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Summary

The implementation of environmental policies varies substantially across geographical areas. This paper proposes a conceptual and methodological framework—adapted from the health economics literature— to assess equity in the allocation of environmental policy effort. We define "environmental care" as the set of local policy interventions aimed at improving environmental quality within an area, and evaluate its distribution relative to environmental need. Using direct and indirect standardization techniques, we measure horizontal inequity (unequal care among areas with similar need) and vertical inequity (differential care in response to differing needs). Applying this framework to traffic-related air pollution policies in Italian municipalities from 2012 to 2021, we find that the observed reduction of overall inequality in environmental care is mostly driven by a decline in horizontal inequity. However, we find evidence of persistent socioeconomic disparities, with lower-income municipalities receiving disproportionately less policy effort relative to their environmental needs.

Keywords: environmental equity; environmental inequality; air pollution, distributive justice

JEL Classification: Q53, Q58, R58

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Measuring equity in environmental care: methodology and an application to air pollution

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Abstract

The implementation of environmental policies varies substantially across geographical areas. This paper proposes a conceptual and methodological framework—adapted from the health economics literature—to assess equity in the allocation of environmental policy effort. We define "environmental care" as the set of local policy interventions aimed at improving environmental quality within an area, and evaluate its distribution relative to environmental need. Using direct and indirect standardization techniques, we measure horizontal inequity (unequal care among areas with similar need) and vertical inequity (differential care in response to differing needs). Applying this framework to traffic-related air pollution policies in Italian municipalities from 2012 to 2021, we find that the observed reduction of overall inequality in environmental care is mostly driven by a decline in horizontal inequity. However, we find evidence of persistent socioeconomic disparities, with lower-income municipalities receiving disproportionately less policy effort relative to their environmental needs.

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1 Introduction

Environmental justice has been a central focus in environmental economics, with research demonstrating that, in many cases, socioeconomically disadvantaged communities and minority groups disproportionately bear the burden of environmental hazards (Mohai et al., 2009, Boyce et al., 2016, Banzhaf et al., 2019, Mansur and Sheriff, 2021, Hausman and Stolper, 2021, Sheriff, 2024). These groups often live, work, and study in areas with higher pollution levels and poorer environmental quality, restricting their fundamental right to a safe and healthy environment. Recognized as unjust, these disparities—commonly referred to as environmental inequalities—have prompted governmental agencies to allocate resources to mitigate their effects to gain political support (Andor et al., 2022).

However, an equally critical yet unexplored dimension concerns geographical inequalities in environmental policy provision. The implementation of policies aimed at mitigating and protecting against environmental risks varies greatly among regions. Unlike conventional environmental inequalities, these disparities call for a distributive justice assessment, as they may be *fair*—reflecting differing environmental needs—or *unfair*—signaling an inequitable allocation of policy effort. The latter case is particularly concerning, as it suggests that existing inequalities are not only persisting but potentially deepening, creating a double disadvantage for already vulnerable communities (Laurent, 2011).

Here, we aim to address this gap by developing a conceptual and methodological framework to evaluate equity in environmental policy distribution. By differentiating between fair and unfair disparities in policy allocation, our approach provides a non-parametric estimation strategy for the measurement and assessment of distributional justice of environmental interventions across spatial areas.

We define *environmental care* as the set of public policies designed to enhance environmental quality within a given geographical area. As public

goods, these policies are inherently non-excludable and non-rivalrous, intended to benefit all residents within an area.

Building on the literature on distributive equity (Rawls, 1971, Sen, 1992), this paper introduces a methodological framework to assess horizontal and vertical inequities in environmental care. From an equity perspective, an ideal allocation would ensure that individuals living in areas with the same environmental care need receive comparable levels of care, while individuals living in regions with greater needs receive proportionally higher care—a principle analogous to equity in health care provision (Culyer and Wagstaff, 1993, Wagstaff and van Doorslaer, 2000a, Oliver and Mossialos, 2004).[1]

Departures from this proportionality may signal unfair disparities in policy implementation, which we quantify using both direct and indirect standardization techniques. Additionally, by drawing from health economics (Wagstaff and van Doorslaer, 2000b), we assess the existence of a socioeconomic gradient, where individuals living in areas with limited economic resources (i.e. lower average income) systematically receive less environmental care relative to their needs. As discussed, this aspect is a concern common to the environmental justice literature (for a review, see Hajat et al., 2015) as it implies that inequality in care is reinforcing socioeconomic disparities (i.e. double-disadvantage).

To demonstrate the empirical method proposed, we apply it to traffic-related air pollution (TRAP) in Italian municipalities, leveraging a novel dataset on local environmental policies. Italy presents an ideal case study due to its unique combination of decentralized policy implementation and socioeconomic diversity. Although a common legal framework and national guidelines provide overarching principles, municipalities are primarily responsible for designing and implementing environmental policies to combat air pollution. Using municipality-level data from 2012 to 2021, we assess the

[1]Given our focus on measurement issues, throughout the paper we abstract from local heterogeneity in environmental preferences—despite its clear relevance for understanding underlying causal relationships.

extent to which local policy efforts align with environmental care needs and quantify deviations from an equitable standard.

The findings of this application contribute to policy debates on the allocation of public funding for environmental interventions. Our analysis first quantifies inequality in environmental care provision across Italian municipalities and disentangles the extent to which disparities stem from differences in environmental needs. We then examine how spatial inequity has evolved over time, exploring the extent to which these dynamics reflects shifts in national or European regulatory frameworks. Additionally, we assess whether economically disadvantaged municipalities systematically receive less environmental care relative to their needs, highlighting the role of socioeconomic disparities in policy implementation.

To summarize, our contribution is twofold. We build on approaches developed in health economics—specifically non-parametric methods for assessing the socioeconomic gradient of inequalities in health care—to propose a broader conceptual and methodological framework for measuring inequity in environmental care. This allows us to capture both the extent of environmental inequity and its correlation with socioeconomic disadvantage across spatial units. Furthermore, it provides an empirical evidence demonstrating the applicability of our approach and its potential to help central and local governments identify and address unfair disparities in environmental care provision across local jurisdictions.

The rest of the paper is structured as follows. Section 2 outlines the conceptual framework of environmental care equity and its relation to distributive justice. Section 3 presents the methodology, detailing the direct and indirect standardization approaches used to measure inequity. Section 4 applies this framework to Italian municipalities, presenting key results on the distribution and evolution of environmental care. Section 5 includes robustness checks, including an inequality decomposition by need-type. Finally, Section 6 discusses policy implications and concludes.

2 Distributive justice in environmental care

By the recognition of the human right to a clean, healthy, safe, and sustainable environment (United Nations Human Rights Council, 2021), environmental conditions provided to each individual are acknowledged as having intrinsic moral significance *per sé* (deontology), as well as primary importance for living a healthy and productive life (consequentialism). In this framework, distributive principles can no longer be neglected even if several and conflicting ethical value judgments may be considered (Dietz and Atkinson, 2010, Hänsel et al., 2022, Smith, 2022).

Following the health economics literature (e.g. Fleurbaey and Schokkaert, 2009), distributive justice may concern either individual access conditions to environmental goods (cf. health status), or individual benefits received from institutional effort and investments in the attempt to promote better access conditions (cf. health care). Both perspectives are economically and socially relevant, but the latter approach clearly emphasizes the role of "government's providing various personal goods and services to which we are entitled, as in the case of health care, or of its providing public goods (in the economist's sense), as in the case of measures ensuring public health (clean air and unpolluted water, and the like)" (Rawls, 2001, pp.172).

