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GRINS FOUNDATION

Spoke 7 "Territorial Sustainability"

WP1 - Measuring and monitoring infrastructures and services' gaps

Deliverable 7.1.3

Open Repository of territorial data and indicators

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EXECUTIVE SUMMARY

Deliverable 7.1.3, "Open Repository of Territorial Data and Indicators (WP1)," presents a comprehensive set of simple and composite indicators at municipal and provincial levels. These indicators cover territorial capacities, infrastructure and educational services, municipal provisions (e.g., waste management, local public transport, cultural services), land use, transport infrastructure, and public utilities such as water resources and renewable energy. This deliverable builds on the initial WP1 task—developing a dashboard of geolocated, real-time data to measure and evaluate infrastructure and service provision gaps—and aligns with the Month-18 objective of producing detailed maps illustrating these gaps.

Central to the analysis is the concept of territorial capacities, which include both material and immaterial community assets (Bekkensen et al., 2017). By linking these capacities to measurable indicators, it becomes possible to identify critical gaps hindering sustainable development (UNIBA – POLIMI_DIG). In particular, sector-specific indicators for water and renewable energy have been identified and aggregated into a composite local sustainability index.

In parallel, the relationship between educational outcomes and infrastructural conditions has been examined. Using a spatial framework, high school INVALSI scores were analyzed by extending the conditional autoregressive model within a multilevel mixed linear regression. Each INVALSI subject—Italian and Mathematics—was treated as a response variable, requiring spatial modeling to account for geographic variability in performance (UNIBA_DIEF).

At the municipal level, resilience and attractiveness were assessed through expenditure-gap indicators. The total local capital expenditure gap was used as a proxy for resilience, reflecting whether municipalities invest sufficiently in long-term assets such as infrastructure, public facilities, and technological systems. The local culture expenditure gap—capturing investments in cultural events, museums, and theaters—served as an indicator of attractiveness. From 2016 to 2022, four sector-specific gap indicators were calculated (adjusted for population, area, and urbanization) to highlight disparities between actual and "standard" per capita expenditures: Waste Management (WMGI), Local Transport and Roads (LMGI), Cultural Services (CMGI), and Total Services (TMGI). Quantifying these gaps makes it possible to identify critical infrastructural needs and provides local governments with evidence-based tools to prioritize investments and guide policy decisions (UNIBA_DEMDI).

Another key focus has been the interaction between land use change and transportation infrastructure. Data on land consumption per capita were compiled and harmonized over time alongside provincial road, highway, and rail network lengths. These data support the development of the Infrastructure_Land Use_Index, which relates total transport network length to provincial area (kilometers of network per km^2). Spatial autocorrelation techniques were applied to reveal patterns and relationships across regions (UNIVE). The datasets underpinning all simple and composite indicators described in this deliverable are available at both municipal and provincial levels and have been uploaded to Amelia.

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1.1 WP1 Measuring and monitoring infrastructures and services' gaps

1.1.1 Deliverable 1.3 Open Repository of territorial data and indicators

The WP1 intends to measure and assess the gaps among and within territories in terms of infrastructures and service endowments. It aims at developing new indicators to understand and monitor the attractiveness and resilience of territories as a result of the interaction of 'tangible' factors (e.g., physical infrastructure and digital networks) and 'intangible' factors (e.g., social cohesion and inclusion, safety). It will enable to explore relations between diverse data and will provide also a multiparametric characterization of the strength and weaknesses of the territories analyzed.

The dimensions of analysis were identified based on an extensive literature review that moved from the concepts of resilience and attractiveness and focused specifically on the assessing of infrastructures and services inverstments that are responsible for territorial gaps.

The selection of the indicators was also informed by data availability. In particular, the analysis of available public data sources played a crucial role in supporting the selection of measurable variables for assessing territorial capital.

The activities were required to address the following main tasks:

- (i) Collect and harmonize data on infrastructures and services and their use from different data sources (administrative, on-line surveys/lab-in the field experiments and stated preferences/choice exercises, remote sensors, flow data and mobility flows, text and social media data;
- (iv) Identify indicators of attractiveness and resilience;
- (v) Identify the infrastructures and services' gaps;
- and the target of the 10 maps of infrastructures and services gaps.

Starting from the literary research on the investigated themes, the construction of the Open repository of territorial data and indicators follows the identification of a series of datasets useful for monitoring and the definition of some relevant indicators for the identification of criticalities, inequalities and gaps. Through the datasets and indicators of the repository, it was possible to construct some national cartographic representations at the municipal/provincial level.

2. The open repository

2.A Territorial capital

2.A.1 Economic capital score

Methodology/Derivation of indicator

The composite indicator, economic capital score, is built upon the definition of economic capital for resilience and attractiveness of territories. Economic capital refers to the financial and economic assets and resources that households utilize to sustain their livelihoods and living standards. This encompasses income, wealth, savings, access to credit, and the characteristics of the local market structure.

The economic capital score summarizes information on the overall economic performance and labor market dynamics within a territory:

- Economy: overall economic performance of a territory. It includes indicators mapping the income of households, and availability of financial markets.
- Labour market: conditions and dynamics of the workforce within a territory. It includes the number of employees disentangled across NACE (Nomenclature of Economic Activities) rev.2 sectors at a 1-digit level of detail.

The economic capital score is a dimensionless indicator that ranges from 0 to 1. This scale allows for an interpretation of a territory's economic development status. A score closer to 1 indicates a higher level of economic development, characterized by strong economic performance, a good labor market, and access to financial resources. Conversely, a score closer to 0 represents a lower level of economic development, suggesting potential gaps in these areas.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
A.1	Economic capital score	2015-2019[1]	municipality		
A.1.1	Income per capita	2010-2020	municipality	€	Ministry of Economy and Finance
A.1.2	Bank branches	2015-2020	municipality	N	ISTAT
A.1.3	Deposits	2015-2020	municipality	€	ISTAT
A.1.4	Loans	2015-2020	municipality	€	ISTAT
A.1.5	Employment in manufacturing sectors	2012-2020	municipality	N	
A.1.5.1	Employees in sector B	2012-2020	municipality	N	ISTAT
A.1.5.2	Employees in sector C	2012-2020	municipality	N	ISTAT
A.1.5.3	Employees in sector D	2012-2020	municipality	N	ISTAT

[1] The dataset spans several years for many indicators, but it exhibits a different value concentration over time. Therefore, we opted to narrow the analysis on a uniform cross-section of years spanning from 2015 to 2019, thereby excluding years affected by the COVID-19 crisis. Consequently, we aggregated indicators to replace missing values in the resultant dataset, computing averages across the five years of observations from 2015 to 2019.

A.1.5.4	Employees in sector E	2012-2020	municipality	N	ISTAT
A.1.5.5	Employees in sector F	2012-2020	municipality	N	ISTAT
A.1.5.6	Employees in sector G	2012-2020	municipality	N	ISTAT
A.1.6	**Employment in service sectors**	2012-2020	municipality	N	
A.1.6.1	Employees in sector H	2012-2020	municipality	N	ISTAT
A.1.6.2	Employees in sector I	2012-2020	municipality	N	ISTAT
A.1.6.3	Employees in sector J	2012-2020	municipality	N	ISTAT
A.1.6.4	Employees in sector K	2012-2020	municipality	N	ISTAT
A.1.6.5	Employees in sector L	2012-2020	municipality	N	ISTAT
A.1.6.6	Employees in sector M	2012-2020	municipality	N	ISTAT
A.1.6.7	Employees in sector N	2012-2020	municipality	N	ISTAT
A.1.6.8	Employees in sector P	2012-2020	municipality	N	ISTAT
A.1.6.9	Employees in sector Q	2012-2020	municipality	N	ISTAT
A.1.6.10	Employees in sector R	2012-2020	municipality	N	ISTAT
A.1.6.11	Employees in sector S	2012-2020	municipality	N	ISTAT
A.1.7	Concentration of employment across sectors[2]	2012-2020	municipality	HHI Index	

Table A.1: Simple and composite indicators used for the economic capital dimension

A.1_ Economic capital score

Firstly, the dataset spans several years for many indicators, but it exhibits a different value concentration over time. Therefore, we opted to narrow the analysis on a uniform cross-section of years spanning from 2015 to 2019, thereby excluding years affected by the COVID-19 crisis. Consequently, we aggregated indicators to replace missing values in the resultant dataset, computing averages across the five years of observations from 2015 to 2019. This is equivalent to assuming that, in the five years considered, the territorial values have remained relatively stable with respect to their five-year average, which is a reasonable assumption based on the collected data. It is worth highlighting that, while we are employing an aggregate representation in this work, the data provided cover multiple years, offering a dynamic resource for future research endeavors.

