Employment	7791	146.013	545.1	0	24280.391

Socioeconomic variables – 2018

Variable	Obs	Mean	Std. Dev.	Min	Max
Income pc	7508	12847.336	3274.993	3136.911	36391.422
Population	7508	7623.979	43482.984	28	2815541
Total Industries Employment	7507	2211.08	18022.797	1	1041343.3
Total Polluting Industries Employment	7508	137.651	510.183	0	23112.619

Pollution variables

Variable	Obs	Mean	Std. Dev.	Min	Max
PM2.5 µg/m^3 2013	7791	13.892	6.295	5.875	30.821
PM2.5 µg/m^3 2019	7508	12.516	4.668	4.769	24.375

Table 2: Ecoregions. Descriptive Statistics

Ecoregion	Denomination	N° of municipalities	Km2	Population	% Surface	% Population
1	Temperate Group	5,757	188,449.2	33,888,077	62.4	56.3
1A	Alps region	1,839	53,993.1	5,598,943	17.9	9.3
1B	Padana region	2,126	49,835.1	19,497,049	16.5	32.4
1C	Apennines region	1,783	84,350.5	8,553,576	27.9	14.2
1D	Illiric portion	9	270.5	238,509	0.1	0.4
2	Mediterranean Group	2,147	113,619.0	26,356,562	37.6	43.7
2A	Ligure Provenzale region	69	1,041.6	438,2	0.3	0.7
2B	Tyrrhenian region	1,696	86,453.3	20,582,684	28.6	34.2
2C	Adriatic region	382	26,124.2	5,335,678	8.6	8.9
	Total	7,904	302,068.3	60,244,639	100.0	100.0

5. Empirical Strategy

This empirical approach aims to investigate the relationship between PM2.5 and per capita income across municipalities in 2013 and assess its persistence in 2019. By gradually introducing controls for agglomerations and pollution dispersion, the strategy tests hypotheses outlined in the conceptual framework. Environmental inequalities may stem from disparities in income levels, influencing pollution levels, or vice versa (Germani et al., 2014). To mitigate potential endogeneity issues, the analysis considers the lagged effects of economic and socio-demographic conditions on air pollution levels. I perform a logarithmic transformations on all variables to reduce skewness and facilitate the interpretation of estimated coefficients in terms of percentage changes.
I start from testing H1 looking at bivariate correlations, adopting the following model:

$$\ln \mathrm{Pm}_{2.5_{(i,t)}} = \beta_0 + \beta_1 \ln \mathrm{incomepc}_{(i,t-1)} + \alpha_g + \epsilon_{(i,t)} \tag{1}$$

where i indicates the municipality and t indicates the year. Initially, I assess the bivariate correlation between per capita income and PM2.5 levels across all municipalities. Subsequently, I explore whether these correlations remain stable after incorporating population weights and provincial fixed effects, respectively. To account for spatial dependence, I cluster standard errors by administrative provinces. To test H2, I include all variables that isolate the effects of agglomerations on pollution outcomes:

$$\begin{aligned} \ln \mathrm{Pm}_{2.5_{(i,t)}} = {} & \alpha + \beta_1 \ln \mathrm{incomepc}_{(i,t-1)} + \beta_2 \ln \mathrm{PopulationDensity}_{(i,t-1)} \\ & + \beta_3 \ln \mathrm{Industrial\_AGG}_{(i,t-1)} + \beta_4 \ln \mathrm{Polluting\_AGG}_{(i,t-1)} + \epsilon_{(i,t)} \end{aligned} \tag{2}$$

Incorporating population density as a covariate allows for capturing the influence of higher population concentration on pollution levels, thus isolating the specific impact of industrial agglomeration. This control is essential for addressing potential endogeneity issues, as urbanization and industrial agglomeration often exhibit mutually reinforcing dynamics. The variable 'Industrial AGG' is computed by dividing the total industrial sector employment in the municipality by its area in square kilometers. This ratio serves as a measure of the spatial concentration of industrial activities. Additionally, expressing agglomeration as employment concentration per unit area standardizes the measure, making it beneficial for comparing municipalities of various sizes and reducing potential biases arising from larger areas inherently having higher levels of industrial employment. The 'Polluting AGG' variable captures the particularly intense contribution of agglomerations to pollution levels by controlling for the concentration of high emissions-intensive industries. It expresses the employment ratio of these industries over the municipality area.
To test H3 I add ecoregions dummies to the model.

