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Fondazione Eni Enrico Mattei

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Summary

This study offers the first analysis of environmental and climate inequalities at the census tract level in Italy, providing valuable insights into spatial patterns of environmental and social vulnerability. The results highlight significant environmental inequality related to exposure to air pollution (PM2.5), as well as climate inequality linked to thermal discomfort (measured by the Discomfort Index). Among all regions, the Padana Valley stands out as the most severely affected by both stressors, marking its population as particularly vulnerable—regardless of their socioeconomic status.

At the national level, the analysis identifies a negative correlation between exposure to environmental stressors and income proxies, and a positive correlation with the presence of non-European foreign residents. These associations remain robust even when the focus shifts to census tracts within the same municipality, suggesting that environmental and social inequalities persist not only across regions but also within local urban contexts.

Keywords: Environmental inequality, Environmental justice, Air pollution, Socioeconomic status, Climate Justice, Discomfort Index

JEL classification: Q53, Q56, I14, C21

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An Empirical Analysis of Environmental and Climate Inequalities across Italian census tracts

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Abstract

This study offers the first analysis of environmental and climate inequalities at the census tract level in Italy, providing valuable insights into spatial patterns of environmental and social vulnerability. The results highlight significant environmental inequality related to exposure to air pollution (PM2.5), as well as climate inequality linked to thermal discomfort (measured by the Discomfort Index). Among all regions, the Padana Valley stands out as the most severely affected by both stressors, marking its population as particularly vulnerable—regardless of their socioeconomic status.
At the national level, the analysis identifies a negative correlation between exposure to environmental stressors and income proxies, and a positive correlation with the presence of non-European foreign residents. These associations remain robust even when the focus shifts to census tracts within the same municipality, suggesting that environmental and social inequalities persist not only across regions but also within local urban contexts.

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1. Introduction

Climate change and air pollution represent two significant global challenges, with a profound impact on population health and the potential for innovative solutions (Kinney, 2018). In particular, urbanization and climate change are two global trends which, when considered together, give rise to concerns regarding their impact on the health of urban populations. On the one hand, rising urbanization is linked to anthropogenic pollution, especially air pollution, which is currently the most significant environmental threat in the European Union (EEA, 2022). On the other hand, CO2 emissions are affecting temperatures, causing heatwaves to be more frequent and exposing individuals to related health concerns. The combined impact of these trends on population health is a matter of concern, particularly if the distribution of environmental and climatic stressors is inequitable, often burdening socioeconomically disadvantaged communities disproportionately.

Environmental inequalities considering the distribution of pollution and their relative mechanisms have been the subject of academic debate for several decades in both the EU (Drigo 2024; Neier 2021; Ruttenauer 2019; Glatter Gotz et al, 2018; Laurent, 2011) and the US (Banzhaf et al., 2019; Moai et al., 2009; Colmar et al., 2019; Jibaly et al., 2019; Tessum et al., 2021). This has facilitated the identification of vulnerable segments of the population and the possibility to draft targeted policy. However, the study of climate inequalities has lagged behind these developments.

A number of examples can be drawn from the United States, where Harlan et al (2006) were the first to highlight the disproportionate exposure to urban heat as a social justice issue. A comparison of the patterns of urban heat in the city of Phoenix with the socio-demographic composition of the city revealed significant associations between increased temperature and neighbourhoods with weaker social networks, lower median income, and higher proportions of Hispanic residents. More recent studies have sought to determine whether racial and ethnic minority groups are disproportionately represented in neighborhoods experiencing the highest frequency of heat waves, and have examined the spatial distribution of these events (Hoffman et al., 2020; Manware et al., 2022; Dialesandro et al., 2021; Renteria et al., 2022; Hsu et al., 2021). Overall, there is a general lack of an empirical analysis of the distribution of compounding effects of heath stress and pollution stress, especially in European context (Mashhoodi 2024).

This study aims to contribute to the growing body of European environmental and climate justice research by assessing whether elevated levels of heat-related stress—measured through the Discomfort Index (DI)—and air pollution (PM2.5) are inequitably distributed across Italian census tracts with respect to socioeconomic status, race/ethnicity, and age. The aim is to answer the following question What are the intersections between patterns of environmental and climate inequalities at the census tract level? Do communities most exposed to PM2.5 also face greater risks of climate-related heat stress?

2. Conceptual Framework

Although there may be some areas of overlap between the approaches of environmental justice (EJ) and climate justice (CJ), they ultimately originate from slightly different theoretical frameworks. The EJ framework addresses localised environmental exposures, such as air pollution, whereas the CJ framework considers global phenomena with localised impacts, such as heat stress. As both EJ and CJ concentrate on the disparate impacts on vulnerable populations, their combination permits an investigation of the cumulative effects of air pollution and climate-related stressors on marginalised groups.