Secondly, to address data gaps we have replaced missing values using the average value of the indicator in the municipalities in the same NUTS3 area for a limited number of indicators. Finally, for the remaining indicators, missing values were replaced with zeros. This choice was made coherently with the interpretation of the variables; where the missing data could reasonably indicate a null value, they were replaced with zero. In the remaining cases, the average within the NUTS3 area was utilized.

As the last step of the preprocessing procedure, to ensure a consistent interpretation across all variables, we inverted the value scale for indicators with a negative impact, i.e., those for which a higher value implies a less desirable outcome, indicating lower resilient or attractiveness for a territory.

A.1.1_ Income per capita

Income per capita per municipality for the years 2010-2020 (values in €). It measures the disposable income per capita.

A.1.2_ Bank branches

Number of bank branches per municipality for the years 2015-2020. It measures the availability of

[2] To build the indicator "Concentration of employment across sectors" indicators 1.5.1-1.5.6 and 1.6.1-1.6.11 have been used.

financial markets.

A.1.3_ Deposits

Amount of deposits per municipality for the years 2015-2020 (values in €). It measures the availability of financial markets.

A.1.4_ Loans

Amount of loans per municipality for the years 2015-2020 (values in €). It measures the availability of financial markets.

A.1.5_ Employment in manufacturing sectors

Aggregated indicator of the number of employees in manufacturing sectors (A-G) per municipality for the years 2012-2020. It is an indicator of the levels of employment.

A.1.6_ Employment in service sectors

Aggregated indicator of the number of employees in service sectors (H-S) per municipality for the years 2012-2020. It is an indicator of the levels of employment.

A.1.7_ Concentration of employment across sectors

Herfindahl – Hirschman (HHI) index of employment across sectors. Composite indicator obtained from indicators 1.5-1.6. It is an indicator of the levels of employment.

2.A.2 Human capital score

Methodology/Derivation of indicator

The composite indicator, human capital score, is built upon the definition of human capital for resilience and attractiveness of territories. Human capital refers to the skills, knowledge, good health, and the ability to work towards and achieve livelihood objectives.

The human capital score summarizes information on the overall demographic structure, education system and health system within a territory:

- Demography: population structure within a territory in terms of migration patterns.
- Education: skills, knowledge and learning opportunities available within a territory. It includes the number of students enrolled in different universities
- Health: Availability of health assets. It includes the number of alternative types of health infrastructures or hospital beds., as well as mortality patterns.

The human capital score is a dimensionless indicator that ranges from 0 to 1. This scale allows for an interpretation of a territory's human capital development status. A score closer to 1 indicates a higher level of human development, characterized by a resilient demographic structure, good education system performances and health system performances. Conversely, a score closer to 0 represents a lower level of human development, suggesting potential gaps in these areas.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
A.2	Human capital score	2015-2019[3]	municipality		
A.2.1	Internal demographic migratory balance of foreigners	2019-2022	municipality	N	ISTAT
A.2.2	Acquisitions of Italian citizenship	2019-2022	municipality	N	ISTAT
A.2.3	Foreigners - total census balance	2019-2022	municipality	N	ISTAT
A.2.4	Students enrolled in STEM courses	2015-2017	municipality	N	ISTAT
A.2.4.1	Univesity enrollees chemical-pharmaceutical	2015-2017	municipality	N	ISTAT
A.2.4.2	Univesity enrollees engeneering	2015-2017	municipality	N	ISTAT
A.2.4.3	Univesity enrollees economic-statistical	2015-2017	municipality	N	ISTAT
A.2.4.4	Univesity enrollees psycological	2015-2017	municipality	N	ISTAT
A.2.5	Concentration of enrollment across courses [4]	2015-2017	municipality	HHI index	ISTAT
A.2.5.1	Univesity enrollees architecture	2015-2017	municipality	N	ISTAT
A.2.5.2	Univesity enrollees geo-biological	2015-2017	municipality	N	ISTAT
A.2.5.3	Univesity enrollees medical	2015-2017	municipality	N	ISTAT
A.2.5.4	Univesity enrollees agricultural	2015-2017	municipality	N	ISTAT
A.2.5.5	Univesity enrollees political social	2015-2017	municipality	N	ISTAT
A.2.5.6	Univesity enrollees legal	2015-2017	municipality	N	ISTAT
A.2.5.7	Univesity enrollees literary	2015-2017	municipality	N	ISTAT
A.2.5.8	Univesity enrollees linguistic	2015-2017	municipality	N	ISTAT
A.2.5.9	Univesity enrollees teaching	2015-2017	municipality	N	ISTAT
A.2.5.10	Univesity enrollees physical education	2015-2017	municipality	N	ISTAT
A.2.5.11	Univesity enrollees defense-security	2015-2017	municipality	N	ISTAT
A.2.6	Public care institutions	2014-2019	municipality	N	ISTAT
A.2.7	Private care accredited institutions	2014-2019	municipality	N	ISTAT
A.2.8	Ordinary acute care bed	2019	municipality	N	ISTAT
A.2.9	Long-stay ordinary care bed	2019	municipality	N	ISTAT
A.2.10	Rehabilitation ordinary care beds	2019	municipality	N	ISTAT
A.2.11	Total ordinary care beds	2019	municipality	N	ISTAT
A.2.12	Distance from nearest emergency care unit	2018	municipality	km	ISTAT, Openmap
A.2.13	Total number of deaths	2011-2022	municipality	N	ISTAT

Table A.2: Simple and composite indicators used for the human capital dimension

A.2_ Human Capital Score

The methodology used to build the human capital score is the same as the one used for the economic capital score (section 2.1).

A.2.1 Internal demographic migratory balance of foreigners

Number of internal changes of residence from one municipality to another for the years 2019-2022. It is a demographic indicator.

[3] The dataset spans several years for many indicators, but it exhibits a different value concentration over time. Therefore, we opted to narrow the analysis on a uniform cross-section of years spanning from 2015 to 2019, thereby excluding years affected by the COVID-19 crisis. Consequently, we aggregated indicators to replace missing values in the resultant dataset, computing averages across the five years of observations from 2015 to 2019.

[4] To build the indicator "Concentration of enrollment across courses" indicators 2.4.1-2.4.4 and 2.5.1-2.5.11 have been used.

A.2.2 Acquisitions of Italian citizenship

Number of acquisitions of Italian citizenship per municipality for the years 2019-2022. It is a demographic indicator.

A.2.3 Foreigners - total census balance

Number of foreigners per municipality for the years 2019-2022. It is a demographic indicator.

A.2.4 Students enrolled in STEM courses

Aggregated indicator of the number of students enrolled in Sience, Technology, Engineering and Mathematics (STEM) courses per municipality for the years 2015-2017. In particular, to build this indicator data on the number of enrollees in chemical-pharmaceutical, engeneering, economic-statistical and psycological subjects have been aggregated. This is an indicator of the levels of education.

A.2.5 Concentration of enrollment across courses

Herfindahl – Hirschman (HHI) index of enrollment across courses. Composite indicator obtained from indicators 2.5.1-2.5.11. It is an indicator of the levels of education.