$$\begin{aligned} \ln \mathrm{Pm}_{2.5_{(i,t)}} = {} & \alpha + \beta_1 \ln \mathrm{incomepc}_{(i,t-1)} + \beta_2 \ln \mathrm{PopulationDensity}_{(i,t-1)} \\ & + \beta_3 \ln \mathrm{Industrial\_AGG}_{(i,t-1)} + \beta_4 \ln \mathrm{Polluting\_AGG}_{(i,t-1)} + \theta_k X_k + \epsilon_{(i,t)} \end{aligned} \tag{3}$$

Where (X_k) is the ecoregion dummy variable that takes the value of 1 if the observation belongs to ecoregion k and 0 otherwise. θ_k represents the coefficient for the fixed effect of the ecoregion k. These dummy variables account for the pollution dispersion capacity specific to the ecoregion in which the municipalities are situated. By controlling for these variables,

I attempt to mitigate the risk of improperly attributing pollution variations to other variables when they might be primarily driven by land morphology.
I ultimately employ an alternative model in which I substitute ecoregion indicators with fixed effects representing administrative provincial factors. This approach effectively addresses unobservable and time-invariant features, including land characteristics, among the controlled attributes. Additionally, examining within-province variation allows to uncover localized effects or variations that may not be apparent when looking at broader regional or national trends.

$$\ln \mathrm{Pm}_{2.5_{(i,t)}} = \alpha + \beta_1 \ln \mathrm{incomepc}_{(i,t-1)} + \beta_2 \ln \mathrm{PopulationDensity}_{(i,t-1)} + \beta_3 \ln \mathrm{Industrial\_AGG}_{(i,t-1)} + \beta_4 \ln \mathrm{Polluting\_AGG}_{(i,t-1)} + \gamma_j D_j + \epsilon_{(i,t)} \quad (4)$$

D_j is a dummy variable that takes the value of 1 if the observation belongs to region/province j and 0 otherwise. γ_j represents the coefficient for the fixed effect of the region/province j. To enhance robustness, all the models are run also with population weights, for both 2013 and 2019.

6. Results

6.1. Environmental Justice Gap

The findings indicate the existence of two dimensions of injustice. The first dimension is associated with the ecoregion where the municipality is located, which corroborates the capacity of land morphology to affect pollution exposure levels and its relative association with income (H3). The second dimension is related to income-pollution association across municipalities when they belong to the same province. The presence of an environmental justice gap within provinces aligns with H1.
Table 3, Column 1, shows a positive correlation between PM2.5 and income levels across municipalities at the national level. This finding contradicts previous environmental justice literature that predicts an inverse relationship between income and pollution. The results suggest that richer areas in Italy are associated with higher pollution levels.
This result pertains to the disproportionate distribution of economic and industrial activities, which are highly concentrated in the Northern region. In fact, 51% of all Italian firms are located in the Northern region. The presence of industrial and high-emission-intensity industrial agglomerations, even in proximity to urban centers, can influence the relationship between pollution and income. Municipalities with higher levels of industrial agglomeration may exhibit higher per capita income and increased pollution levels. The Padana valley, where 72% of the firms in the Northern region are located, also has 41% of its municipalities placed in the highest income quartile of the distribution. Additionally, it displays some of the highest levels of pollution in the entire country due to the morphology which limits pollution dispersal. This condition drives the results and is persistent across the periods (Table 4, Column 1), robust to population weight or regional and provincial fixed effects (Table 6 in Appendix).
After controlling for agglomeration variables (Table 3, Column 2), the coefficient for per capita income decreases in magnitude. It is worth noting that industrial agglomerations and polluting industrial agglomerations have different effects on pollution, as indicated by the different signs of their coefficients in the two time periods. The correlation between polluting industrial agglomeration and PM2.5 is positive and can be attributed to the high emission intensity of the included sectors (NACE 19, 20, 21, 23, 24, 25), which is an intrinsic characteristic of these sectors and persists throughout the period. The negative coefficient for all agglomerations in 2019 captures the improvements in pollution abatement at the industrial level over the years.

