A MULTIDIMENSIONAL ANALYSIS FOR MONITORING ENVIRONMENTAL HEALTH IN ITALY[1]

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Abstract. In the last few years, attention and sensibility towards problems relating to environmental issues has grown. Consequences of climate change, reduction of water resources, urban pollution and other manifestations of environmental crisis transversally affects the life and activities of human beings. In this work some main indicators for the assessment of environmental quality in the national territory are analysed. The complex and multidimensional nature of environmental phenomena has required identification, selection and measurement of a series of indicators relating to 6 macro areas (geological and natural risks, consumption, emissions, waste, protected areas, sustainability and environmental certification) to the implementation of more effective and incisive information and operational programs in the area. Given multidimensionality of the phenomena, having analyzed and described the individual dimensions, a multivariate synthesis analysis was carried out to compare the state of environmental health at a regional level. The results show that the negative impact on the environment is in all Italian regions but is stronger in southern Italy. It is a study that offers in-depth insights to subjects engaged in development policies in compliance with environmental sustainability.

1. Introduction

The aim of this work is to analyse the impact of human activities on the Italian regions. The environmental analysis presents some critical issues since there are several aspect to identify and sometimes they are not homogeneous. A set of objective indicators has been selected to express the different environmental pressures caused by human and economic activities, moreover a subjective sentiment of environmental satisfaction has also been included. The indicators are evaluated in

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[1] The paper is the result of the common work of the authors. In particular: sections are attributed as follows: F. Fullone paragraphs 1 and 2, M. Carbonara paragraph 3 and G. Lecardane paragraphs 4 and 5.

relation to the regional area and resident population, and then different multidimensional analyses are carried out.

2. Factor analysis

There are many public indicators, provided by the research institutes Istat and Ispra, regarding different aspects of the environmental dimension at regional level. The research hypothesis to be tested is whether there are a few latent factors that influence the observed indicators.

A factor technique has been used to carry out an exploratory analysis of the observed indicators of the environmental phenomena. The assumption is that the analysed variables represent the effects of one or a few latent variables (factors), that are not directly observable and measurable (reflexive model). The indicator's long list is represented in Table 1.

Correlation analysis shows that some indicators are highly correlated (Pearson correlation factor >0,9) for example (nitrous oxide emissions, carbon dioxide emissions). In this case they seem to provide the same information, so a short list has been selected (Tab. 2).

Table 1 - *Environmental indicators, long list.*

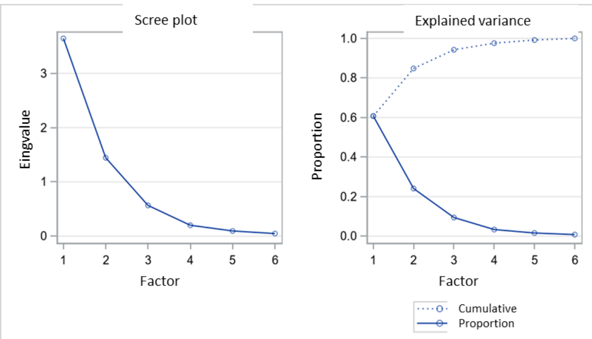
Environmental Issue	Environmental indicators	*Source*	*Year*
Soil	Soil consumption	*ISPRA*	*2021*
	Amount of fertilizer used	*ISTAT*	*2021*
Raw material	Raw material taken	*ISTAT*	*2020*
Population	Population density	*ISTAT*	*2021*
Companies in the environmental area	Active companies with 3 or more employees that reduce the environmental impact of their activities (2018 Census)	*ISTAT*	*2018*
	Environmental quality UNI-EN-ISO 14001 certifications for company and production sites	*ISPRA*	*2020*
Waste Sorting	Urban waste collected separately	*ISPRA*	*2020*
	Special and hazardous waste incinerated and energetically recovered	*ISPRA*	*2020*
Atmospheric emissions	Nitrous oxide emissions N20	*ISPRA*	*2020*
	Carbon dioxide emissions CO2	*ISPRA*	*2020*
Environmental quality Perception	Environmental Satisfaction	*ISTAT*	*2020*

Table 2 - *Environmental indicators, short list.*

Indicators	*Dimension*
Final consumption of electricity (agr, industrial, tertiary, residents) per unit area	*GWh per km^2*
Soil consumption	*% of regional area*
Raw material taken with respect to the regional area	*1000 tons per km^2*
Population density	*residents per km^2*
Percentage of people very or fairly satisfied with the environmental situation (air, water, noise) of the area in which they live.	*% of residents aged 14 and over*
Active companies with 3 or more employees that reduce the environmental impact of their activities (2018 Business Census) compared to the total regional population	*n. companies per residents population*

The selected indicators describe the impact of human activities on the various regional areas, characterised by artificially covered soil, energy consumption, raw material extraction, and population density. At the same time, we will consider the number of companies that reduce the environmental impact of their activities, in relation to the resident population, and the percentage of people who express a positive assessment of the environmental situation of the area in which they live. The factor extraction method used is the main components, which aims to identify a linear combination of the observed indicators, able to explain most of their variance.