This study builds on the previous environmental justice framework as used in the previous literature (Drigo A. 2024(a), Glatter Glots et al 2019, Banzhaf et al 2019, Mohai 2009, Neier 2021, Zwickl et al 2024) according to which, higher level of pollution burdens are correlated to the presence of socioeconomic vulnerabilities. Belonging to lower income levels, belonging to minorities – which in Europe is linked to belonging to the foreigners groups (Glatter Glotz 2019, Ruttenauer 2019, Neier 2019, Drigo A. 2024(a)) are considered main vulnerabilities. Indeed, the foreigner population may be constrained in its ability to escape environmental hazards due to limited participation in politics or cultural/linguistic barriers (Banzhaf et al. 2019; Zwickl et al. 2014).
Therefore it is expected that more vulnerable population relates to higher levels of environmental stress, as follows:

$$Environmental\ Stress = f(Low\ Income, Foreigners, Education, Employment\ Status, Age\ Categories)$$

Following Mitchell and Chakraborty (2014), the EJ framework as defined can be applied to analyze localized climate change impacts and thermal inequality. Therefore, the same conceptual framework is used in the case of higher temperature as environmental stressors.
I add the alleviating/worsening effects of land morphology (Drigo A., 2024 (b)) which in the country of Italy have proven to play a role in altering the ventilation efficiency and consequently the pollution exposure. The effects that different land morphologies have on the intensity of the environmental stressors is taken into account in the framework, as described in the diagram below (Figure 1) which integrates all the core elements. Initially, the socioeconomic drivers of each environmental stressor will be evaluated separately to ascertain whether there are similarities in the sociodemographic characteristics that define the most vulnerable population across census tracts. Subsequently, an analysis will be conducted to ascertain whether there is an overlap between the two stressors. This will entail the computation of an outcome that takes into account the combined health burden.

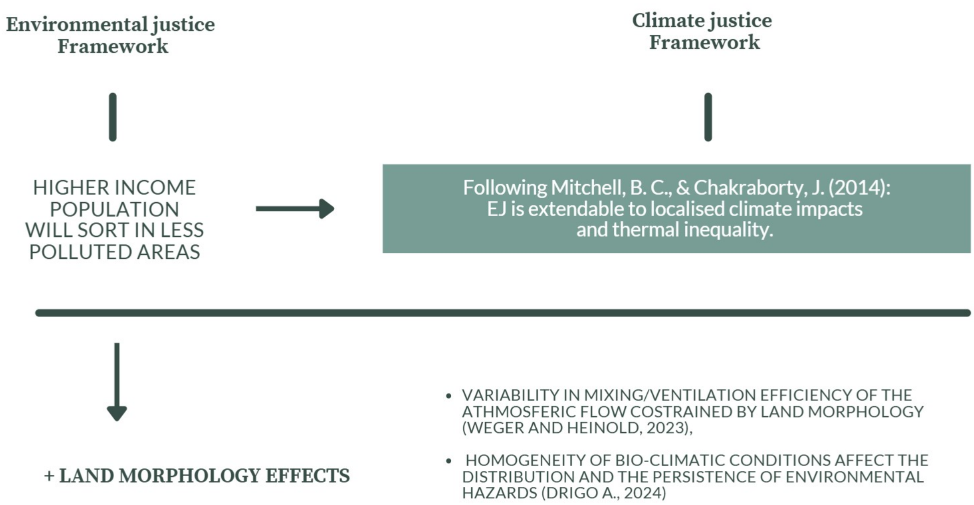

Figure 1: Conceptual Framework

3. Data

3.1. Dependent Variables

To investigate environmental inequalities, the study adopts PM2.5 distribution data from Stafoggia et al 2019 at 0.01x0.01° (1x1km) grids level covering the country of Italy. PM2.5 average annual concentration at the census tracts level are derived from the grids format, calculating the mean of the grids within the census borders. PM2.5 has been chosen as it is one of the most dangerous pollutants for human health (EEA, 2022).
To investigate climate inequalities, the discomfort index (DI) is considered one of the best indices to estimate, in a single value, the effect of temperature and humidity on the sensation of thermal stress perceived by the human body, and therefore is adequate to measure heath stress on summer season. In fact, incorporating humidity largely improves the predictive capacity for heat-related mortality compared to relying solely on air temperature (Guo et al. 2024).
DI (Thom, 1959) comprehensively considers the environmental temperature and humidity. The source of the DI used in this analysis is ERA5 dataset downscaled @2.2km over Italy described in the paper Raffa et al. (2021) produced in the HIGHLANDER (HIGH performance computing to support smart LAND sERvices) project, which is funded by the Connecting European Facility (CEF) Telecommunications sector under agreement number INEA/CEF/ICT/A2018/1815462. Provided by CMCC DDS. The discomfort conditions represented by the DI are as described un Table 1 (Zheng et al. 2021). This study considers the third and the fourth thresholds with the aim to keep into consideration only situations that could be dangerous for at least 50% of the population.