This is consistent with the national-level decrease in PM2.5 concentrations.
The relationship between income and pollution becomes negative and loses significance when Ecoregions dummies are included (Table 3, Column 3). This suggests that the distribution of polluting agglomerations, together with the different morphological characteristics of the areas in which they are situated throughout the country, can absorb the relationship. The baseline category in the model is the Alps region, and the other category coefficients represent the expected difference in the dependent variable between the baseline and the other categories, assuming all other variables are held constant. Areas with limited pollution dispersion, such as the Padana valley, exhibit a strong positive correlation with pollution compared to other morphological region, even prior to the inclusion of agglomeration controls (Table 7 in Appendix). The mere fact of being located in the Padana plain, corresponds to approximately 45% (2013) and 40% (2019) higher pollution levels to which the population is exposed compared to the baseline in both years. Conversely, in the other regions, the coefficients are either not significant or carry a negative sign, indicating no significant difference or, in the case of the Tyrrhenian coastline in 2019, a lowered pollution exposure levels compared to the baseline category. This can be attributed to the air circulation capacity, which leads to better air quality in these regions. Under certain conditions, involving the the distribution of industrial clusters, and certain land morphology characteristics, income may not be the primary predictor of pollution levels. It is important to note that each geography has its own distinct characteristics, making each case unique.
Another approach to account for unobservable features of the land is by including provincial dummies to control for them. I conducted a fixed effects model for provincial features to provide robustness to the previous specification (Table 3, column 4). The fixed effects model is also used to analyze variations or differences in pollution exposure occurring within specific provinces, with the goal to uncover localized effects or variations that may not be apparent when looking at broader regional or national trends. Once provincial fixed effects are taken into account, the coefficient of income pc changes in significance and in sign. The shift in the direction of the effect reveals the presence of an environmental justice gap that emerges within provinces, once accounted the distribution of agglomerations and the unobservable characteristics of the provinces. The theoretical interpretation suggests that richer and lower-income municipalities in the same province could encounter dissimilar levels of pollution, with higher-income areas being less exposed. This environmental inequality condition is stable over time (Table 4, Column 4). Specifically, a 1% increase in income per capita was associated with a 0.17% and 0.10% decrease in pollution levels in 2013 and 2019, respectively. Notably, population density and polluting industrial agglomerations are positively associated with pollution. This ultimate result confirms H1. To ensure the robustness of this result, I tested the same specification using PM2.5 in units and quartiles of income instead of the log of income pc, both with log and units of PM2.5. Please refer to the Tables Appendix for the results of these robustness checks.
Overall, these results identify the existence of an environmental justice gap within provinces conditional on agglomeration distribution and land morphology, which is persistent across the period of analysis. To quantify the main results within provinces, an increase of 10,000 euros in the average income pc of the municipality corresponds to a decrease of 2.01 mg/m^3 in PM2.5 annual average exposure level. In 2019, the gap decreased due to improved air quality. An increase in income per capita was associated with a decrease of 1.05 mg/m^3 in the annual average exposure level of PM2.5.

Table 3: Main Results, year = 2013.

	1	2	3	4
ln PM2.5	Unconditional Model 2013	Agglomeration Controls 2013	Ecoregions& Agglomeration Controls 2013	Within Provinces 2013
ln income pc	0.632***	0.326***	-0.00330	-0.169***
	(0.129)	(0.0805)	(0.0803)	(0.0290)
ln pop. density		0.0449	0.0951***	0.0736***
		(0.0433)	(0.0215)	(0.0107)
ln aggl. (all)		-0.0340	-0.0166	0.0318***
		(0.0393)	(0.0205)	(0.0105)
ln aggl. (polluting)		0.153***	0.0574***	0.0232**
		(0.0190)	(0.0115)	(0.00913)
Padana Valley			0.456***	
			(0.0456)	
Apennines			-0.0376	
			(0.0467)	
Tyrrhenian			-0.103	
			(0.0657)	
Adriatic			-0.0799	
			(0.0556)	
Population weights	yes	yes	yes	yes
Clustered SE	Provinces	Provinces	Provinces	Provinces

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 4: Main Results, year = 2019.

	1	2	3	4
ln PM2.5	Unconditional Model 2019	Agglomeration Controls 2019	Ecoregions& Agglomeration Controls 2019	Within Provinces 2019
ln income pc	0.507***	0.312***	-0.0413	-0.109***
	(0.0956)	(0.0614)	(0.0466)	(0.0287)
ln pop. density		0.0589*	0.0733***	0.0846***
		(0.0307)	(0.0187)	(0.0110)
ln aggl. (all)		-0.0546**	-0.0139	-7.75e-05
		(0.0244)	(0.0161)	(0.00758)
ln aggl. (polluting)		0.121***	0.0367***	0.0174***
		(0.0161)	(0.0103)	(0.00572)
Padana Valley			0.402***	
			(0.0513)	
Apennines			-0.0384	
			(0.0551)	
Tyrrhenian			-0.0994*	
			(0.0551)	
Adriatic			-0.0636	
			(0.0525)	
Population weights	yes	yes	yes	yes
Clustered SE	Provinces	Provinces	Provinces	Provinces