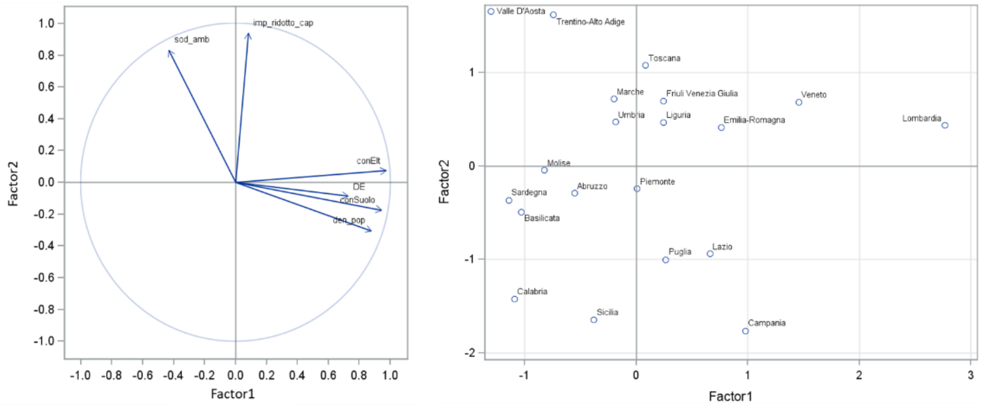
Figure 1 - *Factor analysis: scree plot, eingvalues.*



Kaiser measure of sample adequacy: MSA total = 0.7			
	Eingvalue	*Proportion*	*Cumulative*
1	3,64	0,61	0,61
2	1,44	0,24	0,85
3	0,57	0,09	0,94
4	0,20	0,03	0,98
5	0,10	0,02	0,99
6	0,05	0,01	1,00

From the six indicators described in the short list, two factors have been extracted, that explain 85% of the total variance (Fig. 1). However, the variance explained by the two factors for each variable is not less than 65%.

Figure 2 - *Rotated factor pattern, left image; factor score of the regions on the right*.



The factors are easy to interpret on the basis of figure 2; the first, which explain the 65% of the total variance, is highly correlated with the consumption of resources such as soil and energy, the extraction of raw material and the environmental impact of the population on the territories. The second factor, on the other hand, reflects the reduced impact of economic activities in relation to the resident population and a general sentiment of environmental satisfaction.

The factor score of the regions (Fig.2) gives the representation of each region on the factorial coordinates. In the first quadrant of the Cartesian plane we can observe the central-northern regions where consumption and environmental pressures are high, and at the same time, there is a moderately positive perception of the environmental situation.

In the second quadrant, factor1 which reflects consumption and environmental pressure on the territory, is moderately low, and there is a medium-high environmental perception above all in the Alpine regions. In the third quadrant, consumption and environmental pressures are not high, but the environmental perception is not positive. In the fourth quadrant the large southern regions are represented, where environmental pressures are moderate, but environmental perception is medium-low, especially in Campania.

3. Cluster analysis

In order to explore the main and most significant similarities and differences in the state of environmental health among the Italian regions, the Cluster analysis was carried out.

Ward's hierarchical method was used for the analysis and the quadratic Euclidean distance was used to measure the dissimilarity between the statistical units.

For the analysis, the variables considered in the factor analysis previously described in paragraph 2 were used:

- Final consumption of electricity (agriculture, industry, tertiary, residual)
- Consumed soil
- DE Raw material taken with respect to the regional area
- Population density
- Environmental satisfaction
- Active companies with 3 or more employees that reduce the environmental impact of their activities

The cluster analysis made it possible to identify five different groups' number and territorial distribution (Fig. 3):

Cluster 1: Abruzzo, Molise, Basilicata, Calabria, Sardegna.

Cluster 2: Piemonte, Friuli Venezia Giulia, Liguria, Toscana, Umbria, Marche.

