THE CITY AS A MEASURE OF SUSTAINABILITY. A MULTIDIMENSIONAL ANALYSIS[1]

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Abstract. Cities are at a the turning point in the global comparison of sustainable development, as they are the centre of a growing majority of the world's population. They are the engine of local and national economies and represent the hub of well-being; more than 80% of global economic activities are concentrated in urban centres. The climate crisis and the need to protect the environment have pushed all the countries of the world to reorganise their urban centres, with the intention of creating real "sustainable cities". Goals 11 of the 2030 Agenda of the United Nations calls for making cities and human settlements more inclusive, safe, resilient and sustainable. Cities must meet specific environmental, social, economic criteria and be redesigned in their spatial, social and economic organisation. They must become a laboratory of sustainability and inclusion, able to forge a strong alliance with its citizens and the environment. The aim of this paper is to analyse the requirements for a new urban centre model through exploratory methods of multivariate analysis and the comparison of characteristic indicators that in a common vision can bring out significant peculiarities and dynamics in the urban context. The multidimensional complexity of the study required the identification, selection and measurement of a set of indicators relating to the macro-areas of a demographic, social, economic and environmental nature and a multivariate synthesis analysis for comparisons in terms of urban sustainability. A study that offers insights to understand the logic and dynamics of our cities as the keystone for the interpretation and regulation of urban, social and economic development processes.

1. Introduction

Currently, more than half of the world's population lives in urban areas, a percentage that is expected to increase to 68% by 2050. Cities are the engine of local and national economies, but besides the opportunities, urbanisation also brings considerable challenges.

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[1] The paper is the result of the common work of the authors. In particular: sections are attributed as follows: M. Carbonara paragraphs 1 and 2.1 and 4, A. Pareto paragraph 2.2 and G. Lecardane paragraph 3.

The climate crisis and the need to protect our environmental heritage have prompted countries around the world to reorganise their urban centres with the aim of creating 'sustainable cities'. The concept of sustainable cities is closely linked to the Sustainable Development Goals, set in 2015 by the 193 UN member states. In Goals 11 of the UN 2030 Agenda, the common goal is to make cities and human settlements more inclusive, safe, resilient and sustainable. To achieve this goal, cities must meet specific environmental, social and economic criteria, integrate innovative technologies, have an efficient and accessible transport system, expand public spaces and green areas making them inclusive and safe, implement careful planning of human settlements and, finally, better manage their energy resources for a lower impact on the environment.

The aim of this work is to determine the conditions necessary to identify an ideal model of a 'sustainable city' by establishing a set of individual indicators for macro-areas of a demographic, social, economic and environmental nature. Through a multivariate synthesis analysis, Italian provincial capitals are compared in terms of urban sustainability.

The study also aims to offer food for thought on the logic and dynamics of our cities and the related urban, social and economic development processes.

2. Data and method

2.1 Data

A set of indicators for 9 macro-areas (education, work, economic well-being, politics and institutions, culture, social services, territory and environment, established economy, infrastructure and mobility) (Tab. 1) was identified on the basis of "A misura di comune", a multi-source system, in which sources of an experimental nature are valorised alongside other, more consolidated ones.

The objective of the system is to provide an increasingly detailed integrated information framework of indicators available at municipal level, useful for the planning, programming and management tasks of local authorities.

Table 1 – *Macro-areas and individual indicators.*

Macro-area	Indicator
Education	a1. Alphabetical proficiency of students
	a2. Numerical proficiency of students
Work	a3. Employment rate
	a4. Inactivity rate
Economic well-being	a5. Irpef taxpayers with income of less than 10,000 euros - Incidence on total taxpayers
Politics and institutions	a6. Women and political representation at local level (Municipal Councils) - Impact on total elected
	a7. Women in Municipal Councils – Impact on total Council members
Culture	a8. Libraries registered in the National Library Registry per 100 thousand inhabitants
Social services	a9. Expenditure on social interventions and service for municipalities by type of user
Territory and environment	a10. Urban air quality – PM10
	a11. Total density of green areas
	a12. Differentiated collection of urban waste (Incidence of differentiated collection on total waste)
	a13. Cars in circulation with emission standards lower than Euro 4 (Incidence on total cars)
Established economy	a14. Entrepreneurship rate
Infrastructure and mobility	a15. Road accident rate
	a16. Density of bike paths
	a17. Seat-km offered by local pubblic transport
	a18. Availability of pedestrian areas