3.2. Independent Variables

Inequities in the distribution of environmental stressors were analyzed using a set of demographic and socioeconomic variables from ISTAT 2021 census records. The selection of variables was guided, in part, by previous studies of environmental justice (Drigo A., 2024 (a, b); Neier 2021) and urban heat mortality (Basu et al., 2008; Harlan et al 2006; Chakraborty 2024). In this literature, individuals of lower socioeconomic status, the children and elders, and racial/ethnic minorities have been identified as being particularly vulnerable to the health effects of environmental stressors. Demographic variables include both the percentage of population aged five years and under, as well as those aged sixty-five or more years, percentage of foreigners, education levels. Additionally, population density is considered as a further control variable, calculated as the number of people per square kilometer of the land area of census tracts.

Table 1: D.I. Threshold Levels

Level	**D.I. (°)**	**Discomfort Index**
1	DI < 21	No discomfort
2	21 DI 24	Less than 50% feels discomfort
3	24 DI 27	More than 50% feels discomfort
4	27 DI 29	Most of the population feels discomfort
5	29 DI 32	Everyone feels severe stress
6	DI 32	State of medical emergency

3.3. Proxy of income

In Italy, census tracts do not provide data on income, necessitating the use of alternative indicators to estimate economic conditions. One such proxy is the age structure within geographical units, particularly focusing on individuals aged 35-55 years (Germani et al., 2014). This age group is often associated with higher earning potential, given their career progression and accumulation of professional experience. Employment rates, typically analyzed by the OECD across four broad age categories—15-64 (working-age population), 15-24 (early career entrants), 25-54 (prime working age), and 55-64 (pre-retirement)—further support the relevance of the 35-55 age class as an effective income proxy. By concentrating on this demographic, the variable "proxy income" aims at inferring relative income levels in areas where direct financial data is unavailable.

3.4. Land Morphology

Italy has a total land area of 307,635 square kilometers and diverse geoclimatic regions. All Italian census tracts have been classified into Ecoregions by 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 the categorization 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 and ecosystems.

4. Descriptive Statistics

4.1. Summertime DI

Table 2 provides descriptive statistics for the maximum Discomfort Index (maxDI) during the months of June, July, and August across 451,307 census tracts observations. For June, the mean maxDI is 25.537, with a standard deviation of 1.54, a minimum value of 12.168, and a maximum of 27.854. For July, the mean maxDI increases slightly to 25.728, with a lower standard deviation of 1.441, a minimum of 11.747, and a maximum of 27.44. For August, the mean maxDI is 25.574, with a standard deviation of 1.479, a minimum of 10.612, and a maximum of 27.592.
These statistics indicate that thermal discomfort is relatively consistent across the summer months, with July exhibiting slightly higher average discomfort levels but slightly less variability compared to June and August. The minimum values suggest a subset of areas experiencing significantly lower thermal discomfort, while the maximum values are relatively stable, highlighting regions with consistently high thermal stress. In Figure 2, distribution of D.I. higher

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
maxDI june	451307	25.537	1.54	12.168	27.854
maxDI july	451307	25.728	1.441	11.747	27.44
maxDI august	451307	25.574	1.479	10.612	27.592

Table 2:
Summary statistics for the maximum Discomfort Index (DI) in June, July, and August.

