The assessment of environmental and income inequalities

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Abstract We analyze the income and environmental inequalities and their interrelation by means of both the multidimensional poverty measurement and the Gini index decomposition. We stress how overlap between the two dimensions plays a relevant role and allows powerful insights on the contribution of the environmental dimensions to poverty. Our finding underlines that bad environmental conditions are more likely among low-income units and represent a relevant inequality factor.

Key words: Environmental inequality, income inequality, overlap

1 Introduction

The growing attention and the widespread concern for the SDGs underpin the relevance of the interconnession between the 13 goals, which requires the harmonisation and the coordination of the variety of actions implemented at national and international level. In this work we address three different SDGs and their interaction: the 1st, related to overall inequality, the 10th, related to economic inequality, and the 13th, related to environmental inequality.

Environmental inequality refers to unequal distribution of opportunities related to environment: environmental degradation does not affect everyone equally and the effects of environmental risks are not uniformly distributed. Moreover, environmental inequality has a strong impact on the economic and social system for a wide range of reasons, both ethical, normative and economic.

There is a natural correlation between income and environmental inequalities [9], two of the main dimensions of poverty. In this paper we aim to tackle the interplay

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between these two dimensions, which is a key issue in inequality analyses and can be considered as a major threat to economic resilience [1].

We contribute to the analysis of the interplay between income and environmental dimensions by building on both the multidimensional measurement of poverty and the decomposition of the Gini index. In particular, in the analysis of the income and environmental inequalities, we underline the role of overlap existing between the two dimensions.

There is a wide range of environmental risks and, depending on the definition which we adopt for the environmental dimension [8], results and policy implications change, while usually confirming that bad environmental conditions are more likely among low-income units, be they individuals, households, communities or even geographical partitions [5]. Furthermore, sustainability policies interact and deal with many different subjects but, in order to be effective, are characterized and united by the need to be data based. We contribute to answer to this need and the methods we are going to present are extremely flexible and can be adapted to different definitions and the analysis of multiple risks.

2 Methodology

The most widespread measure of inequality, the Gini index, has already been successfully used in the study of environmental inequality, both in its traditional expression and in an environmental Paglin-Gini extension proposed by [10] or a spatialized Gini index applied to environmental segregation [11].

A relevant source of information about interplay between income and environmental dimensions is represented by overlap existing between income distributions related to low and high quality of environmental conditions. In the absence of overlap, environmental dimension fully explains income inequality, while, on the contrary, a perfect overlap suggests that environmental and economic dimensions are independent.

In order to evaluate the degree of the overlap we have two measures at our disposal, both introduced by Gini: the probability of transvariation, which measures the frequency of overlapping occurrences, and the intensity of transvariation, which evaluates the extent of the overlap.

Beside probability and intensity of transvariation, we can also take into account the overlap within the Gini index, through its decomposition. In particular, we refer to the decomposition proposed by Dagum [7], which has among its strengths the role attributed to overlap.

A preliminary step to the joint analysis of the economic and environmental dimensions is represented by the traditional unidimensional poverty representation. Given a population of n units, it is developed on a vector of incomes, $\mathbf{y} = (y_1, y_2, ..., y_n)$ and on a poverty line z_y on the basis of which we define a zero-one vector $\mathbf{g_y}$ where

$$g_{yi} = \begin{cases} 1 \text{ if } y_i < z_y \\ 0 \text{ otherwise} \end{cases}$$

The number of poor units with respect to income, q_y, is the sum of the vector $\mathbf{g_y}$.

By adding the environmental dimension, a vector $\mathbf{e} = (e_1, e_2, ..., e_n)$ representative of the environmental conditions is introduced, together with a poverty line z_e on the basis of which we define a zero-one vector $\mathbf{g_e}$ where

$$g_{ei} = \begin{cases} 1 \text{ if } e_i < z_e \\ 0 \text{ otherwise} \end{cases}$$

The number of poor units with respect to the environmental dimension, q_e, is the sum of the vector $\mathbf{g_e}$. The use of a z_e threshold allows for the treatment of many different environmental risks and is robust with respect to various definitions of the environmental dimension.

In the following we refer to the case of only two groups, poor and non-poor, for each of the two dimensions, but it is possible to generalize to the case of more than two groups, allowing different levels or intensities of poverty, a situation that we would like to address in a future work.

The joint analysis of the two dimensions leads to classify the n units of the population in four classes which can be reported in the 2x2 Table 1, where we find the q poor units in both dimensions, the $q_e - q$ units which are poor with respect environmental dimension but not according to income, the $q_y - q$ units poor only with respect to income, and the $n - q_e - q_y - q$ units that are not poor for both dimensions.