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

6.2. Quantifying the Mortality Risk Associated with the Environmental Justice Gap

The quantification of mortality risk associated with the environmental justice gap serves to identify the gravity of inequities in environmental exposure. This information facilitates the delivery of a clearer understanding of the pressing necessity for targeted interventions to effectively mitigate these disparities. According to the WHO AQG (2021), long-term exposure to concentrations of 5 mg/m^3 or higher may result in a minimal amount of health outcomes. This threshold is based on the lack of evidence from the data indicating a linear correlation between exposure and risk below 5 mg/m^3. To quantify the mortality risk related to PM2.5 exposure, the WHO recommends assuming a linear increase in mortality risk of x% for a y mg/m^3 increase in concentration. Using the concentration-response functions provided by WHO (2021), we can quantify the increased health risk in the most exposed areas due to high PM2.5 concentrations. When considering WHO AQG, the mortality rate is increased by 1.08, meaning the mortality risk increases by 8% for a 10 mg/m^3 increase in PM2.5 annual mean concentrations (Soares et al., 2022). Table 5 shows the average PM2.5 level of the municipalities located within the Padana valley is 22 mg/m^3, the gap relatively to the WHO threshold of 5 mg/m^3 is 17 mg/m^3. Exposure to that excessive pollution increases the mortality risk by 13.8% for the population of the Padana Valley municipalities, which have the highest mortality risk in Italy. Although the mortality risk registered a slight drop to 10.88% in 2019, its persistence over time indicates that the environmental justice gap remains and can be considered a form of discrimination affecting the population of this area. The largest gap in relative measures shows a difference in mortality risk of 9.31% in 2013 and 7.04% in 2019 between the populations of the most polluted ecoregion (Padana valley) and the least polluted one (Apennines). Given the initial injustice of being located in a particular ecoregion, it appears that within provinces, the wealthiest municipalities are exposed to lower levels of pollution. Following the results displayed in Table 3, Column 4 and Table 4, Column 4, an increase of 10,000 euros in the average income per capita of the municipality corresponds to a decrease of 1.6% in mortality risk in 2013 and 0.7% in 2019.

Table 5: Quantification of the mortality risk by ecoregion

		Mean PM2.5 (µg/m3)	**Excessive exposure (µg/m3)**	**Mortality Risk (%)**
Padana valley	2013	22	17	13,6
	2019	18,6	13,6	10,88
Alps	2013	11,34	6,34	5,07
	2019	10,21	5,21	4,17
Apennines	2013	10,36	5,36	4,29
	2019	9,8	4,8	3,84
Tyrrhenian	2013	10,57	5,57	4,46
	2019	10,2	5,2	4,16
Adriatic	2013	11,7	6,7	5,36
	2019	10,95	5,95	4,76

7. Discussion and Conclusions

Contrary to previous US research on environmental justice, I find a positive unconditional correlation between PM2.5 levels and per capita income across Italian municipalities. When controlling for urban and industrial agglomerations distribution, the magnitude of the income pc coefficient lowers while maintaining its significance over the years. When assessing pollution dispersion capacity by adding Ecoregions dummies (Alps, Padana plain, Apennines, Tyrrhenian, and Adriatic), any correlation with income is completely absorbed by the distribution of agglomerations and the limited/favorable pollution dispersal conditions of the land in which they are located. Relatively to the ecoregions, the most striking findings involve the Padana Valley. Being located in the Padana plain corresponds to more than 40% higher pollution exposure than the baseline (Alpine ecoregion) in both years. This persistent and inequitable exposure condition affects municipalities within the region in comparison to those located elsewhere. This situation of environmental disadvantage affects 32.4% of the Italian population, who have been persistently exposed to PM2.5 concentration levels higher than WHO targets. The exposure to the excessive pollution registered annually in the Padana valley increases the mortality risk by 13.8% for the population of affected municipalities in 2013. Although it registered a slight drop to 10.88% in 2019, its persistence over time indicates a persistent environmental inequality. The largest relative environmental justice gap was measured as an increased risk of 9.31% in 2013 and 7.04% in 2019 between the populations of the most polluted ecoregion (Padana Valley) and the least polluted one (Apennines). These results raise questions about whether residing in a morphological region lacking pollution dispersion can be considered a form of environmental inequality.