For our purposes, we define *environmental care* (E^C) as the quantity and quality of (local) public environmental policies implemented within a given spatial unit, aimed at improving its environmental conditions. By nature, these policies are largely non-excludable and non-rival, as they are intended to benefit all inhabitants of the area equally. Moreover, as far as spatial units consisting of demographic groups are considered, our analysis concerns the disparities—behind the veil of ignorance—among individuals having an equal chance to belong to each of the spatial units (e.g. Mansur and Sheriff, 2021).

Given that environmental care received by each individual has a geographical dimension, the proposed method takes the spatial unit as its ref-

erence. Any empirical application should first define the appropriate spatial unit (e.g., district, city, region, or country), similar to how income levels are measured based on individuals or households as reference units.[2] As this approach involves drawing inferences about individuals from aggregate spatial data, it implies an *ecological fallacy*, whose relevance varies with the size of the spatial unit (Boyce et al., 2016, Banzhaf et al., 2019).

Inequality of environmental care is a statistical concept measuring the uneven distribution of E^C across spatial units. In a scenario of perfect environmental care equality, all spatial units receive the same level of environmental care. While measuring environmental care *inequality* is informative on its own, we aim to evaluate it from an *equity* perspective. This means that a distinction is made between *fair* and *unfair* inequalities, as our framework recognizes that certain inequalities may be deemed legitimate and not warrant compensation.

Within a distributive justice perspective, we adapt Aristotle's principle of horizontal equity to our framework, asserting that areas with similar environmental care needs should receive equal care and, as a corollary, those with unequal needs receive appropriately unequal care according to some principle of vertical equity. As for the latter, the health care literature often assumes proportionality (or neutrality), meaning that care should be allocated in proportion to needs (Wagstaff and van Doorslaer, 2000a). Proportionality ensures that areas with equal needs receive equal care, and it also introduces a vertical standard for areas with different needs. Within this normative framework, inequalities in care are considered *fair* if they are driven by differences in needs, according to the proportionality assumption. However, any other inequality in care is deemed *unfair*. We refer to this as the principle of *equal care-per-need* (Oliver and Mossialos, 2004).

Equity assessments, thus, depend on the definition of environmental care

[2]In our approach, the analysis focuses on a population of spatial units. However, the proposed methodology can be easily adapted to account for a population of individuals by incorporating population size within each spatial unit.

need (E^N). Alternative definitions can be considered. Firstly, analogous to the literature on health care equity (Culyer and Wagstaff, 1993), the need for environmental care may be identified in terms of "initial", or existing, environmental conditions. Secondly, the environmental need might be defined in terms of "capacity to benefit", by which the need is identified in terms of expected benefit of care. Thirdly, the need might be defined on a normative ground by applying some value judgment to identify how much "care a unit ought to have". Fourthly, need might be defined as the amount of "care required to exhaust a need for care", that is, to achieve a situation where further care is not going to produce any benefit.

It is important to underline that the principle of equal care-per-need is not the only plausible distributive value judgment one may consider in this field; for instance, efficiency considerations may support existing disparities in care. Nevertheless, we argue that other attempts to legitimate environmental care inequalities are unlikely to find support, at least in the scientific community, due to the centrality of the right to a healthy environment for full development of human beings as free and equal persons. Within this framework, the key question we seek to address is: how should inequities in the delivery of environmental care be measured in a normative context where care inequalities are considered legitimate if driven by differences in needs?

3 Methodology

In this section, we introduce three alternative non-parametric strategies for measuring equity in the provision of environmental care across different spatial areas. The first two rely on *direct* and *indirect* standardization techniques, which are commonly used in the field of health economics to measure the socioeconomic gradient of inequalities in health care (Wagstaff and van Doorslaer, 2000a). The third is a methodological extension, based on the decomposition of environmental care inequality, that allows identifying hor-

izontal inequities independently from any proportionality assumption.

3.1 Direct standardization

Let $E^C = (E_1^C, ...E_n^C) \in \Re_+^n$ and $E^N = (E_1^N, ...E_n^N) \in \Re_+^n$ be the distribution of environmental care (hereafter, care) and environmental care need (hereafter, need) in a population of n spatial areas, respectively.

To the extent that differing needs may drive disparities in care, we adopt a *counterfactual* approach by constructing the hypothetical care distribution that would have been observed under the assumption of equal needs.

First, we partition the spatial areas into k-quantiles based on their need-type, denoted by $\hat{E}_i^N(k)$.[3] Let $\bar{E}^C$ represent the unconditional average care across the entire population, and $\bar{E}^C|\hat{E}_i^N(k)$ represent the average care conditional on the need-type of area i. Therefore, the need-standardized care for each area i is defined as:

$$E_i^{C|N} = E_i^C \frac{\bar{E}^C}{\bar{E}^C|\hat{E}_i^N(k)} \quad \forall\ i \in (1, ...n) \tag{1}$$

Intuitively, in spatial areas with higher (lower) need, average care is expected to be higher (lower) than that of the population, so one would reasonably expect $E_i^{C|N} < E_i^C$ ($E_i^{C|N} > E_i^C$). As a result, inequality in the need-standardized care distribution is expected to be reduced (increased) compared to the factual distribution. This happens because the re-scaling procedure in (1) preserves pairwise care disparities among areas with same needs while compensating for differences among areas with different needs according to a proportionality rule between care and need.[4]

[3] In the context of socioeconomic gradients in medical care, direct need-standardization is applied by Wagstaff and van Doorslaer (2000a) using income-based population partitions.

[4] The marginal effect of care may vary—either increase or decrease—depending on the specific context. Nevertheless, despite the possibility of departures from proportionality, we regard this framework as the most general in line with the literature on equity in health

In a partial ordering setting, given the set of $p\%$ spatial areas with the lowest level of care, let $L_A^{C|N}(p)$ and $L_B^{C|N}(p)$ be the Lorenz curves of need-standardized care for two populations A and B, respectively. It must be the case that the distribution of care in A is more equitable than in B if, and only if, $L_A^{C|N}(p)$ lies nowhere below $L_B^{C|N}(p)$ $\forall p \in (0,1)$.

In a complete ordering setting, let $G(\cdot) : \Re_+^n \to \Re$ denote the Gini index. The care distribution in A is more equitable than in B if $G_A(E^{C|N}) < G_B(E^{C|N})$; the two distributions reflect an identical degree of equity in care if $G_A(E^{C|N}) = G_B(E^{C|N})$. Accordingly, we propose using $G(E^{C|N})$ as an indicator of equity in environmental care.

An important methodological aspect should be noted. Dis-proportionality can create disparities between need-standardized care distributions, even when areas with same need-type receive equal care. For instance, in a population of four areas and two possible need-types, e.g. $E^N = (1,1,2,2)$, suppose the care distribution is $E^C = (x,x,2x,2x)$. This case would ensure horizontal equity and the need-standardized care distribution would be egalitarian. However, if the care distribution were $E^C = (x,x,3x,3x)$, horizontal equity would still be preserved, but the need-standardized care distribution would no longer be egalitarian due to dis-proportionality between need and care. As such, this approach for the measurement of equity in care delivery inherently incorporates a proportionality requirement for inequalities between unequal spatial areas (vertical equity judgment).[5]

Given our proposal for a measure of inequity in the delivery of care—

care.