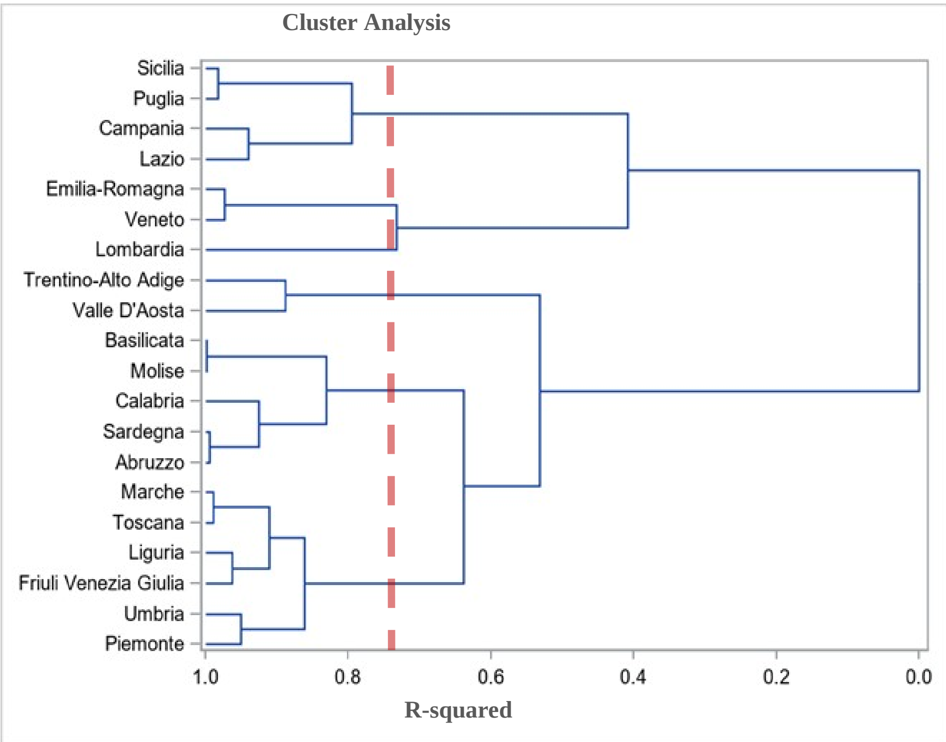
Cluster 3: Campania, Lazio, Puglia, Sicilia.

Cluster 4: Lombardia, Veneto, Emilia-Romagna.

Cluster 5: Valle D'Aosta, Trentino-Alto Adige.

R-squared equal to 0.73 indicates the validity of the chosen partition.

Figure 3 – *Dendogram.*



The following graph and table (Fig.4 and Tab. 3) illustrate their spatial distribution and composition.

Cluster 5, which includes Valle d'Aosta and Trentino-Alto Adige, is the one that is best positioned with a reduced environmental impact on the territories, while the number of companies that reduce the environmental impact of their activities and environmental satisfaction they are taller.

Cluster 1, which includes Abruzzo, Molise, Basilicata, Calabria and Sardegna, also has a good advantage situation with a high level of satisfaction.

In Clusters 2 and 4, which include the central-northern regions, consumption and environmental pressures are higher and there is a moderately positive perception of the environmental situation.

In Cluster 3, where the large southern regions are represented, environmental pressures are higher but the perception and number of companies that reduce the environmental impact of their activities are lower.

Figure 4 – *Representation of clusters on factors.*

Table 3 – *Average values of variables calculated within each cluster.*

Cluster	DE	Final consumption of electricity	Consumed soil	Population density	Active companies that reduce the environmental impact of their activities	Environmental satisfaction
5	0,5	0,4	3%	58,7	16,1	86,9
1	0,8	0,4	4%	86,0	10,0	75,8
2	0,8	0,9	7%	170,9	13,0	78,7
3	1,1	1,0	8%	284,4	9,4	62,8
4	1,6	1,9	11%	294,4	13,3	71,8

4. A multidimensional measurement of the environmental phenomenon in Italy with synthetic index

The objective is to provide a synthetic tool the state of the environmental phenomenon starting from a set of selected indicators considered relevant in their impact with the territory and subsequently comparing performances at the regional level. Based on the latest data provided by Istat and Ispra on the environmental quality of our Italian regions, a set of elementary indicators were selected and combined (Tab. 4). Indicators present a rather pronounced variability and little correlation with each other, characteristics for the purposes of the objective being proposed. It's the basis for the aggregation process through the construction and comparability of some main composite methods.