Source: Istat

2.2 Composite index construction

The 18 individual indicators of sustainability have different units of measurement and ranges; some have positive polarity[2] (e.g., employment rate), while others have negative polarity (e.g., urban air quality – PM10). Therefore, they were normalised by transformation into *z*-scores and the signs of the indicators with negative polarity were reversed. Assuming that the indicators of each macro-area are substitutable (i.e., a deficit in one component may be compensated by a surplus in another and

[2] The polarity of an individual indicator is the sign of the relation between the indicator and the phenomenon to be measured (+ if the individual indicator represents a dimension considered positive and - if it represents a dimension considered negative).

vice versa), a set of 9 full compensatory composite indices (one for each macro-area) was obtained by arithmetic mean of individual indicators. In the case of macro-areas with only one individual indicator (i.e., economic well-being, culture, social services and established economy) no aggregation was done. Finally, the Wroclaw taxonomic method was applied for constructing a ranking of the cities according to their sustainability (Mazziotta and Pareto, 2017). The method rests on the concept of 'ideal unit': a hypothetical city that has, for each indicator, the most desirable value among all the cities (optimal score). The Euclidean distance from each city to the 'ideal unit' is then calculated as follows:

$$\mathrm{D}_i = \sqrt{\sum_{j=1}^{m} (z_{ij} - z_{0j})^2}$$

where z_{ij} is the standardised value[3] of the index j for the city i and z_{0j} is equal to $\max_i(z_{ij})$, as all the 9 indices have positive polarity. The composite index for the unit i is given by:

$$\mathrm{WTM}_i = \frac{\mathrm{D}_i}{\overline{\mathrm{D}}_0 + 2\sigma_0}$$

where $\overline{\mathrm{D}}_0$ and σ_0 are the mean and the standard deviation of the distances D_i.

WTM is a partially compensatory composite index, since we assume that a deficit in one area may be only partially compensated by a surplus in another and viceversa. The index is equal to zero when the distance between a given city and the 'ideal unit' is null (all the values coincide). The higher is the index, the greater is the difference between the two units.

3. Results

Through a multivariate synthesis analysis, the Wroclaw taxonomic method was applied to the Italian provincial capitals to build a ranking based on urban sustainability and comparability with respect to the ideal city. A hypothetical city that has, for each indicator, the most desirable value among all the cities (optimal score).

With WTM method, a weighting of the elementary indicators is implicitly implemented, which are more influential on the synthetic index, the greater the distances recorded with respect to the ideal situation.

[3] Each indicator is transformed into a standardised variable with mean 0 and variance 1.

Table 2 – *Summary statistics – 2021.*

Indicator	Mean	Median	Min	Max	Std. dev.	CV
a1	199.7	200.8	181.4	213.0	6.8	3.4
a2	45.7	46.7	35.0	54.2	5.0	10.9
a3	196.2	197.6	173.2	215.8	9.9	5.0
a4	49.4	48.3	41.4	58.5	4.1	8.3
a5	26.1	25.3	18.8	40.8	4.9	18.9
a6	30.1	28.1	9.4	47.5	8.1	27.1
a7	40.7	40.0	10.0	66.7	7.6	18.6
a8	30.5	27.3	3.1	141.3	19.2	63.0
a9	160.7	142.9	13.4	618.8	87.6	54.5
a10	24.1	18.0	0.0	75.0	20.2	84.0
a11	18.9	13.9	0.3	71.2	16.1	84.9
a12	62.1	66.5	11.3	87.5	16.1	25.9
a13	26.9	26.0	2.7	50.9	7.9	29.5
a14	90.0	89.0	52.1	145.7	16.9	18.8
a15	3.6	3.6	1.2	7.1	1.1	31.3
a16	40.4	20.0	0.0	197.8	49.1	121.4
a17	2.321.2	1.688.0	158.0	16.827.2	2.202.0	94.9
a18	43.4	23.4	0.0	684.0	82.6	190.2

Source: Istat

Starting from the comparison of the distributions of the 18 indicators through the main statistical measures of location and statistical dispersion (Table 2), the outcome of the descriptive analysis outlines almost symmetrical distributions with mean and median similar to each other but heterogeneous, with considerable levels of dispersion (Std. dev. and CV) for several indicators (a9, a16, a17 and a18).