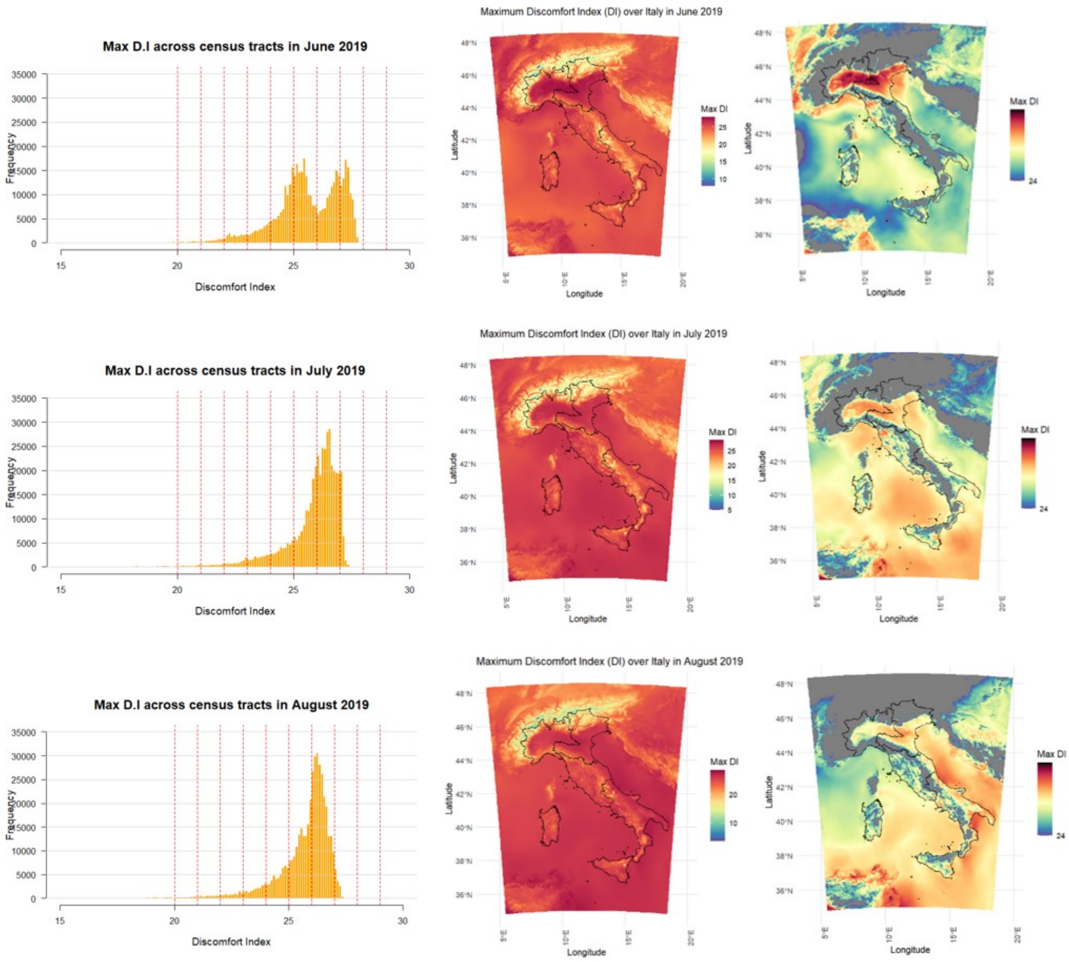

Figure 2: Discomfort Index distribution across months of summertime 2019.

than the value of 24 is seen persistently in the Padana Valley (panels on the right).

4.2. PM2.5 annual levels

Variable	Obs	Mean	Std. Dev.	Min	Max
mean pm25	451307	14.602	4.298	4.592	26.339

Table 3: Summary statistics for PM2.5

Table 3 provides descriptive statistics for the variable mean PM2.5 across 451,307 census tracts, representing the average levels of particulate matter (PM2.5) in the analyzed dataset. The mean value of PM2.5 is 14.602, with a standard deviation of 4.298, indicating moderate variability around the mean. The minimum recorded value of PM2.5 is 4.592, while the maximum reaches 26.339. These statistics suggest a wide range of air pollution levels across the observed units, with some areas (Padana Valley) experiencing significantly higher concentrations of PM2.5.

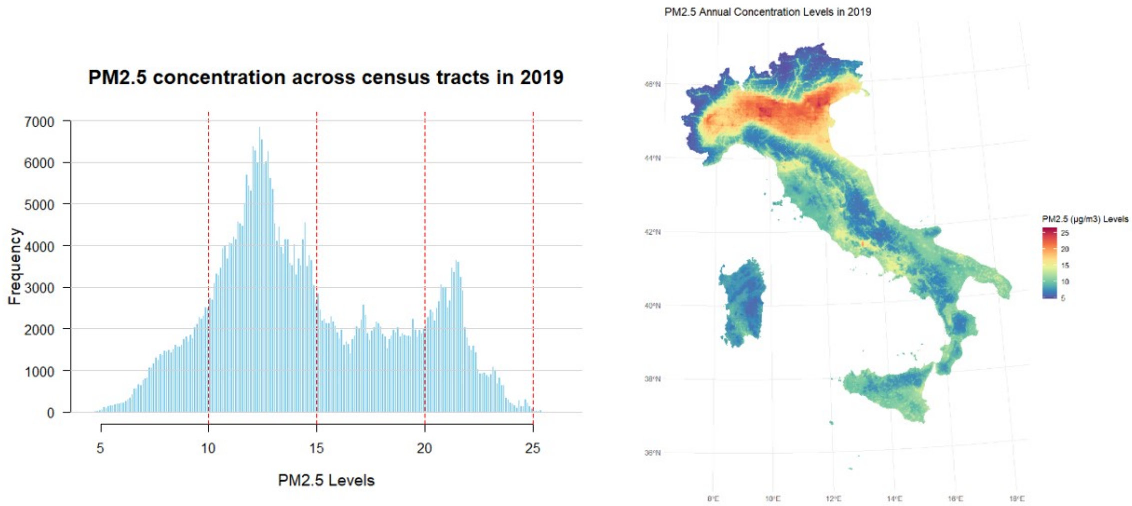

Figure 3: Distribution of PM2.5 conconetration (left). Map of PM2.5 distribution (right).