Table 4 – *Environmental indicators selected*

Environmental issues	Environmental indicators			
	Polarity (+/-)	Indicators	Year	Source
Energy	(-)	a1. Final energy consumption (residents, industry and tertiary sector) *(GWh/km2)*	2021	ISPRA
Soil	(-)	a2. Soil consumption *(% of regional area)*	2021	ISPRA
Raw material	(-)	a3. Raw material taken *(1,000 tons per km²)*	2020	ISTAT
Population	(-)	a4. Population density *(residents per km2)*	2021	ISTAT
Perception of environm. quality	(+)	a5. Environmental Satisfaction *(% residents aged 14 and over)*	2020	ISTAT
Companies in the environm. area	(+)	a6. Active companies with 3 or more employees that reduce the environmental impact of their activities *(n. companies per residents population)*	2018	ISTAT

Elementary indicators have been normalized and standardized to obtain data purified from units of measurement and comparison process. Standardized deviation in the composite index allows the construction of a robust measure and not very sensitive to remove a single elementary index (Mazziotta M. and Pareto A., 2013).

In addition, *polarity* (positive or negative) of the relationship between indicator and phenomenon was specified.

Finally, standardized indicators were aggregated. The choice of aggregation process follows the Mazziotta-Pareto Index (MPI) methodology as the MPI penalises the simple average with horizontal variability. This approach is of absolute importance when dealing with the multidimensional phenomenon; combination of domains that must be as homogeneous as possible. Following, steps to calculate composite index by comparing the following methods.

Given the matrix $X=\{x_{ij}\}$ with n rows (units) and *m* columns (indicators), composite methods have the following mathematical properties:

Adjusted MPI *(AMPI)*

$$MPI_{ci}^{\pm} = M_{ri} \pm S_{r_i} cv_i$$

$$\text{con } r_{ij} = \begin{cases} \frac{(x_{ij} - Min_{xj})}{(Max_{xj} - Min_{xj})} 60 + 70 \text{ if the indicator } j \text{ has positive polarity} \\ \frac{(Max_{xj} - x_{ij})}{(Max_{xj} - Min_{xj})} 60 + 70 \text{ if the indicator } j \text{ has negative polarity} \end{cases}$$

$$M_{r_i} = \frac{\Sigma_{j=1}^{m} r_{ij}}{m} \qquad S_{r_i} = \sqrt{\frac{\Sigma_{j=1}^{m} (r_{ij} - M_{ri})^2}{m}} \qquad cv_i = \frac{S_{ri}}{M_{r_i}}$$

The *AMPI* is a non-compensatory (or partially compensatory) composite index and allows min-max standardization of the indicators j and aggregation with the arithmetic mean penalized by the "horizontal" variability of the indicators themselves. Normalized values are approximately in the range (70; 130), where 100 is the reference value[2]. From the exploratory data analysis, indicators show a pronounced variability and little correlated with each other, except values corresponding to a1, a2 and a4, characteristics suitable to achieve the aims (Tab. 5).

Figure 5 shows cartograms of MPI^+ and MPI^- method calculated in the Italian regions. Result of the regional ranking with the *composite index* method is like groupings obtained with the *cluster* and *ACP analysis.*

[2] In the Bienaymé-Cebycev theorem, terms of the distribution within the interval (70; 130) constitute at least 89 percent of the total terms of the distribution.

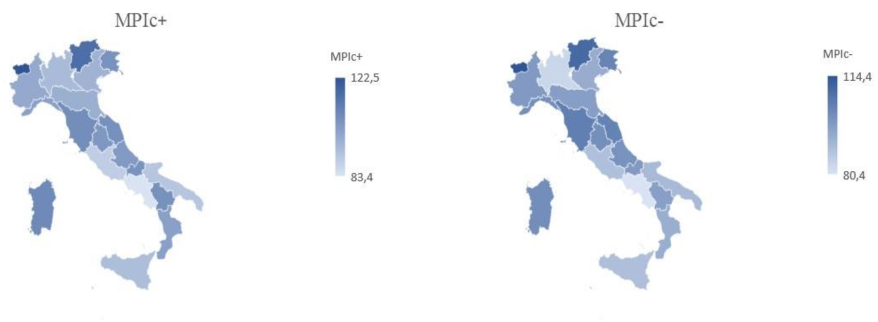
Table 5 – *Average and variability measures of environmental indicators.*

	a1	a2	a3	a4	a5	a6
M	0,90	0,06	0,97	179,66	64,59	11,87
S.q.m.	0,59	0,04	0,62	109,68	47,91	8,48
C.V.	0,66	0,68	0,64	0,61	0,74	0,71