A.2.6 Public care institutions

Number of public care institutions per municipality for the years 2014-2019. It is an indicator of the quality of sanitary services.

A.2.7 Private care accredited institutions

Number of private care institutions accredited to the national public health system per municipality for the years 2014-2019. It is an indicator of the quality of sanitary services.

A.2.8 Ordinary acute care bed

Number of hospital beds for ordinary acute care per municipality for the year 2019. It is an indicator of the quality of sanitary services.

A.2.9 Long-stay ordinary care bed

Number of hospital beds for long-stay ordinary care per municipality for the year 2019. It is an indicator of the quality of sanitary services.

A.2.10 Rehabilitation ordinary care beds

Number of hospital beds for rehabilitation ordinary care per municipality for the year 2019. It is an indicator of the quality of sanitary services.

A.2.11 Total ordinary care beds

Total number of hospital beds for ordinary care per municipality for the year 2019. It is an indicator of the quality of sanitary services.

A.2.12 Distance from nearest emergency care unit

Distance (in kilometres) of the municipality's centroid from the nearest emergency care unit for the year 2018. It is an indicator of the quality of sanitary services.

A.2.13 Total number of deaths

Total number of deaths per municipality for the years 2011-2022. It is an indicator of mortality.

2.A.3 Physical capital score

Methodology/Derivation of indicator

The composite indicator, physical capital score, is built upon the definition of physical capital for resilience and attractiveness of territories. Physical capital refers the to basic infrastructure or built environmental features that can help people, households, and businesses to support their livelihoods. This encompasses housing or residential structures, along with commercial and industrial buildings, infrastructure, and essential lifelines (water, sewer, tourism, and transportation).
The physical capital score summarizes information on the overall environmental characteristics, housing and household assets and infrastructure and services available within the territory:

- Environment: natural resources and ecological conditions within a territory. It includes factors such as greenery, water capacity and emissions.
- Housing and household assets: quality and availability of housing, along with the assets owned by households within a territory. It includes a wide set of indices related to the quality of the urban area such as the housing dispersion and concentration indices.
- Infrastructure and services: built structures and infrastructures and essential services. It mainly includes the availability of infrastructures related to the transportation and tourism sectors.

The physical capital score is a dimensionless indicator that ranges from 0 to 1. This scale allows for an interpretation of a territory's pysical capital development status. A score closer to 1 indicates a higher level of physical development, characterized by a resilient environment, housing and household assets and infrastructure and services available within the territory. Conversely, a score closer to 0 represents a lower level of pysical development, suggesting potential gaps in these areas.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
A.3	Physical capital score	2015-2019[5]	municipality		
A.3.1	Production of urban waste per capita	2019	municipality	Kg per inhabitants	Urban Index
A.3.2	Percentage of differentiated waste collection	2019	municipality	%	Urban Index
A.3.3	Concentration of PM2.5 emissions	2014-2020	municipality	$\mu g/m^3$	Copernicus
A.3.4	Urban green (non agricultural) per capita	2019	municipality	m^2 per inhabitant	Urban Index

[5] The dataset spans several years for many indicators, but it exhibits a different value concentration over time. Therefore, we opted to narrow the analysis on a uniform cross-section of years spanning from 2015 to 2019, thereby excluding years affected by the COVID-19 crisis. Consequently, we aggregated indicators to replace missing values in the resultant dataset, computing averages across the five years of observations from 2015 to 2019.

A.3.5	Percentage of agricultural land use	2019	municipality	%	Urban Index
A.3.6	Percentage of municipal area with high hydraulic hazard P3	2019	municipality	%	Urban Index
A.3.7	Resident population at risk in areas with high hydraulic hazard	2019	municipality	N	Urban Index
A.3.8	Area of consumed soil in areas with high hydraulic hazard - P3	2019	municipality	Km^2	Urban Index
A.3.9	Incidence of resident population in nuclei and scattered houses	2019	municipality	%	Urban Index
A.3.10	Index of housing dispersion	2019	municipality	Values between 0 and 1	Urban Index
A.3.11	Index of concentration of building use types	2019	municipality	%	Urban Index
A.3.12	Building expansion index in centers and inhabitated nuclei	2019	municipality	%	Urban Index
A.3.13	Use of private vehicles	2019	municipality	%	Urban Index
A.3.14	Daily mobility for study or work	2019	municipality	%	Urban Index
A.3.15	University presence index	2019	municipality		Urban Index
A.3.16	Mobility index	2019	municipality	Values between 0 and 1	Urban Index
A.3.17	Self-sufficiency index	2019	municipality	Values between 0 and 1	Urban Index
A.3.18	Public mobility	2019	municipality	%	Urban Index
A.3.19	Slow mobility	2019	municipality	%	Urban Index
A.3.20	Percentage of Euro 5 and Euro 6 cars on total cars	2019	municipality	%	Urban Index
A.3.21	Potable water introduced into the municipal network per capita	2019	municipality	Litres per inhabitant	Urban Index
A.3.22	Index of compactness of urban areas	2019	municipality	%	Urban Index
A.3.23	Index of fragmentation of the urban landscape	2019	municipality	%	Urban Index
A.3.24	Incidence of population in overcrowded conditions	2019	municipality	%	Urban Index
A.3.25	Consumed soil per capita	2012-2022	municipality	m^2 per inhabitant	Urban Index
A.3.26	Number of hotels and similar	2012-2022	municipality	N	ISTAT
A.3.27	Number of beds in hotels and similar	2012-2022	municipality	N	ISTAT
A.3.28	Number of additional facilities	2012-2022	municipality	N	ISTAT
A.3.29	Number of beds in additional facilities	2012-2022	municipality	N	ISTAT
A.3.30	Total number of hotel, similar and additional facilities	2012-2022	municipality	N	ISTAT
A.3.31	Total number of beds in hotel, similar and additional facilities	2012-2022	municipality	N	ISTAT
A.3.32	Receptivity index	2012-2022	municipality	Beds per inhabitants	ISTAT
A.3.33	Index of receptive density	2012-2022	municipality	Beds per km^2	ISTAT

Table A.3: Simple and composite indicators used for the physical capital dimension

A.3_ Physical capital score

The methodology used to build the physical capital score is the same as the one used for the economic capital score.

A.3.1_ Production of urban waste per capita

Annual kilograms of urban waste produced by each inhabitant per municipality for the year 2019. It is an indicator of the environmental conditions.

A.3.2_ Percentage of differentiated waste collection

Percentage of differentiated waste collection per municipality for the year 2019. It is an indicator of the environmental conditions.

A.3.3_ Concentration of PM2.5

PM2.5 concentration (μg/m3) per municipality for the years 2014-2020. It is an indicator of the level of emissions.

A.3.4_ Urban green (non agricultural) per capita

Squared metres of urban green (non agricultural) per inhabitant per municipality for the year 2019. It is an indicator of greenery and park coverage.

A.3.5_ Percentage of agricultural land used

Percentage of agrucultural land used on total agricultural land per municipality for the year 2019. It is an indicator of greenery and park coverage.

A.3.6_ Percentage of municipal areas with high hydraulic hazard-P3

Percentage of municipal areas with high hydraulic hazard (P3 level) per municipality for the year 2019. It is an indicator of water capacity.

A.3.7_ Resident population at risk in areas with high hydraulic hazard

Number of inhabitants at risk in areas with high risk hydraulic hazard (P3 level) per municipality for the year 2019. It is an indicator of water capacity.

A.3.8_ Area of consumed soil in areas with high hydraulic hazard - P3

Squared kilometres of consumed soil in areas with high hydraulic hazard (P3 level) per municipality for the year 2019. It is an indicator of water capacity.

A.3.9_ Incidence of resident population in nuclei and scattered houses

Percentage of resident population living in nuclei and scattered houses per municipality for the year 2019. It is an indicator of housing stock construction quality.