When analyzing pollution variation within provinces, the results reveal a negative correlation between income per capita and pollution. Wealthier municipalities are associated with lower levels of pollution, which remain persistent over time. Specifically, a 1% increase in per capita income in municipalities is correlated with a reduction in pollution of -0.17% in 2013 and -0.10% in 2019. The negative correlation between income and mortality risk is consistent with the environmental justice framework, which suggests that more disadvantaged areas are exposed to higher concentrations of pollution. To quantify these findings, an increase of 10,000 euros in the average income per capita of the municipality corresponds to a decrease of 1.6% in mortality risk in 2013 and 0.7% in 2019.

Although the magnitude of environmental injustice affecting municipalities in the same province is much less than that arising from the morphological characteristics of the areas, it is still a relevant finding that aligns with previous European studies (Pasetto et al., 2019). Despite the different pollution data and geographical disaggregation of the analysis, the outcomes of this study are comparable with Neier (2021), who used E-PRTR punctual emissions, and the socio-economic information of residents close by polluting facilities. Neier (2021) found environmental inequalities on the income dimension conditional on urban/rural land classification of the Austrian territory. While the rural area shows a positive correlation between the income of residents living near E-PRTR facilities with high industrial emissions, the coefficient is negative in urban areas. In addition, as well as the case of provinces, while controlling for unobservable differences across Austrian federal states, results suggest that inequality is more pronounced within federal states than across the country. Salesse (2022) evaluate the relationship between Income and the number of days of exposure to air pollutants across French municipalities. Its results showed that urban areas concentrate the most days of fine particulate matter (PM2.5), Among the dense urban municipalities, the poorest are significantly overexposed to these two pollutants in terms of number of days. Instead, in rural areas the most affluent municipalities accumulate more PM2.5 pollution days.

In conclusion, the study identifies the persistence of environmental injustice in Italy in two main dimensions. Firstly, in relation to the ecoregion to which it belongs, the morphology of the territory exerts a significant influence on the levels of pollution exposure and their association with income. Secondly, within the same province, richer municipalities are less exposed to pollution. These results can serve as a reference for potential regional strategies against air pollution and provincial-specific policies, with the goal of ensuring clean air for all.

Acknowledgments

This study was carried out within the PRICE (PRoductivity and equity Implications of Climate change in Europe) projected funded by the European Union Next-GenerationEU - National Recovery and Resilience Plan (NRRP) – MISSION 4 COMPONENT 2, INVESTIMENT 1.1 Fondo per il Programma Nazionale di Ricerca e Progetti di Rilevante Interesse Nazionale (PRIN) – CUP N. H53D23005070006. This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

References

Anderton DL, Anderson AB, Oakes M, Fraser MR. 1994. Environmental equity: the demographics of dumping. Demography 31:229–48

Banzhaf, S., Ma, L., & Timmins, C. (2019). Environmental justice: The economics of race, place, and pollution. Journal of Economic Perspectives, 33(1), 185-208.

Been V. 1994. Locally undesirable land uses in minority neighborhoods: disproportionate siting or market dynamics? Yale Law J. 103:1383–422

Bloom, D. E., Canning, D., & Fink, G. (2008). Urbanization and the wealth of nations. Science, 319(5864), 772-775.

Bontadini, F., & Vona, F. (2023). Anatomy of Green Specialisation: Evidence from EU Production Data, 1995–2015. Environmental and Resource Economics, 1-34.

Carvalho, A. C., Carvalho, A., Gelpi, I., Barreiro, M., Borrego, C., Miranda, A. I., & Pérez-Muñuzuri, V. (2006). Influence of topography and land use on pollutants dispersion in the Atlantic coast of Iberian Peninsula. Atmospheric Environment, 40(21), 3969-3982.

Colmer, J., Hardman, I., Shimshack, J., & Voorheis, J. (2020). Disparities in PM2. 5 air pollution in the United States. Science, 369(6503), 575-578.

Cohen, J. P., & Paul, C. J. M. (2005). Agglomeration economies and industry location decisions: the impacts of spatial and industrial spillovers. Regional Science and Urban Economics, 35(3), 215-237.

Deguen, S., & Zmirou-Navier, D. (2010). Social inequalities resulting from health risks related to ambient air quality—A European review. European Journal of Public Health, 20(1), 27-35.