4.3. Socioeconomic variables

Table 4 provides descriptive statistics for demographic and socioeconomic variables across 451,307 observations. The mean census tracts population is 130.798, with a high standard deviation of 209.458, reflecting substantial variation in population size across the census tracts -the minimum value is 1, while the maximum is 8,545. On average, 6% (mean = 0.06) of the population are extra-European foreigners, with a standard deviation of 0.124. The share ranges from 0 to 1, indicating areas with no foreign residents and areas where the entire population is composed of extra-EU foreigners. The average share of children is 3.2% (mean = 0.032), with a standard deviation of 0.044, ranging from 0 to 1. Elders make up 13.7% (mean = 0.137) of the population on average, with a standard deviation of 0.15, also ranging from 0 to 1. The mean share of unemployed individuals is 50.2% (mean = 0.502), with a standard deviation of 0.184, ranging from 0 to 1. On average, 85.9% (mean = 0.859) of the population have not graduated, with a standard deviation of 0.138, and a range from 0 to 1. These statistics reveal notable heterogeneity in population demographics and socioeconomic characteristics, with particular variation in population size, unemployment, and education levels.

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
Population	451307	130.798	209.458	1	8545
Share of foreigner Extra UE	451307	0.06	0.124	0	1
Share of children	451307	0.032	0.044	0	1
Share of elders	451307	0.137	0.15	0	1
Share of unemployed	451307	0.502	0.184	0	1
Share of not graduated	451307	0.859	0.138	0	1

Table 4: Descriptive statistics of socioeconomic variables

4.4. Ecoregions

Figure 4 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.

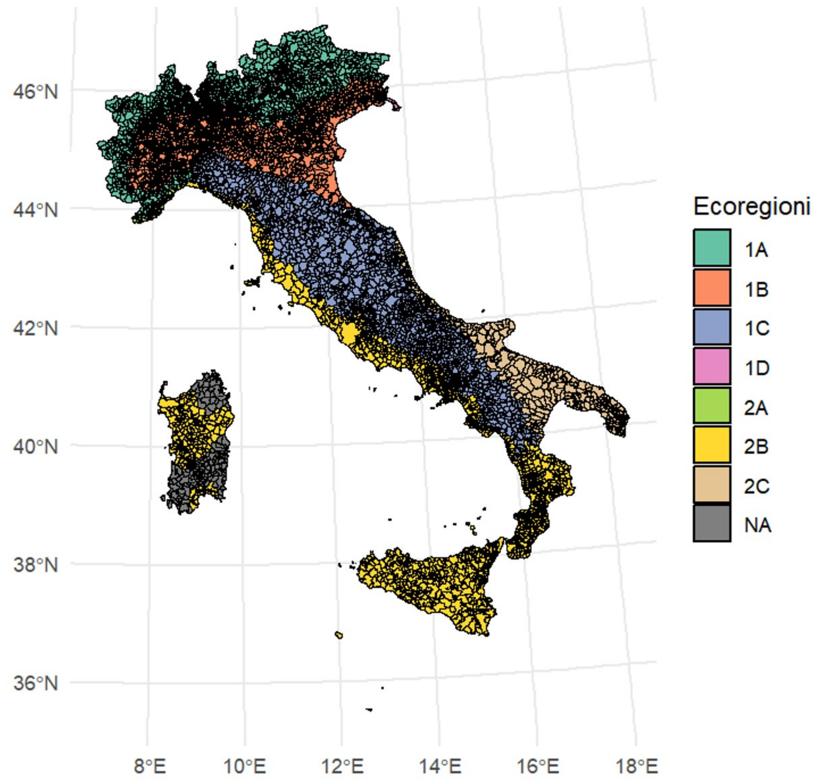

Figure 4: Map of Ecoregion. Note: 1A Alps ecoregion, 1B Padana ecoregion, 1C Apennines Ecoregion, 1D Illiric ecoregion, 2A Provenzale Ligure ecoregion, 2B Tyrrhenian ecoregion, 2C Adriatic ecoregion. The map does not show the municipalities that were excluded from the analysis.

5. Empirical Strategy

The goal is to investigate the correlations between PM2.5, D.I. and the socioeconomic characteristics at the census tract level, respectively. By gradually introducing fixed effects and ecoregion controls, the strategy tests what outlined in the conceptual framework. Since these empirical studies are still in the development phase, the optimal empirical method for best practices remains uncertain. However, this study employs OLS with clustered errors, which is widely regarded as an acceptable baseline in recent literature (Zwickl et al. 2024). I perform a logarithmic transformation on the dependent variable and on the income proxy to reduce skewness and facilitate the interpretation of estimated coefficients.