[5]An additional methodological issue concerns the impact of standardization. If there are unobserved variables influencing care which are not identically and independently distributed (i.i.d.) with respect to E^N, then the inequality in the distribution of need-standardized care may be systematically influenced by variables other than needs (Ramos and Van de Gaer, 2016). For instance, if both need and care are strongly correlated with GDP, then standardizing care by need in (1) would implicitly offset some of the variation in care that originates from GDP. While this would be a major issue in casual analysis (biased estimates), it is an aspect to consider but negligible for our purpose of measuring equity in care delivery according to the equal care-per-need principle.

drawing on the health economics literature (Wagstaff and van Doorslaer, 2000a)—it may be of interest to examine the direction of this inequity in relation to the broader socioeconomic conditions of the environments in which individuals live, rather than focusing solely on each individual's own socioeconomic status, which is the approach typically adopted in the health economics literature. Remarkably, poor levels of care may be particularly harmful in spatial areas with fragile socioeconomic conditions, because it may engender a *double-disadvantage* for individuals living in those areas (e.g., Abatemarco et al. (2025), De Jong and Madamba (2001)). With this purpose in mind, let $SES = (SES_1, ...SES_n)$ represent the distribution of socioeconomic status of each area, and let $C^{C|N}(p)$ denote the concentration curve of need-standardized care, where areas are ranked by their SES. Using a partial ordering approach, if $C^{C|N}(p)$ lies entirely below the bisectrix (45-degree) line, inequity in care delivery penalizes low-SES areas, and vice versa. Alternatively, no socioeconomic gradient is found if either (i) the need-standardized care distribution ($E^{C|N}$) is perfectly egalitarian, or (ii) the concentration curve crosses the bisectrix line and areas on either side are perfectly offsetting each other.

In the complete ordering setting, the socioeconomic gradient of inequity can be measured using the concentration index, $I^c(\cdot) : \Re^n \to \Re$, for the need-standardized care distribution ordered by SES. If a socioeconomic gradient exists, then the concentration index will be positive, with greater values indicating a stronger gradient. Conversely, a negative concentration index implies that inequity in care penalizes high-SES areas. No socioeconomic gradient is observed if: (i) the distribution of need-standardized care ($E^{C|N}$) is perfectly egalitarian, (ii) the concentration curve crosses the bisectrix line and areas on either side are perfectly offsetting each other.

In summary, using the direct standardization strategy, we can measure equity in care with the Gini index, $G(E^{C|N})$, and assess the socioeconomic gradient of inequity with the concentration index, $I^c(E^{C|N})$.

3.2 Indirect standardization

If the distribution of care E^C were perfectly proportional to the distribution of needs E^N, then the Lorenz curve of care will coincide with the concentration curve of needs ranked by care, i.e., $L^C(p) = C^N(p) \; \forall \; p \in (0,1)$. Hence, $C^N(p)$ can be intended as the counterfactual care distribution that would have been observed if care were distributed proportionally to needs. Any distance between these two curves indicates a deviation from proportionality which may be due to horizontal inequities (but not necessarily).

Such dis-proportionality has been extensively used in health economics to assess inequity when shares of care and need are ordered by SES (Guo et al., 2020, Wagstaff and van Doorslaer, 2000b). This approach is known as *indirect standardization*, where inequity in care is measured by the inequality in factual care after accounting for the inequality in need (i.e. counterfactual care).

Within this framework, let A and B be two sets of spatial areas with the same distribution of needs, and let $L^C(p)$ and $C^N(p)$ denote the Lorenz curve of care and the concentration curve of needs, respectively, when areas are ordered by care. The distribution of care in population A is more equitable than in population B if, and only if, $|L^C_A(p) - C^N_A(p)| \leq |L^C_B(p) - C^N_B(p)| \; \forall \; p \in (0,1)$. If $|L^C_A(p) - C^N_A(p)| = |L^C_B(p) - C^N_B(p)| \; \forall \; p \in (0,1)$, then both sets exhibit the same equity in care delivery.

In a complete ordering setting, inequity can be estimated by considering the gap between $G(E^C)$ and $I^c(E^N)$, where $I^c(E^N)$ is the concentration index for the distribution of needs ordered by care. More precisely, if areas with low care levels receive less (more) care than what would be proportional to their needs, then $\Big(G(E^C) - I^c(E^N)\Big) > (<) 0$; if $G(E^C) = I^c(E^N)$, then either E^C and E^N are proportionally distributed, or the Lorenz and the concentration curve intersect, with perfectly offsetting deviations on either side. Thus, as far as inequalities in need legitimate inequalities in care, we propose the indicator $\Big(G(E^C) - C(E^N)\Big)$ to identify the contribution (i.e., share) of fair

inequalities to overall inequality in care according to the principle of equal care-per-need.

Once again, it might be noticed that inequity in care is even more concerning if it disproportionately penalizes low-SES areas, indicating that the departure from proportionality is driven by socioeconomic disparities. Similar to the Horizontal Inequity Index in (Wagstaff and van Doorslaer, 2000a), the gap between the concentration curve of care, $C^C(p)$, and the concentration curve of needs, $C^N(p)$—both ordered by SES—can be used to assess this effect. If $C^C(p)$ lies entirely above the bisectrix line, low-SES areas are receiving more care than high-SES ones; however, if $C^C(p)$ lies below $C^N(p)$, dis-proportionality between care and needs is penalizing low-SES areas. In other words, even if low-SES areas receive more care than high-SES areas, they may still be disadvantaged in proportional terms if their needs are greater. This would show that the dis-proportionality between care and need is driven by the socioeconomic gradient, creating a double-disadvantage for low-SES areas.

In the complete ordering approach, the socioeconomic gradient affecting dis-proportionality between care and need can be measured by $\Big(I^c(E^C) - I^c(E^N)\Big)$. A positive value indicates that dis-proportionality penalizes low-SES areas, while a negative value suggests it benefits them. A value of zero occurs when the two concentration curves intersect and the deviations are perfectly offsetting.

To summarize, under an indirect standardization procedure, inequity in care can be measured by $\Big(G(E^C) - C(E^N)\Big)$, while the socioeconomic gradient of inequity in care is captured by $\Big(I^c(E^C) - I^c(E^N)\Big)$.

From a methodological perspective, it is worth observing that the indirect standardization method is often preferred because, unlike the direct approach, it does not require a definition *a priori* of need-types for standardization. As observed in Wagstaff and van Doorslaer (2000a), grouping areas by need (equation (1)) reduces within-group variability, potentially leading

to an overestimation of inequity in care by failing to account for some (ignored) heterogeneity in needs within each group. This limitation becomes more pronounced when a small number of quantiles is used for partitioning the population based on needs.[6]

3.3 Horizontal inequity without proportionality assumption

Sections 3.1 and 3.2 illustrate two approaches to the measurement of inequity in care, both rooted in the principle of horizontal equity and incorporating vertical equity judgments based on the proportionality assumption (Wagstaff and van Doorslaer, 2000a, Oliver and Mossialos, 2004).

In this section, we propose an alternative strategy for measuring horizontal inequity in care which, in the attempt to exclude any impact of the proportionality assumption, is independent of any vertical equity judgment (*pure* horizontal inequity). This approach is based on the direct standardization of care by income while accounting for inequality decomposition by need-type according to the Gini decomposition proposed by Lambert and Aronson (1993).