Suitable characteristics for the application of the WTM synthesis method and the purposes of the analysis.

Subsequently, assuming the principle of substitutability of the indicators of each macro-area, the synthesis analysis was concentrated on a more limited number of complete compensatory composite indices from 18 to 9 (one for each macro-area) by means of the arithmetic mean of the individual indicators (Table 3). Furthermore, the polarity (positive or negative) of the relationship between indicator and phenomenon was specified.

Table 3 - *Indicators for Wroclaw Taxonomic Method (WTM) and polarity (+/-) – 2021.*

Indicator	Macro-area	Polarity
V1	Education	+
V2	Work	+
V3	Economic Well-Being	+
V4	Politics and Institutions	+
V5	Cukture	+
V6	Social Services	+
V7	Territory and Environment	+
V8	Established Economy	+
V9	Infrastructures and Mobility	+

Source: Istat

The indicators have been normalized and standardized to obtain data purified from the units of measurement and the comparison process. This approach is of absolute importance when dealing with the multidimensional phenomenon; combination of domains that must be as homogeneous as possible.

Figure 1 shows the cartogram of the WTM index developed for the 109 Italian provincial capitals. The values assumed by the synthetic indicator highlight the positioning of Italian cities in terms of sustainability, which decreases as one proceeds towards the highest positions.

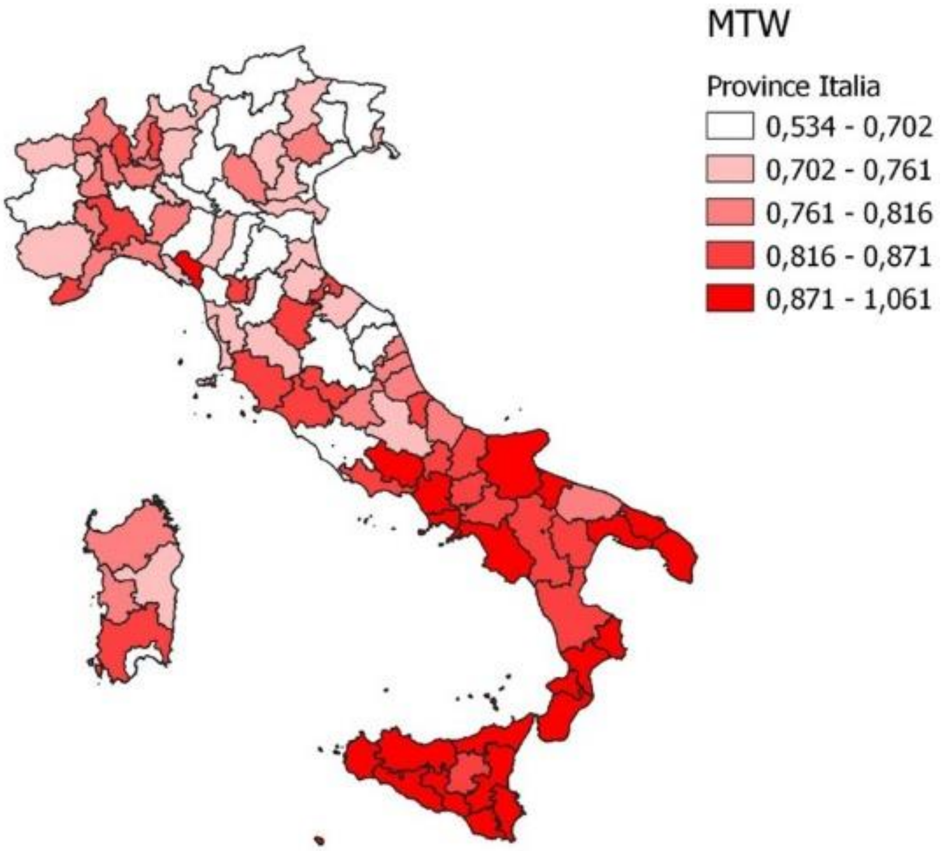
The outcome of the analysis returns the classic subdivision of the decreasing territorial dualism North and South.