A.3.10_ Index of housing dispersion

Index of housing dispersion (with values between 0 and 1) per municipality for the year 2019. It is an indicator of housing stock construction quality.

A.3.11_ Index of concentration of building use types

Percentage of concentration of building use types per municipality for the year 2019. It is an indicator of housing stock construction quality.

A.3.12_ Building expansion index in centers and inhabitated nuclei

Percentage of expansion of buildings in centers and inhabitated nuclei per municipality for the year 2019. It is an indicator of housing stock construction quality.

A.3.13_ Use of private vehicles

Percentage of resident people who have private vehicles per municipality for the year 2019. It is an indicator of transportation access.

A.3.14_ Daily mobility for study or work

Percentage of people who travel daily for study or work per municipality for the year 2019. It is an indicator of transportation access.

A.3.15_ University presence index

University presence index (university and branches) per municipality for the year 2019. It is an indicator of transportation access.

A.3.16_ Mobility index

Mobility index (values between 0 and 1) for people commuting for work reasons per municipality for the year 2019. It is an indicator of transportation access.

A.3.17_ Self-sufficiency index

Self-sufficiency index (values between 0 and 1) for people commuting for work reasons per municipality for the year 2019. It is an indicator of transportation access.

A.3.18_ Public mobility

Percentage of public mobility per municipality for the year 2019. It is an indicator of transportation access.

A.3.19_ Slow mobility

Percentage of slow mobility (on foot or by bicycle) per municipality for the year 2019. It is an indicator of transportation access.

A.3.20_ Percentage of Euro 5 and Euro 6 cars on total cars

Percentage of Euro 5 and Euro 6 cars on total number of cars per municipality for the year 2019. It is an indicator of transportation access.

A.3.21_ Potable water introduced into the municipal network per capita

Litres of potable water per inhabitant introduced into the municipal network per municipality for the year 2019. It is an indicator of density of water supply.

A.3.22_ Index of compactness of urban areas

Percentage of compactness of urban areas per municipality for the year 2019. It is an indicator of the quality of infrastructures and services.

A.3.23_ Index of fragmentation of the urban landscape

Level of fragmentation (percentage) of the urban landscape per municipality for the year 2019. It is an indicator of the quality of infrastructures and services.

A.3.24_ Incidence of population in overcrowded conditions

Percentage of population leaving in overcrowded conditions per municipality for the year 2019. It is an indicator of the quality of infrastructures and services.

A.3.25_ Consumed soil per capita

Squared metres of consumed soil per inhabitant per municipality for the years 2012-2022. It is an indicator of the quality of infrastructures and services.

A.3.26_ Number of hotels and similar

Number of hotels and similar facilities per municipality for the years 2012-2022. It is an indicator of tourist capacity.

A.3.27_ Number of beds in hotels and similar

Number of beds in hotels and similar facilities per municipality for the years 2012-2022. It is an indicator of tourist capacity.

A.3.28_ Number of additional facilities

Number of additional facilities per municipality for the years 2012-2022. It is an indicator of tourist capacity.

A.3.29_ Number of beds in additional facilities

Number of beds in additional facilities per municipality for the years 2012-2022. It is an indicator of tourist capacity.

A.3.30_ Total number of hotel, similar and additional facilities

Total number of hotels, similar and additional facilities per municipality for the years 2012-2022. It is an indicator of tourist capacity.

A.3.31_ Total number of beds in hotel, similar and additional facilities

Total number of beds in hotels, similar and additional facilities per municipality for the years 2012-2022. It is an indicator of tourist capacity.

A.3.32_ Receptivity index

Receptivity index (beds per inhabtants) per municipality for the years 2012-2022. It is an indicator of tourist capacity.

A.3.33_ index of receptive density

Index of receptive density (beds per km2) per municipality for the years 2012-2022. It is an indicator of tourist capacity.

2.A.4 Social capital score

Methodology/Derivation of indicator

The composite indicator, social capital score, is built upon the definition of social capital for resilience and attractiveness of territories. Social capital refers the to the set of rules and principles governing interactions and interdependencies among individuals, the institutions they are affiliated with, the relational networks established among different social actors, and the overall cohesion of society.

The social capital score summarizes information on the overall civil society: it includes the results of electoral turnout at municipal, regional and political elections.

The social capital score is a dimensionless indicator that ranges from 0 to 1. This scale allows for an interpretation of a territory's social capital development status. A score closer to 1 indicates a higher level of social development, characterized by a civil sociey. Conversely, a score closer to 0 represents a lower level of social development, suggesting potential gaps in these areas.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
A.4	Social capital score	2015-2019[6]	municipality		
A.4.1	Electoral turnout at political elections (Camera)	2015-2022	municipality	Values between 0 and 1	Eligendo
A.4.2	Electoral turnout at political elections (Senato)	2015-2022	municipality	Values between 0 and 1	Eligendo
A.4.3	Electoral turnout at regional elections	2015-2022	municipality	Values between 0 and 1	Eligendo
A.4.4	Electoral turnout at municipal elections	2015-2022	municipality	Values between 0 and 1	Eligendo

Table A.4: Simple and composite indicators used for the social capital dimension

A.4_ Social capital score

The methodology used to build the social capital score is the same as the one used for the economic capital score (section 2.1).

A.4.1_ Electoral turnout at political elections (Camera)

Index (with values between 0 and 1) of participation of citizens to political Camera elections per municipality for the years 2015-2022. It is an indicator of political participation.

A.4.2_ Electoral turnout at political elections (Senato)

Index (with values between 0 and 1) of participation of citizens to political Senato elections per

[6] The dataset spans several years for many indicators, but it exhibits a different value concentration over time. Therefore, we opted to narrow the analysis on a uniform cross-section of years spanning from 2015 to 2019, thereby excluding years affected by the COVID-19 crisis. Consequently, we aggregated indicators to replace missing values in the resultant dataset, computing averages across the five years of observations from 2015 to 2019.

municipality for the years 2015-2022. It is an indicator of political participation.

A.4.3 _ Electoral turnout at regional elections

Index (with values between 0 and 1) of participation of citizens to regional elections per municipality for the years 2015-2022. It is an indicator of political participation.

A.4.4 _ Electoral turnout at municipal elections

Index (with values between 0 and 1) of participation of citizens to municipal elections per municipality for the years 2015-2022. It is an indicator of political participation.

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2.B Public utilities' gaps

Three public utility service indicators related to the sustainability dimension have been identified, included among the target indicators of the Sustainable Development Strategy. Specifically, the indicators concern (i) water loss, (ii) installed photovoltaic power, and (iii) the difference in domestic energy consumption. Currently, the data is provided with a provincial-level detail (NUTS3) for the most recent available years. A historical series analysis at a more granular level (NUTS 4) will be conducted in the coming months, once the required data is made available by ISTAT, TERNA, and GSE.

2.B.1 Water loss in provincial capitals

Methodology/Derivation of indicator

The percentage of water losses (indicator M1b) is defined as the ratio between the volume of total water losses and the total volume entering the water supply system in the considered year. The data pertains to the year 2022 and is grouped by provincial capital cities. In 2022, the volume of total water losses in the water distribution phase amounted to 3.4 billion cubic meters, which is 42.4% of the water supplied to the network.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
B.1	% of total water losses	2022	Province	%	ISTAT

Table B.1: Our elaboration s on ISTAT data.

B.1_ Water loss

The percentage ratio between the volume of total water losses and the volume of water introduced into the network in 2022 per province.

2.B.2 Energy - Installed photovoltaic power

Methodology/Derivation of indicator

The second indicator is the nominal or installed power of a photovoltaic system (MW per 1000 ab.). This indicator corresponds to the nominal (or peak) power of its photovoltaic generator, determined by the sum of the electrical power of each module constituting the photovoltaic generator, measured under Standard Test Conditions (radiation of 1,000 W/m² and temperature of 25°C) and weighted by the resident population. The data on installed power was collected from the statistics section of the Energy Services Manager (Gestore dei Servizi Energetici) for 2023, while the population data was collected from the ISTAT website for the same year.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
B.2	Installed power of photovoltaic systems per 1,000 inhabitants	2023	province	MW/1000 abitanti	GSE and ISTAT

Table B.2: Elaborations on GSE and ISTAT data (2023).