Table 1 Poor and non-poor units by income and environmental conditions

		Income		
		poor	non poor	
Environment	poor	q	$q_e - q$	q_e
	non poor	$q_y - q$	$n - q_e - q_y + q$	$n - q_e$
		q_y	$n - q_y$	n

In absence of overlapping, we have

$$q_e = q_y = q,$$

which implies both

$$q_e - q = q_y - q = 0 \text{ and } n - q_e - q_y + q = n - q :$$

poor (non poor) units according to income are also poor (non poor) units for the environment.

On the other side, when the overlap is perfect, the conditional distributions are the same, that is

$$q_y/n = q/q_e = (q_y - q)/(n - q_e).$$

Overlap becomes a critical issue since, when it is absent, the groups of the poor identified by the two dimensions are coincident and, therefore, the environmental dimension fully explains economic inequality, and vice versa. As overlap increases, we have a weaker influence of environmental dimension on economic inequality, with the minimum effect corresponding to the case of perfect overlap. Notwithstanding the relevant information provided by the analysis by column of Table 1, it is its analysis by row that results essential for the analysis of overlap and that can be carried out by means of both unidimensional and multidimensional indicators.

2.1 Unidimensional indicators

The simplest indicators that analyze the two dimensions separately are the head count ratios

$$H_y = \sum_{i=1}^{n} g_{yi}/n = q_y/n \text{ and}$$

$$H_e = \sum_{i=1}^{n} g_{ei}/n = q_e/n.$$

In the case (such as the SHIW data analyzed in the next Section) of sample surveys, it is necessary to also include the weight a_i attached to each sample unit, thus obtaining

$$H = \sum_{i=1}^{n} g_i a_i / \sum_{i=1}^{n} a_i.$$

The head count ratio can be computed not only for marginal distributions, but also with respect to conditional ones: the head count for income conditonally to environmental poor is

$$H_{y|ep} = q/q_e$$

and, analogously, we have

$$H_{y|enp} = (q_y - q)/(n - q_e),$$

$$H_{e|yp} = q/q_y \text{ and}$$

$$H_{e|ynp} = (q_e - q)/(n - q_y).$$

In case of perfect overlap, given equal conditional distributions, we get

$$H_y = H_{y|ep} = H_{y|enp}$$

while an increasing overlap leads to an increasing difference between head count ratios related to marginal and conditional distributions.

A further widely known and widely used unidimensional indicator is the Gini index G, which, similarly to the head count ratio, can be calculated on the n total observations, but also on the conditional distributions: with reference, for example, only to units poor for income, we obtain G_{py}, conditionally to units poor for the environment we have G_{pe}, etc.

Overall, we get a set of measures which allow to througously evaluate and compare the inequality levels of different groups of units.

A last relevant unidimensional poverty indicator is the Sen index [12], which can be expressed as

$$S = H_y(I_{py} + (1 - I_{py})G_{py})$$

where I_p is the mean over the poor of the normalized poverty gap,

$$I_{py} = \frac{1}{q_y} \sum_{i=1}^{q_y} \left(\frac{z_y - y_i}{z_y} \right)$$

and G_{py} is the Gini index of the poor.

Sens's proposal is based on the three *Is*, i.e., the three key elements of poverty, its size, H_y, its depth. I_{py}, and its distribution among the poor, G_{py}, and allows powerful insight on different aspects of poverty.

2.2 Bidimensional indicators

From H_y and H_e a two-dimensional indicator can be easily derived as a weighted average of the unidimensional measures:

$$H_{ye} = (H_y w_y + H_e w_e)/(w_y + w_e).$$

Among the possible weighting structures we refer to

$$w_y = log(n/q_y) \text{ and } w_e = log(n/q_e),$$

following the proposal by Cerioli and Zani [4] which aim to measure the intensity of deprivation and social exclusion related to each dimension. The more q_e is less than q_y, the more w_e is greater than w_y (or viceversa), thus indicating the different level of social exclusion attached to the two dimensions investigated in the paper. Within this framework, $w_y = w_e$ if and only if $q_y = q_e$, that is if $H_y = H_e$.

Alternatively, the simplest weight structure implies an equally-weighted multidimensional index:

$$w_y = w_e = 0.5.$$

Beyond the value of the indicator H_{ye}, the relevant aspect in the choice of the weighting system is the different composition of the set of poor units determined by different weights.