From the ranking (Table 4) we can observe the positioning of Italian municipalities according to the degree of sustainability that decreases moving towards the highest ranks. The positioning distinguishes Bologna and Trento as the cities with the best performances of urban sustainability, differently Catania as the city with the highest negative impact.

In the ranking of the top five most sustainable cities, Macerata, Trieste and Venice stand out, cities of small and medium demographic size in central-northern Italy. It is also interesting to note the ninth place occupied by Cagliari among the most sustainable, smart and inclusive Italian cities.

At the bottom of the list, with the worst livability, are the cities of southern Italy and in particular: Trapani, Barletta, Crotone and Agrigento. These are the cities that struggle the most to respond to urban emergencies and to guarantee an acceptable quality of life for their inhabitants.

Figure 1 - *Map of the WTM index – 2021.*



The characteristics of a sustainable city are intrinsic to those of a circular city, embracing the use of renewable energy sources, virtuous waste management, the adoption of practices for sustainable mobility and the reuse of the material and energy resources used. The goal is to organize more efficient, livable, green and digital city spaces, perfectly integrated with each other and it is clear how urgent it is to make cities more inclusive, safe, resilient and sustainable.

In Italy there is still a long way to go but let's see in detail how far our cities are from the ideal and sustainable one using the WTM method. In the analysis of the 9 sustainability indicators, the "ideal" city has a WTM index equal to zero with optimal performance. Furthermore, the index is equal to zero when the distance between a given city and the ideal unit is zero (all values coincide). The higher the index, the greater the difference between the two units.