B.2_ Installed photovoltaic power

The installed power of photovoltaic systems in 2023, expressed in megawatts (MW) divided by the resident population in 2023 per 1,000 inhabitants.

2.B.3 Energy - Difference in domestic energy consumption

Methodology/Derivation of indicator

The third indicator concerns domestic energy consumption in kWh divided by the resident population. The goal is to promote responsible domestic energy consumption by reducing waste and improving efficiency. The data is on a provincial basis and is collected from Terna's energy consumption report, focusing on the difference between 2022 and 2021. This indicator shows the difference in domestic energy consumption between two years (in this case, 2021-2022). It is calculated as domestic energy consumption (kWh) divided by the population.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
B.3	Difference in Domestic Electricity Consumption between 2022 and 2021	2021-2022	province	% of reduction Kw/inhabitant	Terna

Table B.3: Elaborations on Terna data. Difference in Domestic Electricity Consumption 2021-2022.

B.3_ Difference in Domestic Electricity Consumption

The difference in domestic energy consumption in kilowatts per capita over the last two available years. This indicator is expected to decrease over the years. It measures domestic energy consumption in kilowatts per capita.

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2.C Gaps in education services and infrastructures

In this section we show four indicators referring to the dimensions of education services and infrastructure. In all cases, our interest regards the territorial level of municipalities.

For the former dimension, we focus on the aspects of school supply availability and education quality.

Regarding the availability in school supply, we propose to correct a simple ranking indicator for the municipality population. Conceptually speaking, we aim at displaying whether a municipality has a better or worse supply in different school orders with respect to what one could expect based on its population.

The quality of education is measured by the Invalsi score; in our case we chose the Mathematics score (based on consideration that can be found e.g. in [5]).

For the infrastructural dimension, the first indicator we display has an immediate meaning in terms of accessibility: we build a composite index to summarise the endowment in four categories of public transport, as provided by the open database of the Italian Ministry of Education, namely urban and interurban public transport, railway transport and school bus availability.

The second composite indicator regarding the infrastructural dimension attempts at summarising the adequacy of school buildings infrastructures; we take into account the presence of adequate teaching spaces, collective spaces, as well as more functional spaces, namely gyms, auditoriums and canteens (the presence of a school canteen implies that students are enabled to receive full-time education); another variable we include is the availability of ultra-broadband connection.

2.C.1 Education services: schools availability

Methodology/Derivation of indicator

Here we show the tentative definition of a composite index; it represents the supply in schools of different orders across municipalities, corrected by the municipality population. The school orders supply is expressed with a simple ranking indicator; then we regress this ranking indicator on the municipality population and display the surplus of the actual ranking with respect to the expected ranking.

Input data are obtained by the Unique School Data Portal, from the School Buildings registry and are referred to school year 2022/2023. Only schools directly identifiable as primary, middle or high are taken into account.

To define the schools supply, we distinguish across primary schools, middle schools, lyceums (scientific lyceum, classical lyceum, human sciences schools, artistic lyceums, art institutes) and technical institutes (technical institutes properly said and vocational schools), i.e. two distinguished types of high school. This distinction between high schools is made in accordance to e.g. the Inner areas classification by ISTAT, which requires a municipality to host both a lyceum and a technical/vocational institute to be considered central.

Each municipality is assigned one point for each school type it hosts; a score of 1 e.g. means that only one order of schools is located in the municipality (typically, a primary school in this case); a score of 4 means that not only does a municipality include all school orders, but it also hosts both a lyceum and a technical high school. Thus, the simple indicator we obtain can be treated as a ranking. Then, we regress this ranking on the logarithm of municipalities populations by an ordinal logistic regression model. The predicted ranking is the one with the highest estimated probability. The resulting composite indicator is conceptually close to a regression residual, since it is the ranking difference between the observed and the predicted score.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
C.1	Schools availability surplus	2022/23	Municipality	Integer	MIUR/ISTAT
C.1.1	Schools availability by municipality	2022/23	Municipality	Integer	MIUR
C.1.2	Population on Jan. 1st 2022	2022	Municipality	Units	ISTAT

Table C.1: Simple and composite indicators used for the schools availability surplus

C.1_ Schools availability surplus

The function `bind_dummy` transforms a qualitative variable into a set of dummies (one dummy for each value it can assume). The input dataset is obtained from the MIUR website. The function `School.order.v1` determines the order of a school based on the mechanographical code distinguishing between lyceums and technical high schools; then we remove the observations not classifiable as primary, middle or high, namely comprehensive institutes (IC), superior institutes (IS) and other orders (NR). The variable `availab` is the schools availability ranking.
Next we predict (variable `rhat`) this ranking by regressing it on the logarithm of population (object `mod`). Finally, we calculate the difference between actual and expected ranking.

C.1.1_ Schools availability by municipality

Number of schools by municipality distinguished across primary schools, middle schools, lyceums (scientific lyceum, classical lyceum, human sciences schools, artistic lyceums, art institutes) and technical institutes (technical institutes properly said and vocational schools).

C.1.2_ Population on Jan. 1st 2022

Number of inhabitants in 2022 by municipality.

2.C.2 Education services: Invalsi scores

Methodology/Derivation of indicator

For all orders of schools, the Invalsi institutes publishes a municipality-level average of the student-specific score, which is defined as a component of the probability of answering the Invalsi test questions correctly. This probability is estimated on a logit scale, hence the domain of the students ability indicator is virtually unbounded. Since this variable is unbounded, the Invalsi institute decides to scale it around a mean of of 200 points with a standard deviation of 40 points. For a simpler displaying, we plot the quintiles of the scores distribution rather than the actual scores.
The geographical interpretation is straightforward and confirms a long-debated issue, namely

the North-South divide in education quality. Differently from high schools, middle schools have a more standardised educational offer, hence the uneven territorial distribution of Invalsi scores cannot be addressed to the distribution of different school addresses.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
C.2	Invalsi scores	2022/23	Municipality	Quantile	Invalsi

Table C.2: Composite indicator used for Invalsi scores

C.2_ Invalisi scores

Input data are obtained from the Invalsi statistical service and are referred to school year 2022/2023. As stated by the Institute, only municipalities with at least two schools of a given order are included in the survey. Therefore, the Invalsi survey only includes 1.959 municipalities, of which 1.958 report the average. Instead of the actual score, we plot the quintiles of its distribution.