Diekmann, A., & Meyer, R. (2010). Democratic smog? An empirical study on the correlation between social class and environmental pollution. KZfSS Kölner Zeitschrift für Soziologie und Sozialpsychologie, 62, 437-457.

Dong, F., Wang, Y., Zheng, L., Li, J., & Xie, S. (2020). Can industrial agglomeration promote pollution agglomeration? Evidence from China. Journal of Cleaner Production, 246, 118960.

Downey L. 1998. Environmental injustice: Is race or income a better predictor? Soc. Sci. Q. 79:766–78

Downey L. 2006. Environmental racial inequality in Detroit. Soc. Forc. 85:771–96

EEA (2022) Air quality in Europe 2022. Report no. 05/2022.

Ellison, G., & Glaeser, E. L. (1997). Geographic concentration in US manufacturing industries: a dartboard approach. Journal of political economy, 105(5), 889-927.

Ellison, G., Glaeser, E. L., & Kerr, W. R. (2010). What causes industry agglomeration? Evidence from coagglomeration patterns. American Economic Review, 100(3), 1195-1213.

Gillingham, K., & Huang, P. (2021). Racial disparities in the health effects from air pollution: Evidence from ports (No. w29108). National Bureau of Economic Research.

Glatter-Götz, H., Mohai, P., Haas, W., & Plutzar, C. (2019). Environmental inequality in Austria: do inhabitants' socioeconomic characteristics differ depending on their proximity to industrial polluters?. Environmental Research Letters, 14(7), 074007.

Guimaraes, P., Figueiredo, O., & Woodward, D. (2011). Accounting for neighboring effects in measures of spatial concentration. Journal of Regional Science, 51(4), 678-693.

Hajat, A., Hsia, C., & O'Neill, M. S. (2015). Socioeconomic disparities and air pollution exposure: a global review. Current environmental health reports, 2, 440-450.

Hoover, E. M. (1936). The measurement of industrial localization. The Review of Economic Statistics, 162-171.

Jbaily, A., Zhou, X., Liu, J., Lee, T. H., Kamareddine, L., Verguet, S., & Dominici, F. (2022). Air pollution exposure disparities across US population and income groups. Nature, 601(7892), 228-233.

Krugman P.R., 1991a. Increasing returns and economic geography. Journal of Political Economy 99, 483-499.

Maurel, F., & Sédillot, B. (1999). A measure of the geographic concentration in French manufacturing industries. Regional Science and Urban Economics, 29(5), 575-604.

McDuffie, E.E., Martin, R.V., Spadaro, J.V. et al. Source sector and fuel contributions to ambient PM2.5 and attributable mortality across multiple spatial scales. Nat Commun 12, 3594 (2021). https://doi.org/10.1038/s41467-021-23853-y

Mohai, P., Pellow, D., & Roberts, J. T. (2009). Environmental justice. Annual review of environment and resources, 34, 405-430.

Neier, T. (2021). Austrian air–just clean for locals: A nationwide analysis of environmental inequality. Ecological Economics, 187, 107100.

Ostro, B., Malig, B., Broadwin, R., Basu, R., Gold, E. B., Bromberger, J. T., ... & Green, R. (2014). Chronic PM2. 5 exposure and inflammation: determining sensitive subgroups in mid-life women. Environmental research, 132, 168-175.

Ottaviano, G., & Thisse, J. F. (2004). Agglomeration and economic geography. In Handbook of regional and urban economics (Vol. 4, pp. 2563-2608). Elsevier.

Padilla, C. M., Kihal-Talantikite, W., Vieira, V. M., Rossello, P., Le Nir, G., Zmirou-Navier, D., & Deguen, S. (2014). Air quality and social deprivation in four French metropolitan areas—A localized spatio-temporal environmental inequality analysis. Environmental research, 134, 315-324.

Pastor Jr, M., Morello-Frosch, R., & Sadd, J. L. (2005). The air is always cleaner on the other side: Race, space, and ambient air toxics exposures in California. Journal of urban affairs, 27(2), 127-148.

Pun, V. C., Kazemiparkouhi, F., Manjourides, J., & Suh, H. H. (2017). Long-term PM2. 5 exposure and respiratory, cancer, and cardiovascular mortality in older US adults. American journal of epidemiology, 186(8), 961-969.

Raffaelli, K., Deserti, M., Stortini, M., Amorati, R., Vasconi, M., & Giovannini, G. (2020). Improving air quality in the Po Valley, Italy: some results by the LIFE-IP-PREPAIR project. Atmosphere, 11(4), 429.