Consider a disjoint and exhaustive partition of the population by need-type. As before, one can use a k-quantile partition of areas based on their needs E^N, or any other partition based on some *a priori* classification of need-types. Once each area is assigned to a single group, the Gini index of care can be decomposed into within-group (G^W) and between-group (G^B) inequality across need-types (or groups):

$$G(E^C) = G^W(E^C) + G^B(E^C) + R(E^C) \tag{2}$$

[6] As noted in the literature on tax progressivity (Dardanoni and Lambert, 2002, Jakobsson, 1976), the indirect standardization method is not entirely rigorous either. Valid orderings across populations (i.e. across countries or over time) formally require a fixed and common distribution of E^C (analogous to pre-tax income) for all distributions of E^N (analogous to post-tax income) being compared.

where, given K groups, with n_k and $\bar{E}_k^C$ representing the size of the population and the mean care in quantile k,

$$
\begin{aligned}
G^W(E^C) &= \sum_{k=1}^{K} \frac{n_k \bar{E}_k^C}{n\bar{E}^C} G_k(E^C) \\
G^B(E^C) &= \frac{1}{2} \sum_{z=1}^{K} \sum_{k=1}^{K} \frac{n_z n_k}{n^2 \bar{E}^C} |\bar{E}_z^C - \bar{E}_k^C| \\
R(E^C) &= \frac{2}{n^2 \bar{E}^C} \sum_{z=1}^{K} \sum_{k=1}^{K} \sum_{i=1}^{n_k} \sum_{j=1}^{n_z} \max\{(E_{jz}^C - E_{ik}^C), 0\}.
\end{aligned}
\tag{3}
$$

Specifically, $R(E^C)$ is known to measure the overlap across group-specific care distributions (Lambert and Aronson, 1993).[7] For our purposes, it is worth observing that *pure* horizontal inequity is measured by the within-group inequality component, that is a weighted aggregation of inequalities in care detected among groups of areas with the same need-type. Compared to previous methods, this approach provides a measurement of horizontal inequity that is independent of the dis-proportionality assumption.

Within this framework, horizontal inequity is zero if, and only if, all areas with same needs receive equal care. In contrast, within-group inequality reaches its maximum when the Gini index for each need-type equals 1, i.e., if only one spatial area in each group receives care.[8]

To assess the impact of socioeconomic gradient on the observed (horizontal) inequity, given the decomposition by Lambert and Aronson (1993), we propose a simple extension based on the direct standardization by SES-type. Let $\widehat{SES}_i(k)$ represent the SES-type assigned to area i based on its SES-quantile. The counterfactual care distribution independent of socioeconomic

[7] As shown in Abatemarco (2010), the $R(E^C)$ component reflects the shape (not just the mean) of group-specific distributions and can be also rewritten as a weighted aggregation of pairwise gaps between individuals belonging to different need-types.

[8] While the the Gini index is used here for consistency with previous methodologies, any decomposable inequality indexes, such as entropy measures, could be employed for similar purposes

status can be constructed as:

$$E_i^{C|SES} = E_i^C \frac{\bar{E}^C}{\bar{E}^C|\widehat{SES}_i(k)} \quad \forall\ i \in (1, ...n) \tag{4}$$

where, assuming that unobserved variables affecting care are i.i.d. with respect to *SES*, $E_i^{C|SES}$ measures the counterfactual care that area i would have received independently of its SES. If high-SES areas receive more care than average, the rescaling factor will be less than one, implying $E_i^{C|SES} < E_i^C$, and vice versa.

By considering the Gini index of the counterfactual care distribution, i.e. $G(E^{C|SES})$, and the inequality decomposition in (2), the difference $G^W(E^C) - G^W(E^{C|SES})$ provides a measure of the contribution of the socioeconomic gradient to horizontal inequity in care. The difference is positive if SES disparities increase within-group inequality in care, and negative if they reduce it. Importantly, this metric exclusively identifies the socioeconomic gradient's effect on horizontal inequity in care delivery, independent of any vertical equity judgments.

4 An application to TRAP

Since 1990, air pollution levels have generally declined. However, many European Union regions still exceed the limit and target values established by European directives and the World Health Organization (WHO), and air pollution remains one of Europe's leading environmental health risk factor in Europe (European Environment Agency, 2024b). According to the latest statistics, in 2022 96% of the global urban population breathed air that surpasses WHO air quality limits (WHO, 2024). In Italy specifically, air pollution is estimated to have caused over 50,000 premature deaths in 2020 alone, the highest number among EU member states (European Environment Agency, 2022). Furthermore, in 2021, 11,282 premature deaths were

attributed solely to NO_2 exposure in the Po Valley region, one of the most polluted areas in Europe (European Environment Agency, 2024b).

An extensive body of research provides consistent evidence of the adverse effects of air pollution on human health and well-being. Exposure to air pollution is linked to a range of diseases, including stroke, cancer, aggravated asthma, and lower respiratory infections. Moreover, its impact extends beyond the healthcare system, affecting the economy at large. For instance, a study by CE Delft (de Bruyn and de Vries, 2020) estimated that in 2018, the social costs of air pollution in the European Union amounted to €166 billion, with each European city dweller incurring an average annual welfare loss exceeding €1,250 due to health-related issues stemming from poor air quality.

Unlike greenhouse gas emissions, which have a global impact, air pollutant emissions are highly localized and their concentrations depend on proximity to emission sources, such as power plants, traffic, and industrial or domestic combustion activities. Among air pollutants, nitrogen dioxides (NO_2) is one of the most relevant, particularly in urban areas, with road transport accounting for approximately 72% of these emissions in EU27 countries (European Environment Agency, 2024a).

This application focuses on Italy, where air pollution remains a major public concern, particularly in the Po Valley region, which experiences some of the highest concentrations of pollutants in Western Europe (European Environment Agency, 2023, SNPA, 2024). While national and EU regulations set overarching air quality standards, the implementation of traffic and mobility policies to reduce pollution occurs primarily at the sub-national level. As a result, the extent and effectiveness of these policies vary significantly across municipalities. Considering the level of municipal policy implementation as the previously defined measure of care, a key question arise: does the spatial distribution of these policies, i.e. the distribution of care, align with the level of need? Or, in other words, is the inequality in these policies

across Italian municipalities fair or unfair from an equity standpoint?

As discussed at the end of Section 2, defining need is not straightforward as multiple definitions are possible. In this instance, one possible approach is to define need as the average annual concentration of NO_2 aligning with the first definition, where need is determined by existing environmental conditions. Alternatively, need could be defined based on meteorological factors, specifically wind speed—one of the key determinants of air pollution dispersion (Thompson, 2001, Lazaridis, 2011, Xie et al., 2022). Higher wind speeds facilitate pollutant dispersion, reducing pollution levels, whereas lower wind speeds contribute to its accumulation. This alternative corresponds to the fourth definition of need, where meteorological conditions reflect the extent of intervention required to mitigate pollution exposure. In the results section, we primarily adopt the first definition but we assess the robustness of our findings by replicating the inequity analysis using the alternative definition (see Appendix A).

4.1 Data

In Italy, the division of responsibilities across government levels is often ambiguous, making it challenging to identify the authority responsible for specific environmental policies. To ensure consistency and comparability, we have focused exclusively on policies defined and implemented at the municipal level, as these directly reflect the municipal care provided to reduce air pollution.