2.C.3 Education infrastructure: Transport connection

Methodology/Derivation of indicator

This is a composite index, expressing a generic status of reachability of school buildings by public transport. To build it up, we take into account the reachability by urban and interurban public transport, railway transport and school buses. In this example, we refer to middle schools.
Input data are obtained from the Unique School Data Portal and are referred to school year 2022/2023. These data binary indicators (1 or 0) and they are defined at the level of school buildings. In the input dataset, each school building is mapped to the municipality in which it is located, not to the municipality of the reference institute.
We then need to aggregate them at the level of municipalities. To do so, we compute the municipality-level average of the observed values, ignoring the missing observations (rather than, e.g., imputing them to 0). This brings us to the definition of the simple index.
The composite index is calculated on a selection of variables with the package `compindexR` (link to the package; here is the source code). The composite index is a weighted mean of simple indexes.
Weights are initialised with the aim of minimising the mean square error of the R-squared coefficients that are obtained by regressing the sum of the scaled input variables on the single scaled input variables, under the constraint of summing to one.
Then, for a number of iteration equal to the number of variables minus two (the index needs to be calculated by averaging at least two variables), this procedure is repeated, but the "dependent" variable in the linear regression is now the average of scaled input variables weighted with the weights of the previous iteration.
An acceptance interval for the R-squared coefficients is centred around the reciprocal to the number of variables; the default interval width is 0.10, namely the interval is from the centre minus 0.05 and the centre plus 0.05. Now, when an R-squared coefficient does not lie in this interval, the corresponding variable is dropped. If instead all the R-squared coefficients lie in the acceptance interval, this means that the weights determine a sufficiently homogeneous indicator and the

algorithm stops earlier.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
C.3	Public transport availability	2022/23	municipality	quantile	MIUR
C.3.1	Interurban public transport	2022/23	municipality	%	MIUR
C.3.2	Urban public transport	2022/23	municipality	%	MIUR
C.3.3	Railway transport	2022/23	municipality	%	MIUR
C.3.4	School bus	2022/23	municipality	%	MIUR

Table C.3: Simple and composite indicators used for Public transport availability

C.3_ Public transport availability

The object `DB23` is a more encompassive dataframe including several variables referring to the school system. Among these, we need five ones (namely: `Municipality_code`, `Urban_public_transport`, `Interurban_public_transport`, `Railway_transport`, `School_bus`), and only for middle schools. Thus, the df1 object includes the municipality-level percentage of middle schools served by these kinds of transport. Then, we polish this object from the municipalities in which the percentage of schools served by any kind of transport is NA – this happens because all school in a municipality are missing records, thus the municipality-level indicator cannot be but a missing value itself (we prefer not to impute missing observations to zero). Finally, the composite indicator is calculated. Instead of the actual score, we plot the quintiles of its distribution. Simple indexes are defined as follows.

C.3.1_ Interurban public transport

Municipality-level share of schools with at least one interurban public transport hub within 500 metres.

C.3.2_ Urban public transport

Municipality-level share of schools with at least one urban public transport hub within 250 metres.

C.3.3_ Railway transport

Municipality-level share of schools with at leas a train station within 500 metres.

C.3.4_ School bus

Municipality-level share of schools served by school buses.

2.C.4 Education infrastructure: state of school buildings

Methodology/Derivation of indicator

This is a composite index, expressing the generic infrastructural status of school buildings. To define it, we take into account the intended use of spaces (e.g. the presence of gyms or canteens in schools) and the availability of ultra-broadband internet connection at the beginning of school year 2022/23. In this example, we refer to middle schools.
Input data are obtained from the Unique School Data Portal and from the website of the National ultra-broadband plan and are referred to school year 2022/2023. They are binary indicators (1 or 0) and

they are defined at the level of school buildings (MIUR data) or single schools (broadband data). In the input dataset, each school or school building is mapped to the municipality in which it is located, not to the municipality of the reference institute.
We then need to aggregate them at the level of municipalities. To do so, we compute the municipality-level average of the observed values, ignoring the missing observations (rather than, e.g., imputing them to 0). This brings us to the definition of the simple index.
The composite index is calculated on a selection of variables with the package compindexR (**link** to the package; **here** is the source code). The composite index is calculated with the methodology described for the previous indicator.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
C.4	Infrastructural state of school buildings	2022/23	municipality	quantile	MIUR
C.4.1	Teaching spaces	2022/23	municipality	%	MIUR
C.4.2	Collective spaces	2022/23	municipality	%	MIUR
C.4.3	Auditorium	2022/23	municipality	%	MIUR
C.4.4	Gymnasium	2022/23	municipality	%	MIUR
C.4.5	Canteen	2022/23	municipality	%	MIUR
C.4.6	Ultra-broadband connection availability	2022/23	municipality	%	Infratel SPA

Table C.4: Simple and composite indicators used for Infrastructural state of school buildings.

C.4_ Infrastructural state of school buildings

The composite index is calculated with the methodology described for the previous indicator.
Simple indexes are defined as follows:

C.4.1_ Teaching spaces

Municipality-level share of schools provided with teaching spaces.

C.4.2_ Collective spaces

Municipality-level share of schools provided with collective spaces

C.4.3_ Auditorium

Municipality-level share of schools provided with an auditorium

C.4.4_ Gymnasium

Municipality-level share of schools provided with a gymnasium

C.4.5_ Canteen

Municipality-level share of schools provided with a canteen

C.4.6_ Ultra-broadband connection availability

Municipality-level share of schools provided with ultra-broadband connection (1 gigabit/second with minimum guaranteed of 100 megabit/second) at the beginning of the school year (September 1st 2022).

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2.D Gap in public utility services

Regional disparities in infrastructural transport, culture, and waste management endowment could be better grasped by estimates expressed in physical terms. Indeed, sometimes radically diverse topography means that equal investment in money amounts is not equivalent in physical unity across the regions. However, the *monetary measurement* of public capital certainly has advantages in terms of great uniformity and flexibility, properties of additivity, etc. The estimated monetary differences between expenditure and physical endowment allows us to obtain the representative estimated price/cost of the considered infrastructure.

2.D.1 Waste management gap

Methodology/Derivation of indicator

The Waste Management Gap Indicator (WMGI) measures the per capita monetary difference between actual and standard capital expenditures in waste management at the municipal level. The standard is defined as the national average capital expenditure from 2016 to 2022, weighted by the following variables:

- Resident population,
- Municipal area in square kilometres,
- Classification of municipalities into six urbanization clusters: Center, Intermunicipal, Belt, Intermediate, Periphery, and Ultra-periphery.

This indicator provides an estimate of the infrastructural gap in monetary terms for the waste management sector at the municipal level as measured in 2022, considering changes from 2016 to 2022.

Data for this analysis is primarily sourced from the "Banca Dati delle Amministrazioni Pubbliche (BDAP)", focusing on accrual-based capital expenditures by service. The period of analysis spans from 2016 to 2022, encompassing all Italian municipalities (7,901 local authorities) and integrating expenditures with contextual variables such as population, municipal area, and urbanization level. This comprehensive approach allows for a robust evaluation of infrastructural needs across Italy, where municipalities account for 20% of total public investments.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
D.1	Waste Management Capital expenditure gap	2022	municipality	Euro per capita	BDAP, municipal balance sheet
D.1.1	Waste management Capital expenditure	2022-2016	municipality	Euro per capita	BDAP, municipal balance sheet
D.1.2	Resident Population	2022-2016	municipality	n.	ISTAT
D.1.3	Municipal surface	2011	municipality	Km sq.	ISTAT
D.1.4	Rural area	2020	municiaplity	Dummy	ISTAT

Table D.1: Data employed in the evaluation of the Waste management capital expenditure gap 2022

D.1_ Waste Management Capital Expenditure Gap

The index for the year 2022, for each municipality i, corresponds to the following formula in equation (1):

$$\mathrm{WGAP}_i^{2022} = \frac{WSEXP_i - WHEXP_i^{2022}}{Pop_i^{2022}}, \ \ if\ WSEXP_i > WHEXP_i^{2022} \quad (1)$$

Where:

- i indicates the municipality index;
- $WHEXP_i^{2022}$ corresponds to the historical capital expenditure allocated to the waste management service in 2022;
- Pop_i^{2022} corresponds to the resident population of the municipality in the year 2022;
- $WSEXP_i$ corresponds to the standard capital expenditure computed as the average capital expenditure at the national level between 2016 and 2022 conditional on the population of the municipality, the surface of the municipality in Km sq. and, finally, to the classification of the municipalities into six urbanization clusters (Center, Intermunicipal, Belt, Intermediate, Periphery, and Ultra-periphery).