5.1. Multivariate Model

$$\ln PM2.5_{c,t} = \alpha + \beta_1 \text{ share of foreigners}_{c,t-1} + \beta_2 \text{ proxy income}_{c,t-1} + \gamma X'_{c,t-1} + \varepsilon_{c,t}$$
$$\ln \text{Max DI summertime}_{c,t} = \alpha + \beta_1 \text{ share of foreigners}_{c,t-1} + \beta_2 \text{ proxy income}_{c,t-1} + \gamma X'_{c,t-1} + \varepsilon_{c,t},$$
if at least 1 day of $DI > 27$

Initially, I explored the correlation between each environmental stressors (PM2.5, D.I.) and the socioeconomic variables separately. The most relevant independent variables to answer the questions addressed in the theoretical framework are the share of foreigners and the proxy of income, which identify situation of high social vulnerability. A vector of other socioeconomic controls (share of children, share of elders, share of people without a higher education, share of unemployed) is added for each census c at time t. The vector of control includes population density to capture the influence of higher population concentration on environmental stressors. This model reflects the structure of standard environmental justice OLS specification.
For the D.I. OLS model, the model considers only the census tracts which had at least one day of discomfort index above 27. The objective of the present study is to incorporate observational data in which at least the 50% of the population experienced discomfort for a period of at least one day during the summer months. The rationale underpinning this approach is to ensure that the focus remains firmly on observations in areas where there is unequivocal evidence of thermal stress experienced by the population.

5.2. Controlling for Ecoregion effects

$$\ln \text{Max DI summertime}_{c,t} = \alpha + \beta_1 \text{ share of foreigners}_{c,t-1} + \beta_2 \text{ proxy income}_{c,t-1} + \gamma X'_{c,t-1} + \delta_k \theta'_k + \varepsilon_{c,t}$$

Building on Drigo (2024, b), I attempt to mitigate the risk of improperly attributing environmental stressors variations to other variables when they might be primarily driven by land morphology.
To this aim I add Ecoregion controls, where θ_k is the ecoregion dummy variable that takes the value of 1 if the observation belongs to ecoregion k and 0 otherwise. δ_k represents the coefficient for the fixed effect of the ecoregion k. These dummy variables account for the pollution dispersion capacity and the climatic features specific to the ecoregion in which the observations are situated.

5.3. Municipality fixed effects

$$\ln PM2.5_{c,t} = \alpha + \beta_1 \text{ share of foreigners}_{c,t-1} + \beta_2 \text{ proxy income}_{c,t-1} + \gamma X'_{c,t-1} + \rho_m + \varepsilon_{c,t}$$
$$\ln \text{Max DI summertime}_{c,t} = \alpha + \beta_1 \text{ share of foreigners}_{c,t-1} + \beta_2 \text{ proxy income}_{c,t-1} + \gamma X'_{c,t-1} + \rho_m + \varepsilon_{c,t}$$

I ultimately employ an alternative model in which I substitute ecoregion indicators with fixed effects representing administrative provincial factors (ρ_m). This approach effectively addresses unobservable and time-invariant features, including land characteristics, among the controlled attributes. Additionally, examining within-municipality variation allows to uncover localized effects that may not be apparent when looking at broader national trends.
All models are weighed by census population.

6. Results

6.1. Environmental Justice Gap

Table 5 shows the results of each model. The correlation of PM2.5 and share of foreigners and proxy of income follows the direction of environmental justice literature in terms of sign and significance. That is to say that higher levels of pollution are positively correlated with higher presence of foreigner extra UE across census tracts, meaning that this faction of population, which is considered more vulnerable since it often faces cultural/linguistic barriers to integration and to policy representation, correlates with this environmental burden. The coefficient remains positive and significant across all the models. The magnitude decreases with the introduction of the ecoregion dummies, which capture a large part of the relationship, as previously seen in Drigo 2024(b). Looking at the proxy of income, the correlation in model 1, as in model 3, remains negative, indicating that higher income census are correlated with less pollution level, as pictured in the theoretical framework. Interestingly, the environmental justice gap is observed in Model 1 and 3. In model 1, accounting for socioeconomic controls and population weights, the presence of foreigners and lower income population is correlated to higher levels of pollution. However, once ecoregion dummies are taken into account, the relationship between the proxy of income and pollution levels lose significance. This suggests that different morphological characteristics of the areas in which people live 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 regions, following previous results from Drigo 2024(b).

Another approach to account for unobservable features of the land is by including municipalities dummies. Indeed, Model 3 is a fixed effects model for municipalities features to provide robustness to the previous specification (Table 5, column 2). 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 national trends. Once fixed effects are taken into account, the coefficient of income pc becomes significance and keeps a negative sign. This reveals the presence of an environmental justice gap that emerges within municipalities, once accounted for the distribution of socioeconomic vulnerabilities and the unobservable characteristics of the municipalities. The theoretical interpretation suggests that richer and lower-income census tracts in the same city could encounter dissimilar levels of pollution, with higher-income areas being less exposed. The coefficient of the share of foreigners is robust to the inclusion of municipality fixed effects, suggesting that within cities census tracts with a higher presence of extra-Europeans are more polluted (Drigo 2024 (a)). Model 3 is the preferred specification – given the R2 higher explanatory power – and quantifying the relationship between pollution and income, a 1% increase in the proxy of income variable is correlated to a -0.22% decrease in pollution levels. Whereas if the share of foreigners extra EU increases by 0.10, PM2.5 is expected to change by +5.6%.