Richardson, E. A., Pearce, J., Tunstall, H., Mitchell, R., & Shortt, N. K. (2013). Particulate air pollution and health inequalities: a Europe-wide ecological analysis. International journal of health geographics, 12(1), 1-10.

Rüttenauer T. (2018), Neighbours matter: a nation-wide small-area assessment of environmental inequality in Germany. Soc. Sci. Res., 70 (2018), pp. 198-211

Salesse C. (2022). Inequality in exposure to air pollution in France: bringing pollutant cocktails into the picture. ffhal-03882438v2

Soares, J., González Ortiz, A., Gsella, A., Horálek, J., Plass, D. & Kienzler, S. (2022). Health risk assessment of air pollution and the impact of the new WHO guidelines (Eionet Report – ETC HE 2022/10). European Topic Centre on Human Health and the Environment.

Tessum, C. W., Paolella, D. A., Chambliss, S. E., Apte, J. S., Hill, J. D., & Marshall, J. D. (2021). PM2. 5 polluters disproportionately and systemically affect people of color in the United States. Science Advances, 7(18), eabf4491.

Weger, M., & Heinold, B. (2023). Air pollution trapping in the Dresden Basin induced by natural and urban topography. Atmospheric Chemistry and Physics Discussions, 2023, 1-37.

Wolverton, A. (2009). Effects of socio-economic and input-related factors on polluting plants' location decisions. The BE Journal of Economic Analysis & Policy, 9(1).

World Health Organization. (2021). WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. https://iris.who.int/handle/10665/345329. License: CC BY-NC-SA 3.0 IGO

Zeeman, M., Holst, C. C., Kossmann, M., Leukauf, D., Münkel, C., Philipp, A., ... & Emeis, S. (2022). Urban atmospheric boundary-layer structure in complex topography: an empirical 3D case study for Stuttgart, Germany. Frontiers in Earth Science, 10, 840112.

Zhang, Z., Xu, X., Qiao, L., Gong, D., Kim, S. J., Wang, Y., & Mao, R. (2018). Numerical simulations of the effects of regional topography on haze pollution in Beijing. Scientific reports, 8(1), 5504.

Zhu, Y., & Xia, Y. (2019). Industrial agglomeration and environmental pollution: Evidence from China under New Urbanization. Energy & Environment, 30(6), 1010-1026.

Zwickl, K., Miklin, X., & Naqvi, A. (2024). Sociodemographic disparities in ambient particulate matter exposure in Austria. Ecological Economics, 224, 108180.

A. Appendix

Table 6: OLS, regional FE, and provincial FE model results for the correlation between income per capita and PM2.5 in 2013 and 2019.

	1	2	3	4	5	6
ln PM2.5	OLS 2013	OLS 2013	OLS 2013	OLS 2019	OLS 2019	OLS 2019
ln income pc	0.632***	0.374***	0.297***	0.507***	0.267***	0.233***
	(0.129)	(0.0518)	(0.0433)	(0.0956)	(0.0448)	(0.0423)
Fixed effects	no	Regional	Provincial	no	Regional	Provincial
Population Weights	yes	yes	yes	yes	yes	yes
Constant	-3.242***	-0.629	0.247	-2.211**	0.187	0.598
	-1.211	(0.495)	(0.417)	(0.899)	(0.427)	(0.410)
Observations	7,791	7,791	7,791	7,508	7,508	7,508
R-squared	0.271	0.680	0.795	0.252	0.673	0.796

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 7: OLS results including ecoregion dummies.

	1	2	3	4
ln PM2.5	OLS 2013	OLS 2013	OLS 2019	OLS 2019
Padana	0.557***	0.456***	0.471***	0.402***
	(0.0618)	(0.0456)	(0.0622)	(0.0513)
Apennines	-0.0545	-0.0376	-0.0492	-0.0384
	(0.0624)	(0.0467)	(0.0669)	(0.0551)
Tyrrhenian	0.0629	-0.103	0.0276	-0.0994*
	(0.0710)	(0.0657)	(0.0651)	(0.0551)
Adriatic	0.0177	-0.0799	0.000547	-0.0636
	(0.0678)	(0.0556)	(0.0649)	(0.0525)
ln income pc	0.276***	-0.00330	0.157**	-0.0413
	(0.0904)	(0.0803)	(0.0609)	(0.0466)
ln pop. density		0.0951***		0.0733***
		(0.0215)		(0.0187)
ln aggl. (all)		-0.0166		-0.0139
		(0.0205)		(0.0161)
ln aggl. (polluting)		0.0574***		0.0367***
		(0.0115)		(0.0103)
Fixed effects	no	no	no	no
Population weights	yes	yes	yes	yes
Constant	-0.0797	2.004**	0.964	2.444***
	(0.867)	(0.766)	(0.585)	(0.452)
Observations	7,791	7,791	7,508	7,507
R-squared	0.637	0.780	0.657	0.773