Italian municipalities hold formal responsibility for designing and implementing urban mobility measures, both allocative (e.g. investments in bike-lane expansion, car-sharing, and sustainable public transportation) and regulatory (e.g. traffic limitation zones or pedestrian zones).[9]

[9]This is established by: (i) D.Lgs. 112/1998, which devolved to local governments the authority over urban planning, environmental protection, transport, and infrastructure (Repubblica Italiana, 1998); and (ii) D.Lgs. 257/2016 , which introduced PUMS

Variable	Description	Mean	Sd
Environmental care policies			
Bike lanes	km per 100 km^2 of land area	33.99	42.36
Pedestrian area	m^2 for 100 inhabitants	39.54	73.05
Limited Traffic Zone	km^2 per 100 km^2 of land area	0.67	1.60
30 km/h speed zones	1; 0	0.63	0.48
Sharing mobility	vehicles for 10,000 inhabitants	9.62	21.60
Low-emissions buses	vehicles for 100 buses	26.44	27.35
Urban Mobility Plan	1; 0.5; 0	0.38	0.48
Urban Sust. Mobility Plan	1; 0; -1	-0.04	0.48
Low Emission Zone	1; 0	0.07	0.25
Low Emission Zone winter	1; 0	0.06	0.25
Munic. spend. on air qual.	% of total municipal spending	0.11	0.54
Environmental need			
NO_2	Avg annual concentration $\mu g/m^3$	26.46	10.15
Socio-economic status			
Municip. income	Avg per-capita income in euro	14,891	2,973

Table 1: Descriptive statistics for municipalities (2012-2021)

Note: The variable *Municipality spending on air quality* is available since 2016. *Urban Mobility Plan* is a voluntary plan with the aimed, among others objectives, at reducing air pollution (1 if approved, 0.5 if adopted, 0 if neither). *Urban Sustainable Mobility Plan*, introduced in 2017, is compulsory only for municipalities with >100,000 inhabitants (1 if approved and not compulsory, 0 if approved and compulsory or non-approved and non-compulsory, -1 if non-approved and compulsory). **Souces**: The source of the first 9 variables is Istat (ISTAT, 2022); the source of municipality spending on air quality and total municipal spending is Fondazione Openpolis (Fondazione Openpolis, 2025); the source of NO_2 data is ISPRA (ISPRA, 2025); the source of municipality income is Istat (ISTAT, 2024)

We collected data from multiple sources on policies implemented over the calendar year. Data availability is limited to the 110 municipalities that serve as provincial capitals and the years 2012-2021. Table 1 provides an overview of the specific policies included in the analysis, with their relative descriptive statistics and sources. For further details on the policies included in the environmental care score, see Appendix B.

While the selected transport-related policies (i.e. bike lanes, pedestrian

as mandatory strategic plans for cities over 100,000 inhabitants and voluntary for the remaining (Repubblica Italiana, 2016).

areas, limited traffic zones, 30 km/h speed zones, and sharing mobility) may serve multiple objectives, such as traffic reduction or urban livability, we argue that they are also plausibly motivated by environmental concerns. We therefore interpret their adoption as a proxy for municipal environmental care, in line with Banister (2008) and OECD (2012).

To construct the environmental care index, we assign each municipality a score from 0 to 10 for each policy variable, standardizing across years. Continuous variables are transformed into deciles, while binary variables receive a score of 10 if the policy is present and 1 otherwise. For Urban Mobility Plans (PUM) and Urban Sustainable Mobility Plans (PUMS), which are coded with multiple values reflecting approval status and regulatory requirements, we combine the two into a single indicator and rescale it to the 0–10 range. A similar approach is used for Low Emission Zones (LEZs): we combine general and winter LEZs into a single variable, which is then linearly rescaled to fall between 1 and 10. The final environmental care index is the average of all standardized policy scores.[10]

We define "environmental need" at the municipal level using annual average NO_2 concentrations, obtained by averaging the records of all monitoring stations within each municipality's boundary. While this approach does not reflect short-term pollution peaks, annual indicators are widely used in policy evaluation and urban planning, and align with EU regulatory frameworks (e.g. Directive 2008/50/EC). Specifically, municipalities typically respond to chronic exceedance of annual NO_2 thresholds, rather than episodic fluctuations, when planning transport-related environmental interventions.

Finally, for each municipality, SES is measured as per capita income, calculated by dividing the average total taxable income of each municipality by its number of inhabitants.

[10]The authors acknowledge that this approach relies on the hypothesis of full compensation between the different dimensions of care, which may not be entirely realistic. However, developing a non-compensatory indicator for care is beyond the scope of this methodological application.

Figure 1 displays the distribution of the environmental need (left panel) and environmental care (right panel) indices across Italian provincial capitals. For ease of interpretation, municipalities are grouped into quintiles based on their scores for each index. The maps reveal substantial heterogeneity in both pollution exposure and policy response. In particular, the Po Valley stands out as the area with the highest levels of environmental need, while a clear North–South divide emerges: municipalities in northern Italy tend to score higher on environmental care, indicating more widespread implementation of air quality-related policies.

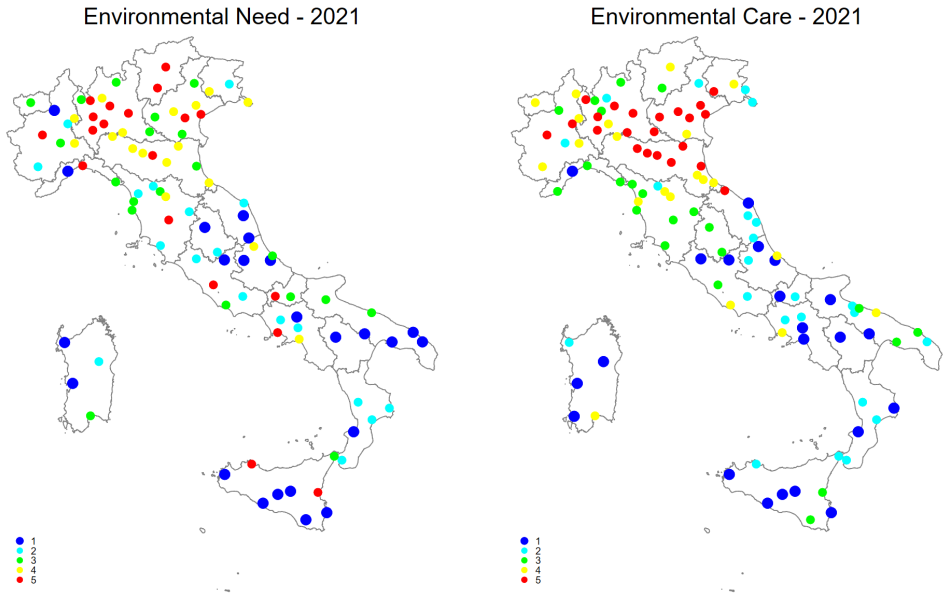

Figure 1: Map of Italy with municipality-level E^N and E^C scores (2021)

Note: Municipalities are grouped into five categories (quintiles) based on their environmental care (Panel A) and environmental need (Panel B) scores. A value of 1 indicates the lowest level of care/need, while 5 corresponds to the highest. These quintiles are constructed using the national distribution of each index.

It should also be noted that a positive trend is observed in E^C from 2012 to 2021, indicating a general increase in the implementation of environmental

policies over the period considered, as shown in Figure 2. This trend likely reflects growing environmental concerns and policy momentum at the European level, particularly in response to initiatives such as the EU Clean Air Policy Package (2013), the European Green Deal (2019), and the increasing emphasis on sustainable urban mobility planning through regulations like Directive 2014/94/EU and the support for PUMS adoption under national and EU funding schemes. These frameworks have promoted local-level actions on air quality, mobility, and climate mitigation, which are captured by our composite index.