6.2. Climate Justice Gap

Table 6 shows the results of thermal inequality across the 98,303 census tracts which had at least one day in the summertime with a Discomfort Index higher than 27. Similarly to the case of pollution levels, here the correlation between Discomfort Index and socio-economic factors shows a comparable picture for what concerns income levels and foreigners presence.

ln PM2.5	Model 1	Model 2	Model 3
share_foreigners (EXTRAUE)	0.667***	0.140***	0.559***
	(0.0481)	(0.0168)	(0.0491)
proxy income	-0.280***	0.00460	-0.220***
	(0.0585)	(0.00546)	(0.0383)
Padana Valley		0.451***	
		(0.0156)	
Apennini		-0.0390**	
		(0.0168)	
Tyrrhenian		-0.0302	
		(0.0203)	
Adriatic		-0.00988	
		(0.0150)	
SE controls	yes	yes	yes
Fixed Effects	no	no	municipality
Constant	3.417***	2.803***	3.244***
	(0.0968)	(0.0280)	(0.0423)
Observations	443,055	443,055	443,055
R-squared	0.260	0.630	0.350

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

Table 5: Main Results OLS. Air Pollution.

Indeed, model 1 and model 3 show an income coefficient negative sign, meaning that there is a climate justice gap concerning income. This result is valid even between municipalities. In addition, the higher the heat stress, the higher the presence of extra Europeans in the census tracts, nationwide and within census tracts. The relevance of the ecoregion features is highlighted by the coefficient of Model 2. Keeping in mind that the baseline is the Alps, the sign of the coefficient are unequivocally picturing the Padana valley as the one capturing most of the correlation. The mere fact of being in the Padana plain corresponds to approximately 0.4% higher thermal stress to which the population is exposed compared to the baseline. In the preferred model (Model 3) a climate justice gap is shown within municipalities, where census tracts with lower income and higher presence of foreigners are more stressed by heath in summertime. Indeed, an increase of 10% in income is related to a decrease of -0.06% in Discomfort Index, and an increase of 0.10 in the share of foreigners to a +0.05%. Although the coefficients display relatively modest magnitudes, they nonetheless suggest several potentially promising directions for future research in this field.

6.3. Compounded Environmental Stressors

To analyze the impact of both environmental stressors, two variables— air pollution (PM2.5) and the Discomfort Index (D.I.)— were normalized, and their distributions were divided into quartiles. This approach allows for a comparative analysis of environmental stress across census tracts. Particular attention was given to census tracts within the highest quartile of both stressor distributions, representing the most affected areas. Specifically, this subset includes census tracts falling within the 4th quartile of the normalized PM2.5 distribution and simultaneously within the 4th quartile of the maximum D.I. distribution. These areas are characterized by the highest levels of air pollution and thermal discomfort, making them critical focal points for studying cumulative environmental burdens and their potential effects on public health. Table 3 shows the OLS results for the combined environmental stressors where the two variables have been summed up, allowing for the two stressors to be substitutes among each other. Table 4 shows the OLS results for the multiplication of the two variables, allowing for complementarity between the two stressors. The coefficients of the two tables (refer to Tables 7 and 8 for substitutes and complementarities, respectively) show comparable coefficients in terms of magnitude and signs. While there is not an environmental justice gap at the level of the combined environmental stressors nationwide, there is an environmental justice gap across census tracts within municipalities (model 3, Table 7, Table 8). Results suggest that census tracts with higher presence of foreigners and lower income are the ones more environmentally stressed. Looking at the results of Table 7, if the share of foreigners increases of 0.10, the environmental stress is expected to increase by 1.9, when the two stressors (air pollution and heath stress) are considered substitutes. If income increases by 10% environmental stress is expected to lower by 0.012.

Table 8 (column 3) instead shows that an increase of the share of foreigners of 0.10 is related to an increase of 1.8 environmental stress. Whereas if income increases by 10% environmental stress is expected to lower by -0.012.

7. Discussion and Conclusions

This descriptive study represents the first attempt to analyze environmental and climate inequalities in Italy at such a fine spatial resolution, offering critical insights into patterns of environmental and social vulnerability. The findings reveal the presence of an environmental

ln Max DI	Model 1	Model 2	Model 3
share_foreigner EXTRAUE	0.0141***	0.0104**	0.00468***
	(0.00459)	(0.00434)	(0.00125)
Proxy income	-0.00696***	-8.40e-05	-0.00603***
	(0.00224)	(0.00295)	(0.000953)
Padana Valley		0.00399***	
		(0.00106)	
Apennini		-0.00241**	
		(0.00120)	
Tyrrhenian		-0.00292**	
		(0.00127)	
Adriatic		-0.00112	
		(0.00139)	
SE controls	yes	yes	yes
Fixed effects	no	no	municipality
Constant	3.325***	3.315***	3.308***
	(0.00888)	(0.00775)	(0.00189)
Observations	98,303	98,303	98,303
R-squared	0.134	0.223	0.510

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

Table 6: Main results OLS. Heat Stress.