In particular, $WSEXP_i$ is obtained from the fitted values of the following regression model and reported in equation (2), estimated using Ordiary Least Squares (OLS) with robust standard errors:

$$WHEXP_{it} = \beta_0 + \sum_b \beta_b Pop\_dummy_{it}^b + \beta_2\, Kmsq_i + \sum_r \gamma_r Rural\_dummy_{it}^r + \varepsilon_{it} \quad (2)$$

Where:

- i indicates the municipality index;
- t indicates the year indicator since we employ a panel of seven years for the analysis ;
- $Pop\_dummy_{it}^b$ corresponds to the resident population brackets to which of the municipality belongs to;
- $Kmsq_i$ corresponds to the surface in km sq. of the mumicipality;
- $Rural\_dummy_{it}^r$ corresponds to the specific classification of the municipalities among the six categories of the rural vs urban area;
- β_0 is the constant of the model;
- β_b are the coefficients associated with the population brackets;
- γ_r are the coefficients associated with the rural vs urban categories;
- ε_{it} is the idiosincratica error of the model.

2.D.2 Local transport and Roads gap

Methodology/Derivation of indicator

The Local Transport and Roads Gap Indicator (LMGI) measures the per capita monetary difference between actual and standard capital expenditures in local transport and road maintenance at the municipal level. This standard is defined as the national average capital expenditure from 2016 to 2022, adjusted for the following variables:

- Resident population,
- Municipal area in square kilometres,
- Classification of municipalities into six urbanization clusters: Center, Intermunicipal, Belt, Intermediate, Periphery, and Ultra-periphery.

This indicator provides an estimate of the infrastructural gap in monetary terms for the Local Transport and Roads sector at the municipal level as measured in 2022, considering changes from 2016 to 2022.
Data for this analysis is primarily sourced from the "Banca Dati delle Amministrazioni Pubbliche (BDAP)", focusing on accrual-based capital expenditures by service. The period of analysis spans from 2016 to 2022, encompassing all Italian municipalities (7,901 local authorities) and integrating expenditures with contextual variables such as population, municipal area, and urbanization level.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
D.2	Local Transport and Roads Capital expenditure gap	2022	municipality	Euro per capita	BDAP, municipal balance sheet
D.2.1	Local Transport and Roads Capital Expenditure	2022-2016	municipality	Euro per capita	BDAP, municipal balance sheet
D.2.2	Resident Population	2022-2016	municipality	n.	ISTAT
D.2.3	Municipal surface	2011	municipality	Km sq.	ISTAT
D.2.4	Rural area	2020	municiaplity	Dummy	ISTAT

Table D.2: Data employed in the evaluation of the Local Transport and Roads capital expenditure gap 2022

D.2_ Local Transport and Roads Capital Expenditure Gap

The index for the year 2022, for each municipality i, corresponds to the following formula in equation (3):

$$\mathrm{LGAP}_i^{2022} = \frac{LSEXP_i - LHEXP_i^{2022}}{Pop_i^{2022}}, \quad if\ LSEXP_i > LHEXP_i^{2022} \qquad (3)$$

Where:

- i indicates the municipality index;
- $LHEXP_i^{2022}$ corresponds to the historical capital expenditure allocated to the local transport and road maintenance service in 2022;
- Pop_i^{2022} corresponds to the resident population of the municipality in the year 2022;
- $LSEXP_i$ corresponds to the standard capital expenditure computed as the average capital expenditure at the national level between 2016 and 2022 conditional on the population of the municipality, the surface of the municipality in Km sq. and, finally, to the classification of the municipalities into six urbanization clusters (Center, Intermunicipal, Belt, Intermediate, Periphery, and Ultra-periphery)..

In particular, $LSEXP_i$ is obtained from the fetted values of the following regression model, reported in equation (4), estimated using Ordiary Least Squares with robust standard errors:

$$LHEXP_{it} = \beta_0 + \sum_b \beta_b Pop\_dummy_{it}^b + \beta_2 Kmsq_i + \sum_r \gamma_r Rural\_dummy_{it}^r + \varepsilon_{it} \quad (4)$$

Where:
- i indicates the municipality index;
- t indicates the year indicator since we employ a panel of seven years for the analysis ;
- $Pop\_dummy_{it}^b$ corresponds to the resident population brackets to which of the municipality belongs to;
- $Kmsq_i$ corresponds to the surface in km sq. of the mumicipality;
- $Rural\_dummy_{it}^r$ corresponds to the specific classification of the municipalities among the six categories of the rural vs urban area;
- β_0 is the constant of the model;
- β_b are the coefficients associated with the population brackets;
- γ_r are the coefficients associated with the rural vs urban categories;
- ε_{it} is the idiosincratica error of the model.

2.D.3 Cultural services gap

Methodology/Derivation of indicator

The Cultural services Gap Indicator (CMGI) measures the per capita monetary difference between actual and standard capital expenditures in local transport and road maintenance at the municipal level. This standard is defined as the national average capital expenditure from 2016 to 2022, adjusted for the following variables:
- Resident population,
- Municipal area in square kilometres,
- Classification of municipalities into six urbanization clusters: Center, Intermunicipal, Belt, Intermediate, Periphery, and Ultra-periphery.

This indicator provides an estimate of the infrastructural gap in monetary terms for the cultural services sector at the municipal level as measured in 2022, considering changes from 2016 to 2022.

Data for this analysis is primarily sourced from the "Banca Dati delle Amministrazioni Pubbliche (BDAP)", focusing on accrual-based capital expenditures by service. The period of analysis spans from 2016 to 2022, encompassing all Italian municipalities (7,901 local authorities) and integrating expenditures with contextual variables such as population, municipal area, and urbanization level.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
D.3	Cultural services Capital expenditure gap	2022	municipality	Euro per capita	BDAP, municipal balance sheet
D.3.1	Cultural services Capital Expenditure	2022-2016	municipality	Euro per capita	BDAP, municipal balance sheet
D.3.2	Resident Population	2022-2016	municipality	n.	ISTAT
D.3.3	Municipal surface	2011	municipality	Km sq.	ISTAT

D.3.4	Rural area	2020	municiaplity	Dummy	ISTAT

Table D.3: Data employed in the evaluation of the Cultural services capital expenditure gap 2022

D.3_ Cultural services Capital Expenditure Gap

The index for the year 2022, for each municipality i, corresponds to the following formula in equation (5):

$$\mathrm{CGAP}_i^{2022} = \frac{CSEXP_i - CHE\ _i^{2022}}{Pop_i^{2022}},\ if\ CSEXP_i > CHEXP_i^{2022} \tag{5}$$

Where:

- i indicates the municipality index;
- $CHEXP_i^{2022}$ corresponds to the historical capital expenditure allocated to the calutral service in 2022;
- Pop_i^{2022} corresponds to the resident population of the municipality in the year 2022;
- $CSEXP_i$ corresponds to the standard capital expenditure computed as the average capital expenditure at the national level between 2016 and 2022 conditional on the population of the municipality, the surface of the municipality in Km sq. and, finally, to the classification of the municipalities into six urbanization clusters (Center, Intermunicipal, Belt, Intermediate, Periphery, and Ultra-periphery).

In particular, $CSEXP_i$ is obtained from the fetted values of the following regression model, reported in equation (6), estimated using Ordiary Least Squares with robust standard errors:

$$CHEXP_{it} = \beta_0 + \sum_b \beta_b Pop\_dummy_{it}^b + \beta_2\, Kmsq_i + \sum_r \gamma_r Rural\_dummy_{it}^r + \varepsilon_{it} \tag{6}$$

Where:

- i indicates the municipality index;
- t indicates the year indicator since we employ a panel of seven years for the analysis ;
- $Pop\_dummy_{it}^b$ corresponds to the resident population brackets to which of the municipality belongs to;
- $Kmsq_i$ corresponds to the surface in km sq. of the mumicipality;
- $Rural\_dummy_{it}^r$ corresponds to the specific classification of the municipalities among the six categories of the rural vs urban area;
- β_0 is the constant of the model;
- β_b are the coefficients associated with the population brackets;
- γ_r are the coefficients associated with the rural vs urban categories;
- ε_{it} is the idiosincratica error of the model.