In order to analyze the interplay between environmental and income dimension the three indices H_y, H_e and H_{ye} are extremely helpful since, on their basis, it is possible to compare the three sets of poor units identified by them.

The joint analysis of the two dimensions can also be obtained by dividing the population in two subgroups, the first with the q_e poor units and the second with $(n-q_e)$ non poor units according to the environmental conditions, and deriving the Gini index for income as

$$G = G_{pe}p_{pe}s_{pe} + G_{npe}p_{npe}s_{npe} + G_{pe.npe}p_{pe}s_{npe} + G_{npe.pe}p_{npe}s_{pe}$$

where
$p_{pe} = q_e/n$ and $p_{npe} = (n-q_e)/n$ indicate the population shares,
$s_{pe} = p_{pe}\bar{y}_{pe}/\bar{y}$ and $s_{npe} = p_{npe}\bar{y}_{npe}/\bar{y}$ the income shares,
G_{pe} and G_{npe} the Gini indices of the two subgroups, and
$G_{pe.npe}$ is the Gini index between the poor and non-poor units according to the environmental conditions, with $G_{pe.npe} = G_{npe.pe}$ and

$$G_{pe.npe} = \frac{1}{q_e(n-q_e)(\bar{y}_{pe}+\bar{y}_{npe})}\sum_{i=1}^{q_e}\sum_{r=1}^{n-q_e}|y_{pei}-y_{nper}|.$$

The Dagum's decomposition of the Gini index, alongside the two traditional components of inequality within, G_w, and inequality between the subgroups, G_b, also introduces a component related to overlap, G_o. The differences between the poor and non-poor units according to the environmental dimension are jointly evaluated by means of G_b and G_o.

The inequality within component G_w is simply obtained as a weighted average of the Gini indices of the subgroups:

$$G_w = G_{pe}p_{pe}s_{pe} + G_{npe}p_{npe}s_{npe}$$

Given $\bar{y}_{pe} < \bar{y}_{npe}$, the components of inequality between subgroups G_b and of inequality related to overlap G_o are derived from $G_{pe.npe}$ and $G_{npe.pe}$, attributing to G_b the differences $|y_{pei}-y_{nper}|$ if $y_{pei} < y_{nper}$ and to G_o the differences $|y_{pei}-y_{nper}|$ if $y_{pei} > y_{nper}$. It is also possibile to obtain (see Costa [6]) semplified expressions for both G_b and G_o as

$$G_b = p_{pe} - s_{pe} + G_o$$

and

$$G_o = (G - G_w - p_{pe} + s_{pe})/2.$$

from wich it is extremely clear the central role that the overlap plays in measuring the differences between the poor and non-poor groups.

In order to take into account the effects of the environmental dimension on the Sen index, it is finally possible to decompose G_p, which allows to further investigate the role of environmental conditions on the income distribution among the poor.

3 A case study on Italian data

With the aim of illustrating the previous methods, we develop a case study on the data from the Bank of Italy's Survey on Households Income and Wealth for 2006, which is, unfortunately, the last year in which information on environmental conditions is available. The survey refers to a representative sample of the Italian population, the size of which allows reliable results at the national and macro territorial level (north-west, north-east, center, south and islands), while, starting from the regional level, the sample size may be insufficient. A complete review of the methodological issues related to the survey is provided in Baffigi et al. [3].

The variable of interest in order to evaluate the environmental dimension classifies the location of dwellings into four groups: degraded areas, neither prestigious nor degraded areas, prestigious areas, other.

In reference to the poverty lines, we set the 60% of the median of the equivalent income as z_y, the poverty line for equivalent income, and we consider households living in degraded areas to be environmentally poor.

Table 2 reports the size of the different groups and also their sample weight, which is the quantity of interest in order to calculate the various indicators, as exemplified for H in Section 2.1.

On the basis of z_y, we detect 1314 poor units, while, on the basis of z_e, we have 350 poor units. Table 2 also shows how only half of the poor units according to the environmental dimension are also poor according to income, while 85% of the non-poor according to the environmental dimension are also not poor according to income: a good match is highlighted between the groups of the non-poor, while there are strong differences between the groups of the poor.