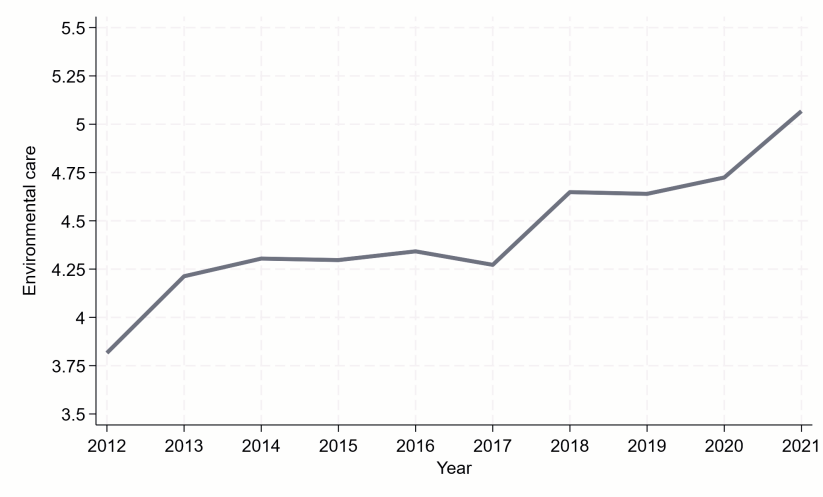

Figure 2: Evolution of average municipal E^C, 2012-2021

4.2 Results: inequity in environmental care

Following the direct standardization method outlined in Section 3.1, we compute the need-standardized environmental care for each municipality. We then estimate the Lorenz curve of $E^{C|N}$ and the corresponding Gini coefficient using the most recent data from 2021. The left panel of Figure 3 presents the Lorenz curve, whose associated Gini coefficient is 0.179. The graphical analysis reveals that, even after standardizing for differences in environmental

needs, environmental care remains unequally distributed across municipalities. Specifically, the bottom 40% of municipalities in terms of $E^{C|N}$ receive less than 30% of total $E^{C|N}$, indicating a deviation from proportional distribution. This residual inequality proves the existence of inequity according to the equal care-per-need principle.

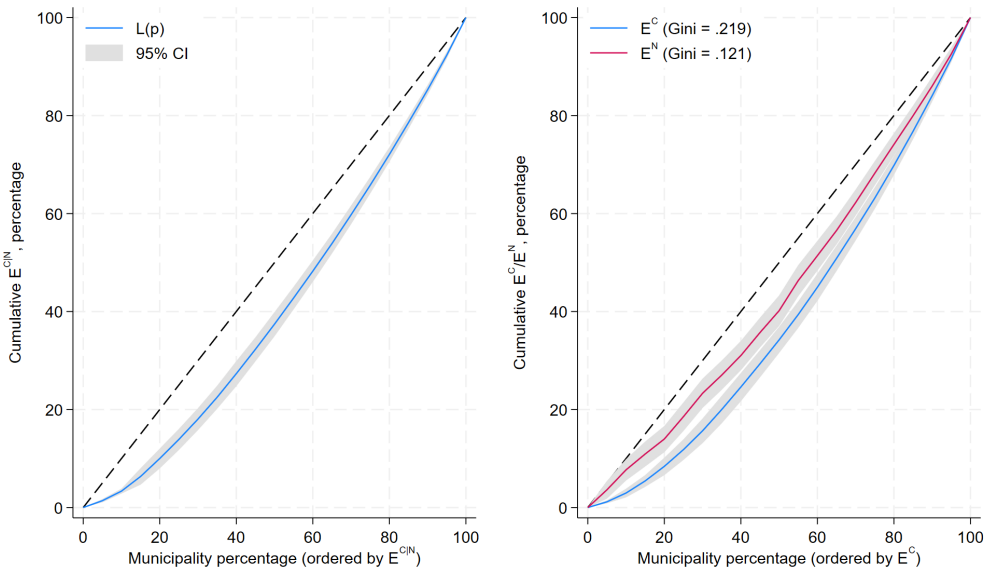

Figure 3: Environmental care inequity in 2021

As discussed in Section 3.2, a similar equity analysis can be conducted using the indirect standardization method. To this end, we estimate the Lorenz curve for E^C and the concentration curve for NO_2 both displayed in the right panel of Figure 3. The area between these two curves quantifies need-standardized inequality in care, representing the portion of care inequalities that cannot be attributed to differences in need. Our results indicate that this inequality is positive and significantly different from zero. However, the indirect standardization approach suggests a lower level of inequality across municipalities: while the direct method yields a Gini coefficient of 0.18, the indirect method results in a value of 0.22 - 0.12 = 0.10. As

noted in the previous section, the overestimation of inequity in the direct approach is expected, provided that partitioning the population by need-types prevents compensation for inequalities originating from heterogeneity within each need-type.

Since the Gini coefficient and concentration index are not clearly interpretable in absolute terms, we compute the need-standardized inequality in care over the period 2012–2021. The results from both the direct and indirect approaches are presented in the left panel of Figure 4.

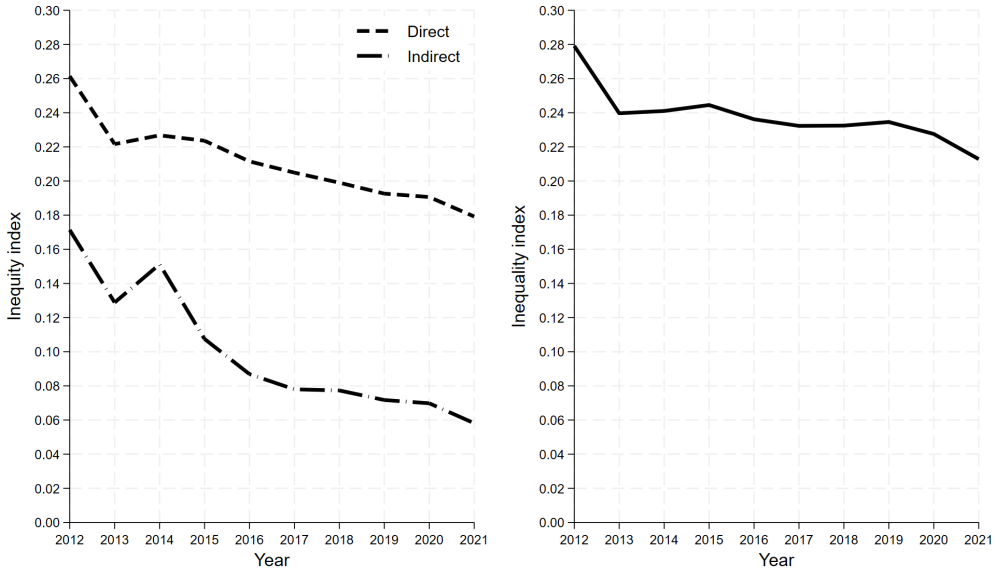

Figure 4: E^C inequity and inequality (2012-2021)

The figure illustrates that the gap between the direct and indirect estimates remained stable throughout the period, suggesting a persistent difference between the two measurement approaches. Additionally, inequity in care has declined by approximately 30% between 2012 and 2021.

In the right panel of Figure 4 is shown the evolution of inter-municipal inequality in E^C. The data exhibit a pronounced downward trend in this inequality measure, with a total reduction of approximately 23% over the

study period. This indicates a substantial convergence in environmental policy outcomes across municipalities.

A key driver of this convergence appears to be the relatively larger improvements realized in municipalities with greater environmental needs: the concurrent decline in inequity implies that lower-performing municipalities experienced disproportionately higher gains in E^C. In other words, the distribution of environmental policy benefits became more balanced, indicating a fairer allocation of efforts and resources across municipalities.

These empirical trends coincide with an intensified policy focus on air quality at both the European and national levels since around 2013. In that year, the European Commission launched the Clean Air Programme for Europe, introducing stricter emission ceilings and encouraging more aggressive local air-quality measures. This supranational initiative – along with parallel domestic regulations – exerted increasing pressure on Italian municipalities to implement active anti-pollution measures. The improved equity in outcomes observed over time may thus reflect the diffusion of these environmental policies across jurisdictions, driven by multilevel governance and the harmonization of standards. In effect, European directives and national frameworks have likely promoted more uniform implementation of air-quality policies, contributing to the reduced inequality in E^C across municipalities.