Source: Istat and Ispra data processed

Ranking, based on the assumed values of the two synthetic indicators, shows the positioning of Italian regions according to the state of environment health that decreases as one moves towards the higher ranks (Tab. 6). The positioning, in terms of pressure on the environment for the issues considered, distinguishes Valle D'Aosta and Trentino Alto Adige as the region with the best perception environmental performance. Instead, Sicilia, Puglia, Lazio and Campania the environmental perception is not positive although consumption and environmental pressures are not high. Also noteworthy is the positioning in the lower ranks of Emilia-Romagna, Veneto and Lombardia where environmental consumption and pressures are high and the perception in terms of household satisfaction is rather negative.

Figure 5 – *Map of the MPI$^+$ and MPI$^-$ composite indices.*



Source: Istat and Ispra data processed

Table 6 – *Regional ranking between MPI[+] and MPI[-] composite indices.*

Region	MPIc+		MPIc-		Region	MPIc+		MPIc-	
	N.	Rank	N.	Rank		N.	Rank	N.	Rank
Valle D'Aosta	122,5	1	114,4	1	Liguria	101,9	11	100,5	8
Trentino-A. A.	115,7	2	109,6	2	Calabria	101,8	12	93,2	15
Sardegna	107,8	3	100,7	6	Piemonte	99,2	13	98,1	10
Toscana	106,7	4	104,4	3	Emilia-R.	97,8	14	97,0	12
Marche	106,0	5	103,5	4	Veneto	96,7	15	93,5	14
Basilicata	105,7	6	96,8	13	Lombardia	94,5	16	83,6	19
Friuli-V. G.	105,6	7	103,3	5	Sicilia	93,7	17	89,3	17
Molise	105,6	8	98,1	11	Puglia	91,5	18	90,3	16
Umbria	104,1	9	100,6	7	Lazio	89,3	19	88,9	18
Abruzzo	103,5	10	99,7	9	Campania	83,4	20	80,4	20

Source: Istat and Ispra data processed

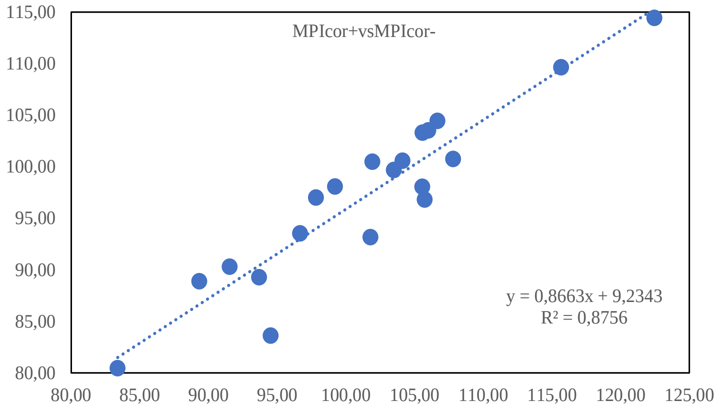
Table 7 shows rank differences compared by means of the absolute difference and Spearman's rank correlation coefficient. Sensitivity analysis shows similar results in the comparison between MPI[+] and MPI[-] method with absolute average rank differences 1.90 positions respectively with a strength of the relationship directly proportional and close to 1 (0.91). Linear relation is also high with R^2 equal to 0.87 (Fig. 6).

Table 7 – *Sum of ranking differences between MPI[+] and MPI[-] composite indices*

Measures	MPIc+-MPIc-
Absolute average rank difference	1,90
Cograduation index ρ	0,91

Source: Istat and Ispra data processed

Figure 6 – *Linear relationship and* R^2 *between MPI methods.*



Source: Istat and Ispra data processed

5. Conclusions

The study on environmental aspects of Italian regions through the comparison of multidimensional *acp*, *cluster* and *compositive methods* led to a convergence judgment of results and offer an important contribution to the interpretation of the phenomenon.

The geography of environmental status, anthropogenic pressure and perception once again shows a unbalanced configuration to the detriment of most of the central and southern regions. At the other end of the distribution, greater satisfaction and environmental performance are recorded in the North where investments in development projects and awareness of environmental issues are growing.

A good result for those who carry out a study of the phenomenon and must give an interpretation that is as representative as possible of the environmental reality.

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