Table 2 Italian households 2006, poor and non-poor by income and environmental conditions

		Income poor	Income non poor	
Environment	poor	q=176 a_q=184.39	$q_e - q$=174 a_{qe-q}=187.71	q_e=350 a_{qe}=372.10
	non poor	$q_y - q$=1138 a_{qy-q}=1217.78	$n - q_e - q_y + q$=6280 $a_{n-qe-qy+q}$=6178.12	$n - q_e$=7418 a_{n-qe}=7395.90
		q_y=1314 a_{qy}=1402.17	$n - q_y$=6454 a_{n-qy}=6365.83	n=7768 a_n=7768

3.1 Unidimensional indicators

The first results which can be derived from Table 2 are the unidimensional head count ratios for the two inequality dimensions which are analyzed here.

As for income, $H_y = 0.181$ indicates the presence of 18.1% of poor families, while $H_{y|ep} = 0.496$ and $H_{y|enp} = 0.165$ show really different dynamics for the conditional distributions, indicating a relevant presence (49.6%) of poor according to income among the poor according to the environmental dimension, against only a 16.5% of poor according to income among the non-poor according to the environmental dimension.

Furthermore, even if only in a descriptive context, the strong difference between $H_{y|ep}$ and $H_{y|enp}$ suggests to reject the hypothesis of perfect overlap.

For the environmental dimension, $H_e = 0.048$ implies 4.8% of poor families, with $H_{e|yp} = 0.131$ and $H_{e|ynp} = 0.029$: the conditional distributions still emphasize the presence of strong differences.

The overall income inequality indicator provided by the Gini index is equal to 0.318, while, conditionally to the income-poor units only, we have $G_{py} = 0.161$, and $G_{npy} = 0.264$ for the income-non-poor, thus suggesting a low inequality level among the poor units according to income.

Furthermore, we can obtain $G_{pe} = 0.314$ on the 350 units that are poor according to the environmental condition and $G_{npe} = 0.328$ on the environmental-non-poor units, indicating a non negligible inequality in both cases.

Finally, the poverty Sen index is equal to 0.071 and it combines the size of poverty, evaluated by $H_y = 0.181$, the depth of poverty (measured by $I_p = 0.279$) and its distribution, summarized by $G_{yp} = 0.161$.

The unidimensional poverty indicators are summarized in Table 3.

Table 3 Results for income and environmental inequalities, unidimensional indicators, Italian households 2006

Head count ratio			
$H_y = 0.181$	$H_{y\|ep} = 0.496$		$H_{y\|enp} = 0.165$
$H_e = 0.048$	$H_{e\|yp} = 0.131$		$H_{e\|ynp} = 0.029$
Gini index			
$G = 0.318$	$G_{py} = 0.161$		$G_{npy} = 0.264$
	$G_{pe} = 0.328$		$G_{npe} = 0.314$
Sen index components			
$S = 0.071$	$H_y = 0.181$	$I_{py} = 0.279$	$G_{py} = 0.161$

3.2 Bidimensional indicators

The first step of the joint analysis of the two dimensions can be illustrated by means of the picture of the income distribution of the two groups of the q_e poor units and the $(n - q_e)$ non poor units according to the environmental dimension (last column of Table 2).

From Figure 1 it is possible to observe how the two groups differ in many aspects, showing quite different distributions, but also sharing a strong overlap.

The probability of transvariation, which evaluates the frequency of overlap between the two dimensions, is 50.3%; the extent of overlap is measured by the intensity of transvariation, which is equal to 39%, thus indicating a non-negligible, albeit not high, value.

Conditionally to income-poor units only (first column of Table 2) we have a different overlap between the poor and non poor for the environmental dimension: probability and intensity of transvariation are 0.79 and 0.72, respectively.

Moving to the multidimensional indicator H_{ye}, which takes into account the two dimensions jointly, we have a percentage of poor families equal to 9.6% for $w_i = log(n/q_i)$, while we have $H_{ye} = 0.116$ for $w_i = 0.5$.

The sets of poor units identified by H_y, H_e and H_{ye} coincide only for the 176 units that are poor for both dimensions, while the multidimensional index also classifies as poor some units which are poor according only to one of the two dimensions. More specifically, on the basis of $w_y = 0.74$ and $w_e = 1.32$, the multidimensional index classifies as poor first the 174 poor units according to the environmental dimension and then some of the poor units according to income. On the contrary, in the equally-weighted index, all poor units for only one dimension are considered on the same level, thus inevitably favouring the poor units only for income, which are far more numerous.

To include the environmental dimension in the analysis, it is also possible to decompose the Gini index on the basis of the two groups of 350 and 7418 units which are, respectively, poor and non-poor with respect to the environmental conditions.