4.3 Results: socioeconomic gradient in environmental care

We now turn to the analysis of the direction of the inequity in relation to socioeconomic conditions. The left panel of Figure 5 shows the concentration curve for need-standardized care, ranking municipalities by their SES. The associated concentration index is equal to 0.07. These results are consistent with a modest but positive double-disadvantage, as municipalities with low average incomes per-capita are receiving proportionally lower levels of environmental care. The right panel shows that the indirect method reaches the

same conclusion, with an estimated inequality of 0.15-0.11=0.04.

The observed concentration indices align with concerns in the environmental justice literature regarding the unequal distribution of public goods (Banzhaf et al., 2019).

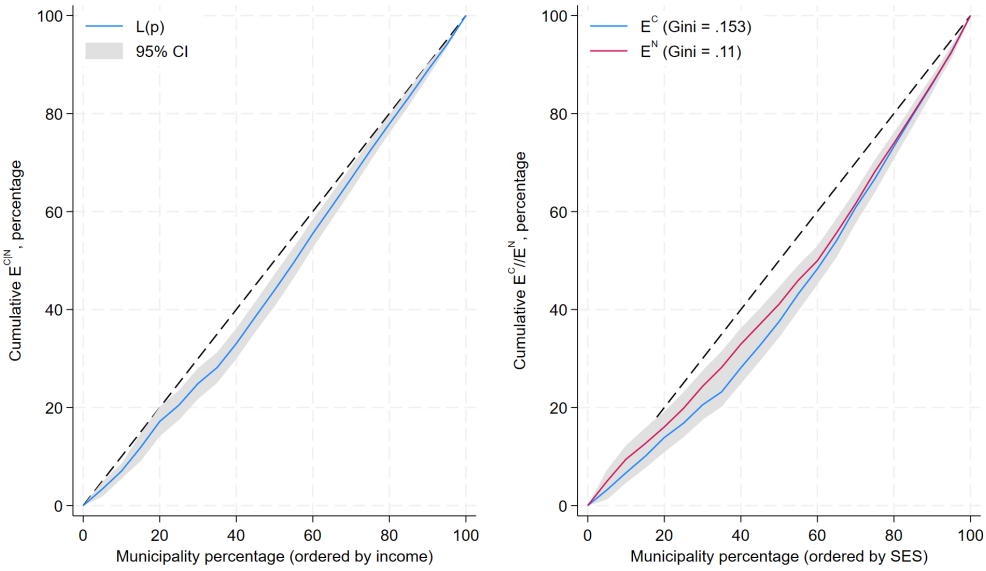

Figure 5: The socio-economic gradient in 2021

Turning to the temporal evolution of these disparities, Figure 6 reveals a declining trend in socioeconomic inequality in environmental care between 2012 and 2021. Both direct and indirect inequality measures exhibit a gradual reduction, suggesting a convergence in policy outcomes. This trend is consistent with the broader decline in environmental policy inequality observed in Figure 4 and may be attributed to increasingly stringent regulatory frameworks at the national and European levels. Specifically, the implementation of EU air quality directives and their domestic enforcement mechanisms may have contributed to a more balanced allocation of environmental policies across municipalities, reducing SES-driven disparities over time.

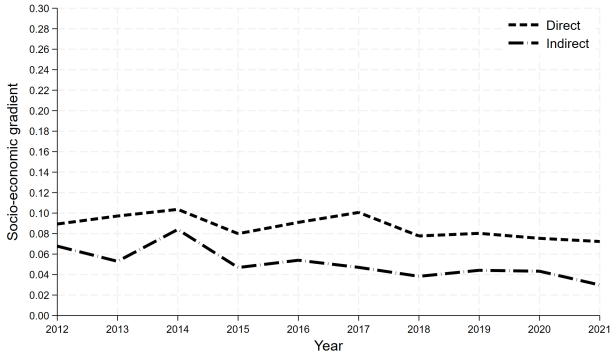

Figure 6: Socio-economic gradient (2012-2021)

4.4 Results: inequality decomposition approach

The left panel of Figure 7 shows the results of the decomposition approach outlined in Section 3.3, together with the results from the direct and indirect standardization approaches. Overall, the horizontal inequity component is lower when considered *per se*. Specifically, it is worth observing that the direct standardization line and the within-group inequality line are obtained by assuming the same quintile-based partition of the population by needs. As such, the distance between these lines suggests a remarkable impact of the proportionality assumption incorporated in the direct standardization estimation strategy. As for the dynamics of inequity, the within-group inequality trend is negative in the study period as observed for the other measurement strategies.

The right panel of Figure 7 shows the socio-economic gradient computed using the inequality decomposition approach. We observe that, in line with previous findings, the results indicate that disadvantaged municipalities receive disproportionally less care, even if the socio-economic gradient is not found to be decreasing when considering the dynamics of horizontal inequity independently of the proportionality assumption. This result suggests that the decreasing pattern of inequity is mostly stemming from a vertical con-

vergence of the distribution of care among spatial areas with different need-types.

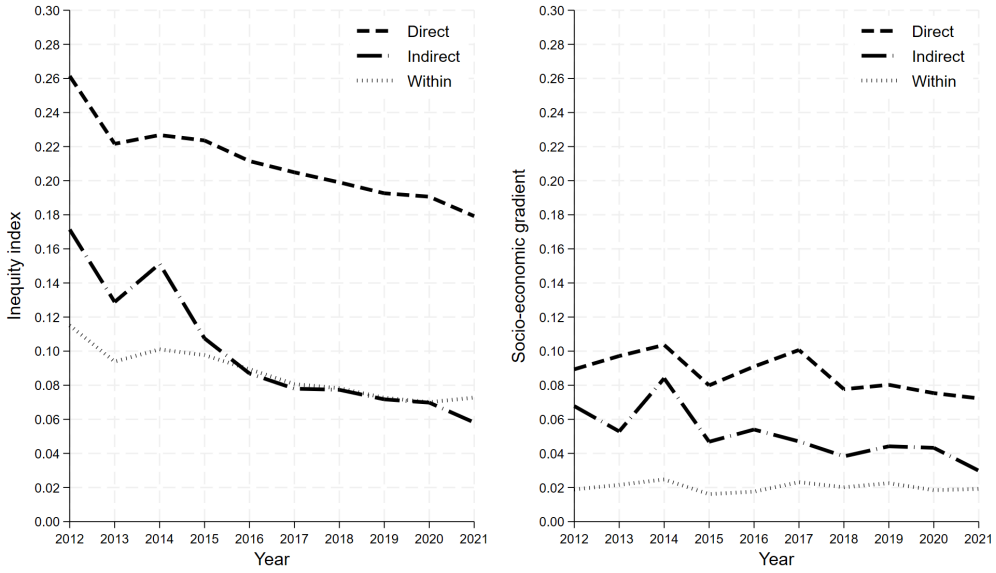

Figure 7: Inequity in E^C and socioeconomic gradient (2012-2021)

The results presented are robust to alternative specifications and definitions of environmental need, as shown in the Appendix A.

4.5 Policy implications

Our findings reveal the presence of unfair inequalities in environmental care across Italy, indicating that municipal governments fail to uphold horizontal equity in its provision. This suggests that the allocation of environmental care is not solely driven by differences in local needs but also by structural and administrative disparities.

In this context, the central government could take a two-step approach. First, it should identify municipalities with the greatest mismatch between environmental care provision and need and investigate the underlying causes.

These disparities may arise from insufficient resources—resulting from low fiscal capacity or technical challenges in implementing environmental programs—or from a lack of political commitment among local administrators.