Env. Stress	Model 1	Model 2	Model 3
share_foreigner (EXTRA UE)	0.454***	0.454***	0.197***
	(0.153)	(0.153)	(0.0608)
proxy income	-0.0922	-0.0852	-0.128**
	(0.111)	(0.110)	(0.0564)
SE controls	yes	yes	yes
Fixed effects	no	no	municipality
Ecoregions dummies	no	yes	no
Constant	2.979***	2.914***	2.480***
	(0.215)	(0.215)	(0.176)
Observations	85,487	85,487	85,487
R-squared	0.048	0.053	0.387

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

Table 7: OLS results. Combined Environmental Stressors.

Env. Stressors	Model 1	Model 2	Model 3
share_foreigner (EXTRA UE)	0.556***	0.555***	0.183***
	(0.201)	(0.200)	(0.0618)
Proxy income	-0.0762	-0.0677	-0.126**
	(0.126)	(0.126)	(0.0563)
SE controls	yes	yes	yes
Fixed Effects	no	no	municipality
Ecoregions	no	yes	no
Constant	2.018***	1.914***	1.374***
	(0.305)	(0.301)	(0.166)
Observations	85,487	85,487	85,487
R-squared	0.062	0.065	0.415

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

Table 8: OLS Results. Combined Environmental Stressors.

justice gap, particularly when air pollution (PM2.5) is considered, and a climate justice gap associated with thermal discomfort (Discomfort Index). Census tracts with a higher proportion of extra-European foreigners and lower-income populations experience disproportionately higher levels of PM2.5 and thermal discomfort, respectively. The Padana Valley emerges as the ecoregion most severely impacted by these stressors, identifying its residents as highly vulnerable, irrespective of income levels or foreigner status. The annual mean of PM2.5 concentration level is 19.6 mg/m^3 whereas the maximum D.I. registered is 27.8°, the highest measured across the entire country. Of the 99,980 census tracts which registered at least one day with a D.I. higher than 27°, the 82% is located in the Padana Valley. At the national level, the study highlights an inverse correlation between income and exposure to environmental stressors, alongside a positive correlation with the presence of extra-European foreigners. These relationships persist when focusing on census tracts within the same municipality, underscoring the persistence of these inequalities. By identifying these inequalities, the study provides a valuable foundation for developing targeted mitigation and adaptation policies that address both environmental and climate stressors, ultimately advancing environmental and climate justice across Italy.

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A. Appendix

A.1. Descriptive statistics of Ecoregions

Code	**Denomination**	**N° of Municipalities**	**Surface (Km^2)**	**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	438,200	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

Table 9: Ecoregion Statistics and Characteristics

A.2. Robustness Checks

levels PM2.5	Model 1	Model 2	Model 3	Model 4
share_foreignerEXTRAUE	10.35***	3.001***	8.525***	0.600***
	(0.879)	(0.376)	(0.766)	(0.0500)
proxy income	-4.785***	0.643	-3.827***	-0.153***
	(0.980)	(0.392)	(0.583)	(0.0396)
Padana Valley		5.352***		
		(0.191)		
Apennini		-1.378***		
		(0.179)		
Tyrrhenian		-1.776***		
		(0.267)		
Adriatic		-1.788***		
		(0.179)		
SE controls	yes	yes	yes	yes
Fixed effects	no	no	municipality	municipality
Constant	25.89***	19.08***	22.92***	3.279***
	(1.757)	(0.784)	(0.667)	(0.0338)
Observations	443,055	443,055	443,055	443,055
R-squared	0.266	0.730	0.376	0.354

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

Table 10: OLS Results with PM2.5 in levels. Model 4 adopts the share of graduated as a proxy of income. The education variable is the share of no schooling people, indicating people who have the ability to read and write but not years of proper schooling.

Levels Max DI summertime	Model 1	Model 2	Model 3	Model 4
share_foreignerEXTRAUE	0.385***	0.284**	0.128***	0.00521***
	(0.126)	(0.119)	(0.0342)	(0.00130)
proxy income	-0.189***	-0.00177	-0.164***	-0.00509***
	(0.0612)	(0.0806)	(0.0260)	(0.00187)
Padana Valley		0.109***		
		(0.0290)		
Apennini		-0.0658**		
		(0.0328)		
Tyrrhenian		-0.0794**		
		(0.0347)		
Adriatic		-0.0304		
		(0.0378)		
SE controls	yes	yes	yes	yes
Fixed Effects	no	no	municipality	municipality
Constant	27.78***	27.51***	27.33***	3.311***
	(0.243)	(0.212)	(0.0513)	(0.00172)
Observations	98,303	98,303	98,303	98,303
R-squared	0.134	0.222	0.511	0.510

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

Table 11: OLS Results with Max D.I. in the summertime in levels. Model 4 adopts the share of graduated as a proxy of income. The education variable is the share of no schooling people, indicating people who have the ability to read and write but not years of proper schooling.

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