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 8: Robustness Check using levels of PM2.5

	1	2
Levels of PM2.5	OLS 2013	OLS 2019
ln income pc	-2.178***	-1.269***
	(0.564)	(0.429)
ln pop. density	0.988***	0.962***
	(0.153)	(0.145)
ln aggl. (all)	0.370**	0.0285
	(0.172)	(0.105)
ln aggl. (polluting)	0.448***	0.255***
	(0.158)	(0.0876)
Population weights	yes	yes
Fixed Effects	provincial	provincial
Clustered SE	provinces	provinces
Constant	33.33***	22.38***
	-4.813	-3.849
Observations	7,791	7,507
R-squared	0.887	0.884

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 9: Robustness Checks using income quartiles.

	1	2	3	4
ln PM2.5	OLS 2013	OLS 2019	OLS 2013	OLS 2019
Q1	0.0918***	0.0616**	1.420***	0.856**
	(0.0268)	(0.0253)	(0.417)	(0.346)
Q2	0.0316*	0.0191	0.396	0.221
	(0.0172)	(0.0163)	(0.279)	(0.235)
Q3	0.0174	0.0112	0.170	0.104
	(0.0112)	(0.00901)	(0.170)	(0.121)
ln pop. density	0.0842***	0.0904***	1.095***	1.023***
	(0.00983)	(0.0102)	(0.143)	(0.134)
ln aggl. (all)	0.0156	-0.00744	0.204	-0.0396
	(0.0108)	(0.00789)	(0.148)	(0.0971)
ln aggl. (polluting)	0.0261***	0.0184***	0.480***	0.266***
	(0.00915)	(0.00545)	(0.158)	(0.0844)
Population weights	yes	yes	yes	yes
Fixed Effects	provincial	provincial	provincial	provincial
Clustered SE	provinces	provinces	provinces	provinces
Constant	2.317***	2.192***	12.44***	10.00***
	(0.0508)	(0.0575)	(0.970)	(0.848)
Observations	7,791	7,507	7,791	7,507
R-squared	0.872	0.874	0.887	0.885

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Our Working Papers are available on the Internet at the following address:
https://www.feem.it/pubblicazioni/feem-working-papers/

"NOTE DI LAVORO" PUBLISHED IN 2024

1. A. Sileo, M. Bonacina, The automotive industry: when regulated supply fails to meet demand. The Case of Italy
2. A. Bastianin, E. Mirto, Y. Qin, L. Rossini, What drives the European carbon market? Macroeconomic factors and forecasts
3. M. Rizzati, E. Ciola, E. Turco, D. Bazzana, S. Vergalli, Beyond Green Preferences: Alternative Pathways to Net-Zero Emissions in the MATRIX model
4. L. Di Corato, M. Moretto, Supply contracting under dynamic asymmetric cost information
5. C. Drago, L. Errichiello, Remote work admist the Covid-19 outbreak: Insights from an Ensemble Community-Based Keyword Network Analysis
6. F. Cappelli, Unequal contributions to CO2 emissions along the income distribution within and between countries
7. I. Bos, G. Maccarrone, M. A. Marini, Anti-Consumerism: Stick or Carrot?
8. M. Gilli, A. Sorrentino, The Set of Equilibria in Max-Min Two Groups Contests with Binary Actions and a Private Good Prize
9. E. Bachiocchi, A. Bastianin, G. Moramarco, Macroeconomic Spillovers of Weather Shocks across U.S. States
10. T. Schmitz, I. Colantone, G. Ottaviano, Regional and Aggregate Economic Consequences of Environmental Policy
11. D. Bosco, M. Gilli, Effort Provision and Incentivisation in Tullock Group-Contests with Many Groups: An Explicit Characterisation

Fondazione Eni Enrico Mattei

Fondazione Eni Enrico Mattei
Corso Magenta 63, Milano – Italia

Tel. +39 02 403 36934

E-mail: letter@feem.it
www.feem.it

Fondazione Eni Enrico Mattei