If resource constraints are the primary issue, as partly indicated by our socioeconomic gradient analysis, targeted financial and technical assistance could help under-resourced municipalities strengthen their capacity to adopt and enforce environmental policies more effectively, thereby reducing unfair inequalities.

However, if disparities stem from a lack of local commitment, stronger integration of equity criteria into environmental policymaking is necessary, following principles similar to those used in healthcare resource allocation (Culyer and Wagstaff, 1993). In this regard, the central government could establish an equalization fund to redistribute resources for environmental protection across municipalities, using need-based allocation formulas to ensure that environmental investments are directed where they are most needed.

5 Concluding remarks

This study develops a methodological framework for evaluating inequity in environmental care distribution, distinguishing between disparities justified by environmental needs and those reflecting unfair allocation patterns. By adapting standardization techniques from health economics, our approach provides a systematic way to assess both horizontal and vertical inequities in environmental policy provision. In our view, the methodological proposal discussed in this paper offers a particularly convenient framework for the analysis of environmental equity, that is easily applicable in several fields of environmental research, such as water quality management or biodiversity conservation.

Applying this framework to TRAP in Italy, we find that while overall inequality in environmental care has declined over time, socioeconomic dispar-

ities persist, with lower-income municipalities receiving disproportionately less care relative to their environmental needs. These findings carry important policy implications for the design and implementation of environmental interventions at multiple levels of governance.

Future research could extend this framework to other environmental domains and geographical contexts, examining how different governance structures and policy instruments affect the distribution of environmental care. Additionally, incorporating causal identification strategies could help isolate the effects of specific policy interventions on environmental equity outcomes. By advancing the measurement and evaluation of environmental care inequity, this study provides a foundation for more informed and equitable environmental policymaking.

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A Appendix

In this section of the Appendix, we replicate the previous analysis by measuring environmental need using the the yearly average level of wind speed at 10 meters above the ground within each municipality. Since higher wind speeds are associated to lower needs, we compute the E^N of each municipality as the municipality's average wind speed. For the year 2021, the resulting E^N levels are represented in Figure 8.

The left panel of Figure 9 presents the estimated inequity obtained using the direct and indirect standardization methods, as well as the decomposition approach. The results align with those from the alternative definition of need, confirming their robustness: we observe a declining trend in inequity in care, comparable values, and a consistent relationship among the different estimation methods.

However, some differences emerge. When wind speed is used to represent environmental need, the decline in inequity over time is slower, and the annual estimates from the indirect method fluctuate more.

With regards to the socioeconomic gradient, the results are also comparable to those obtained with the alternative definition of need, though the estimates in this latter analysis exhibit slightly greater variability over the study period.

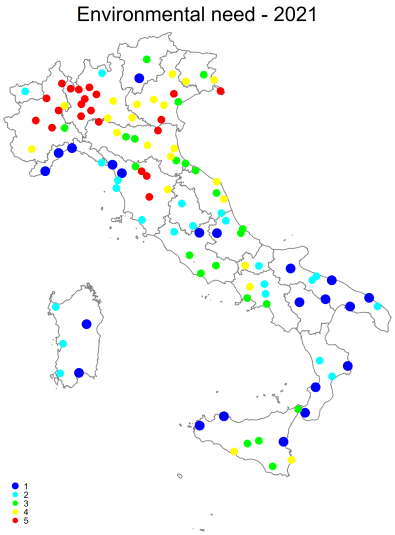

Figure 8: Map of Italy with municipality level E^N = inverted wind speed

Source: Authors' computations from Visual Crossing (Visual Crossing Corporation, 2025)

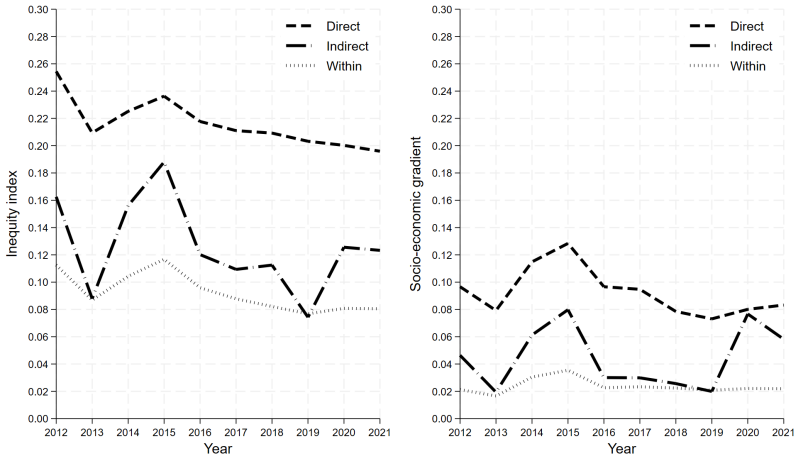

Figure 9: E^C inequity and socioeconomic gradient (E^N = inverted wind speed

Source: Authors' computations from Visual Crossing (Visual Crossing Corporation, 2025)

B Appendix

Table 2: Municipal-level Policies Included in the Environmental Care Index

Policy Measure	**Description**	**Connection to Air Quality Improvement**	**Implementing Authority**
Extension of bike lanes	Kilometers of designated bike lanes for 100 km^2 of land area	Encourages active mobility and reduces car use and related emissions (NO_2, PM)	Municipality
Extension of pedestrian areas	m^2 of car-free zones in urban centers for 100 inhabitants	Reduces vehicular traffic and improves air quality in densely populated areas	Municipality
Limited Traffic Zones	km^2 per $100km^2$ of designated urban areas where vehicle access is restricted based on time, vehicle type, or emissions class	Reduces local air pollution by limiting high-emission vehicles in dense areas	Municipality
30 km/h Speed Zones	Urban areas where maximum vehicle speed is limited to 30 km/h	Reduce emissions by calming traffic, promoting smoother driving, and enhancing safety for pedestrians and cyclists	Municipality
Car sharing services	Number of shared vehicle systems (cars, bikes, scooters) for 10,000 inhabitants	Lowers the number of privately owned cars, reducing total vehicle kilometers and emissions	Municipality (with possible private partnerships)

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Policy Measure	**Description**	**Connection to Air Quality Improvement**	**Implementing Authority**
Low Emission Buses	Percentage of bus fleets using electric, hybrid, or other low-emission technologies	Reduces emissions from public transport, particularly NO_2	Municipality (often co-financed by regional or national programs)
PUM adoption	Formal approval of a Piano Urbano della Mobilità (Urban Mobility Plan), as defined by earlier national legislation	Outlines traffic management strategies and infrastructure priorities, which may include emissions-reducing actions	Municipality
PUMS adoption	Formal adoption of a Sustainable Urban Mobility Plan	Integrated planning tool promoting public transport, soft mobility, and emission reductions	Municipality (mandatory for cities >100,000 inhabitants)
Low Emission Zones	Designated areas where access is restricted to vehicles that meet specific emissions standards	Reduce emissions by limiting the circulation of high-polluting vehicles, especially diesel cars and older models	Municipality

(continued on next page)

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Policy Measure	**Description**	**Connection to Air Quality Improvement**	**Implementing Authority**
Low Emission Zones winter	Designated areas where access is restricted to vehicles that meet specific emissions standards only during winter months	Reduce emissions by limiting the circulation of high-polluting vehicles, especially diesel cars and older models	Municipality
Air Quality Spending (% of Total Budget)	Annual municipal expenditure dedicated to air quality initiatives as a percentage of the overall municipal budget	Indicates explicit financial commitment to air pollution reduction through dedicated projects and infrastructure	Municipality

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