Table 4 - *WTM ranking - Provincial capital cities – 2021.*

Rank	Provincial capitals	Euclidean distances	WTM	Rank	Provincial capitals	Euclidean distances	WTM
1	Bologna	7,319	0,534	56	Verona	10,857	0,792
2	Trento	7,904	0,577	57	Teramo	10,873	0,793
3	Macerata	8,406	0,613	58	Treviso	10,962	0,800
4	Trieste	8,501	0,620	59	Ascoli Piceno	11,012	0,803
5	Venezia	8,543	0,623	60	Prato	11,068	0,807
6	Pavia	8,659	0,632	61	Chieti	11,071	0,808
7	Bolzano	8,692	0,634	62	Rieti	11,084	0,809
8	Pordenone	8,709	0,635	63	Monza	11,150	0,813
9	Cagliari	8,750	0,638	64	Asti	11,174	0,815
10	Firenze	8,860	0,646	65	Terni	11,206	0,817
11	Parma	9,097	0,664	66	Varese	11,236	0,820
12	Udine	9,103	0,664	67	Campobasso	11,274	0,822
13	Roma	9,245	0,674	68	Matera	11,366	0,829
14	Ferrara	9,291	0,678	69	Grosseto	11,367	0,829
15	Mantova	9,291	0,678	70	Rimini	11,380	0,830
16	Perugia	9,355	0,682	71	Benevento	11,428	0,834
17	Lucca	9,372	0,684	72	Pistoia	11,435	0,834
18	Ancona	9,383	0,684	73	Viterbo	11,572	0,844
19	Modena	9,436	0,688	74	Carbonia	11,610	0,847
20	Torino	9,478	0,691	75	Cosenza	11,654	0,850
21	Brescia	9,589	0,699	76	Imperia	11,758	0,858
22	Cremona	9,626	0,702	77	Lecco	11,777	0,859
23	Padova	9,632	0,703	78	Potenza	11,786	0,860
24	Biella	9,687	0,707	79	Alessandria	11,786	0,860
25	Ravenna	9,807	0,715	80	Avellino	11,804	0,861
26	Reggio Emilia	9,812	0,716	81	Isernia	11,818	0,862
27	Belluno	9,815	0,716	82	Enna	11,836	0,863
28	Livorno	9,828	0,717	83	Latina	11,843	0,864
29	Pisa	9,841	0,718	84	Arezzo	11,850	0,864
30	Siena	9,844	0,718	85	Pescara	11,928	0,870
31	Cuneo	9,869	0,720	86	Lecce	11,935	0,871
32	Gorizia	9,885	0,721	87	Salerno	11,952	0,872
33	L'Aquila	10,050	0,733	88	Massa	12,231	0,892
34	Bergamo	10,061	0,734	89	Brindisi	12,365	0,902
35	Pesaro	10,095	0,736	90	Catanzaro	12,370	0,902
36	Nuoro	10,096	0,736	91	Caltanissetta	12,409	0,905
37	Lodi	10,108	0,737	92	Frosinone	12,478	0,910
38	Sondrio	10,252	0,748	93	Caserta	12,488	0,911
39	Aosta	10,272	0,749	94	Ragusa	12,508	0,912
40	La Spezia	10,286	0,750	95	Napoli	12,640	0,922
41	Rovigo	10,335	0,754	96	Messina	12,751	0,930
42	Forlì	10,376	0,757	97	Siracusa	12,752	0,930
43	Vicenza	10,399	0,759	98	Reggio	12,807	0,934
44	Novara	10,484	0,765	99	Taranto	12,828	0,936
45	Fermo	10,498	0,766	100	Vibo Valentia	12,843	0,937
46	Savona	10,527	0,768	101	Foggia	13,007	0,949
47	Genova	10,538	0,769	102	Andria	13,030	0,950
48	Bari	10,614	0,774	103	Palermo	13,090	0,955
49	Verbania	10,641	0,776	104	Trani	13,101	0,956
50	Milano	10,669	0,778	105	Agrigento	13,262	0,967
51	Vercelli	10,679	0,779	106	Crotone	13,394	0,977
52	Como	10,728	0,783	107	Barletta	13,435	0,980
53	Piacenza	10,792	0,787	108	Trapani	13,624	0,994
54	Sassari	10,814	0,789	109	Catania	14,541	1,061
55	Oristano	10,841	0,791				

In figure 2, the Euclidean distances of the provincial capitals belonging to the main territorial divisions (North-East, North-West, Centre, South Italy and in the Major Islands) have been calculated with respect to the ideal value.

Figure 2 - *Distances of Italian cities from the "ideal sustainable city" – 2021.*

The results show better performances and those closer to the "ideal" value in the cities of Bologna and Trento in the North-East (7.319 and 7.904), Pavia in the North-West (8.659), Macerata and Florence in the Centre (8.406 and 8.860), L'Aquila and Bari in the South (10.050 and 10.614), Cagliari in the Major Islands (8.750).

On the contrary, the cities that stand out for worse performances and furthest from the ideal value are Lecco and Alessandria in the North-West (11.777 and 11.786), Treviso and Rimini in the North-East (10.962 and 11.380), Massa and Frosinone in the Centre (12.231 and 12.478), Crotone and Barletta in the South (13.394 and 13.435), Trapani and Catania in the Major Islands (13.625 and 14.541)

The challenge for more sustainable and liveable cities in Italy is still a distant goal, despite the fact that there are realities and good practices in the territories that go in the right direction.

Considering the constant increase in the urban population, it is now essential to focus on sustainable city models, real laboratories to guide new strategies for the transformation of our societies.

4. Conclusions

The analysis of the Italian provincial capitals proposed in this paper has made it possible to identify an ideal model of a 'sustainable city'. We carried out a multivariate analysis using a set of demographic, social, economic and environmental indicators in order to compare Italian provincial capitals in terms of urban sustainability. The results confirmed the North-South dualism. Southern cities, in fact, struggle to respond to urban emergencies and guarantee an acceptable quality of life. The study also offered food for thought on the logic and dynamics of our Italian cities and their urban, social and economic development processes.

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