From Table 4, it is possible to observe how the inequality within represents the most relevant component, with a weight of G_w/G =91.19%, while the inequality

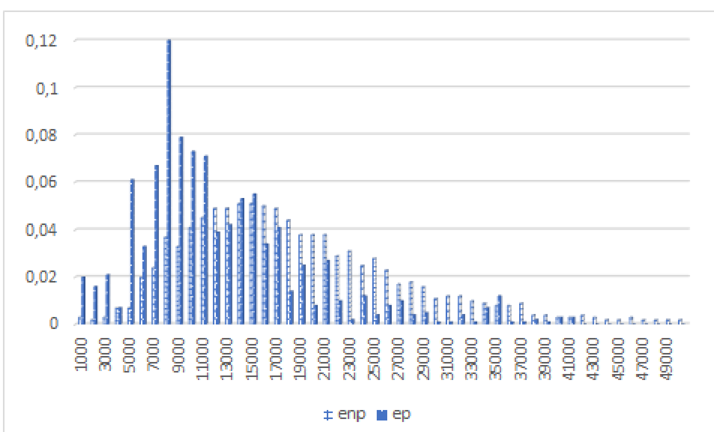

Fig. 1 Poor (ep) and non poor (enp) according to the environmental dimension - Italian households income 2006

between and the overlap component weighs G_b/G =7.23% and G_o/G =1.57%, respectively.

This result should not be read as an indication that the environmental dimension is of little relevance, but as an effect of the weight (94.2%) of the non-poor group on the total. If we look at the decomposition of G_{py}, the Gini index related only to the q_y units which are poor for income, the results are quite different: the inequality within weighs G_{pyw}/G_{py} =75.16%, the inequality between G_{pyb}/G_{py} =15.53% and the overlap component G_{pyo}/G_{py} =9.32%. We can include these three components in the Sen index computation and evaluate their effect on S.

Furthermore, if we decompose G_{pe}, the Gini index for the environmental-poor units, we are able to assess the differences between the $q = 176$ units poor also for income and the $(q_e - q) = 174$ units poor only for environment. For the decomposition of G_{pe} we obtain, obviously, a zero overlapping, since we compare two groups defined on the basis of the poverty line z_y, and we detect a relevant weight of the inequality between, with G_{peb}/G_{pe} =68.1% and G_{pew}/G_{pe} =31.9%, thus suggesting relevant differences between the two groups.

The summary of the bidimensional poverty indicators is shown in Table 4.

Table 4 Results for income and environmental inequalities, multidimensional indicators, Italian households 2006

Two-dimensional indicator					
$w_y = 0.74$	$w_e = 1.32$	$H_{ye} = 0.096$			
$w_y = 0.50$	$w_e = 0.50$	$H_{ye} = 0.114$			
Gini index decomposition					
$G = 0.318$	$G_w = 0.290$	$G_b = 0.023$	$G_o = 0.005$		
$G_{py} = 0.161$	$G_{pyw} = 0.121$	$G_{pyb} = 0.025$	$G_{pyo} = 0.015$		
$G_{pe} = 0.328$	$G_{pew} = 0.104$	$G_{peb} = 0.223$	$G_{peo} = 0$		
Sen index components					
$S = 0.071$	$I_p = 0.279$	$G_{py} = 0.161$	$G_{pyw} = 0.121$	$G_{pyb} = 0.025$	$G_{pyo} = 0.015$

Overall, we identify significantly different patterns for the poor and the non-poor with respect to the environmental dimension, with a strong overlap with the economic dimension only for the non-poor group.

4 Conclusions

Multidimensional poverty indicators and Gini index decomposition allow powerful insights into the interaction between environmental and economic dimensions, especially in reference to the overlap between the two dimensions. These methods are extremely flexible with respect to different definitions of the environmental dimension and can be implemented using a wide range of variables of any type.

In order to assess and to stress the relevance of our results, in a netx paper we aim to develop uncertainty measures of the indicators used in this work, thus allowing to include inferential aspects in the analysis.

As we also find in a case study on Italian data, the poor and non-poor groups show significantly different patterns in the interaction between environmental and economic inequalities.

Environmental poverty is typically stable over time, it is likely linked to persistent poverty, and can therefore be extremely useful in correctly identifying poor units. Our finding confirms and underlines that income alone provides only partial information on poverty conditions, information which can be complemented by the environmental dimension, so as to achieve a relevant improvement both for the poverty measurement and for the implementation of policy actions.

By contributing to the measurement and the evaluation of the interplay between economic and environmental inequalities, we also tackle the interconnession between different SDGS, which represents an essential prerequisite for their successful accomplishment.

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