2.D.4 Total services Capital Expenditure Gap

Methodology/Derivation of indicator

The Total Services Gap Indicator (TMGI) measures the per capita monetary difference between total actual and standard capital expenditures at the municipal level. This standard is defined as the national average capital expenditure from 2016 to 2022, adjusted for the following variables:

- Resident population,

- Municipal area in square kilometres,
- Classification of municipalities into six urbanization clusters: Center, Intermunicipal, Belt, Intermediate, Periphery, and Ultra-periphery.

This indicator provides an estimate of the infrastructural gap in monetary terms for the all sectors at the municipal level as measured in 2022, considering changes from 2016 to 2022.
Data for this analysis is primarily sourced from the "Banca Dati delle Amministrazioni Pubbliche (BDAP)", focusing on accrual-based capital expenditures by service. The period of analysis spans from 2016 to 2022, encompassing all Italian municipalities (7,901 local authorities) and integrating expenditures with contextual variables such as population, municipal area, and urbanization level.

The resilience dimension of an indicator for the total capital expenditure in infrastructural services provided by municipalities measures how robustly these services can withstand and adapt to various challenges. It focuses on aspects like the durability and maintenance of infrastructure (roads, bridges, public buildings), the flexibility of systems to adapt to technological advancements and changing needs (upgradable transport systems, modular cultural venues), emergency preparedness levels (flood defenses, earthquake-resistant structures), and the financial sustainability of infrastructure investments (long-term funding strategies, efficient allocation of resources). This indicator helps local governments assess the resilience and long-term viability of their infrastructure across all sectors, guiding policy decisions to bolster resilience, ensure continuity of services, and enhance overall community stability.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
D.4	Total Capital expenditure gap	2022	municipality	Euro per capita	BDAP, municipal balance sheet
D.4.1	Total Capital Expenditure	2022-2016	municipality	Euro per capita	BDAP, municipal balance sheet
D.4.2	Resident Population	2022-2016	municipality	n.	ISTAT
D.4.3	Municipal surface	2011	municipality	Km sq.	ISTAT
D.4.4	Rural area	2020	municipality	Dummy	ISTAT

Table D.4: Data employed in the evaluation of the Total capital expenditure gap 2022

D.4_ Total services Capital Expenditure Gap

The index for the year 2022, for each municipality i, corresponds to the following formula in equation (7):

$$\mathrm{TGAP}_i^{2022} = \frac{TSEXP_i - THEXP_i^{2022}}{Pop_i^{2022}}, \quad if\ TSEXP_i > THEXP_i^{2022} \tag{7}$$

Where:

- i indicates the municipality index;
- $THEXP_i^{2022}$ corresponds to the historical total capital expenditure allocated in 2022;
- Pop_i^{2022} corresponds to the resident population of the municipality in the year 2022;
- $TSEXP_i$ corresponds to the standard capital expenditure computed as the average capital expenditure at the national level between 2016 and 2022 conditional on the

population of the municipality, the surface of the municipality in Km sq. and, finally, to the classification of the municipalities into six urbanization clusters (Center, Intermunicipal, Belt, Intermediate, Periphery, and Ultra-periphery).

In particular, $TSEXP_i$ is obtained from the fetted values of the following regression model, reported in equation (8), estimated using Ordiary Least Squares with robust standard errors and:

$$THEXP_{it} = \beta_0 + \sum_b \beta_b Pop\_dummy_{it}^b + \beta_2\, Kmsq_i + \sum_r \gamma_r Rural\_dummy_{it}^r + \varepsilon_{it} \tag{8}$$

Where:

- i indicates the municipality index;
- t indicates the year indicator since we employ a panel of seven years for the analysis ;
- $Pop\_dummy_{it}^b$ corresponds to the resident population brackets to which of the municipality belongs to;
- $Kmsq_i$ corresponds to the surface in km sq. of the mumicipality;
- $Rural\_dummy_{it}^r$ corresponds to the specific classification of the municipalities among the six categories of the rural vs urban area;
- β_0 is the constant of the model;
- β_b are the coefficients associated with the population brackets;
- γ_r are the coefficients associated with the rural vs urban categories;
- ε_{it} is the idiosincratica error of the model.

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2.E Land use and transportation infrastructure's gaps

The data used for the creation of this indicator concern kilometers of road, highway and rail network per square kilometer, and aim to construct an Infrastructure_LU_Index indicator (Infrastructure and Land Consumption Index, which is configured as the ratio of the sum of kilometers of road, highway and rail network in relation to the total area in square kilometers) that is presented following.

Regarding data collection, we can note that:

- The kilometers of road and highway network on a provincial basis were extrapolated from the Automobile Club d'Italia (ACI) technical report entitled "Road Infrastructure Endowment on the Italian Territory" .
- The kilometers of rail network on a provincial basis were extrapolated directly from the website of the "Ferrovie dello Stato" .

The indicator is useful for assessing, for each spatial unit, the similarity between observations that relate to a given location in relation to adjacent elements (Balletto et Al., 2022). LISA indices provide an effective measure of the degree of relative spatial aggregation between each spatial unit and surrounding elements, allowing the type of spatial concentration to highlight spatial clusters related to a given phenomenon. This indicator has been widely used in the literature to capture the dynamics of spatial aggregation and, in particular, has been applied to the analysis of urban sprawl at provincial and regional scales (Balletto et Al. 2020).

2.E.1 Infrastructure Land Use Index

Methodology/Derivation of indicator

As presented above, the data used concern kilometers of roads, highways and rail network per square kilometer, and were used to calculate the Infrastracture_LU_Index (Infrastructure and Land Consumption Index) indicator. This indicator represents the relationship between the sum of kilometers of road, highway and rail network in relation to the total area in square kilometers.

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
E.1	Infrastructure_LU_Index	2022	Provincies	-	ACI Report, Istat, RFI

Table E.1: Data employed in the evaluation of the Infrastructure Land Use index (2022)

E.1_ Infrastructure_LU_Index

The indicator is constructed as the reciprocal of the natural logarithm of the ratio of percentage of land consumed per province to kilometers of infrastructure network (roads, highways and rail lines) per square kilometer. The formula is presented below:

$$Infrastructure\ land\ use\ index = \frac{1}{LN\left(\frac{\%\ Suolo\ Consumata}{Km_{infrastrutture}} \cdot 100\right)}$$

2.E.2 Share of Variation in Land Use Consumption Per Capita

Methodology/Derivation of indicator

Land consumption for Italian provinces is currently expressed by a report on land consumption proposed by the Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). At this juncture, the relationship between land consumption and population dynamics is highlighted, noting that the link between demographics and urbanization processes is not direct. Even in cases where the resident population stabilizes or decreases, there is an increase in artificial surfaces.

The time series of land consumption on a provincial scale was considered, going to analyze the change in land consumption per capita on an annual basis.

Land consumption can be a proxy for environmental degradation, associated with biodiversity loss, soil erosion, climate-altering gas emissions, impaired air and water quality, and increased vulnerability to extreme events, particularly in the context of rapid environmental changes and significant anthropogenic pressures. Land consumption also can be defined as the conversion of agricultural, forest or natural land into areas for human use or development, a phenomenon that is becoming increasingly widespread in various regions globally (Holling, 1973; Conacher, Sala 1998).

ID CODE	INDICATOR NAME	TEMPORAL COVERAGE	TERRITORIAL COVERAGE	UNIT OF MEASURE	DATA SOURCE
E.2	Share of Variation in Land Use Consumption Per Capita	2015-2022	Provincies	%	Ispra Report

Table E.2: Data employed in the evaluation of the Variation in Land Use Consumption Per Capita (2015-2022)

E.2_ Share of variation in land use consumption per capita

The indicator measures the dynamics of change in land use and its environmental implications. The change in per capita land consumption was calculated as follows:

$$Variation\ of\ share\ of\ Land\ Use\ Pro\ Capita = \frac{\left(\frac{\%\ of\ Land\ Use_x}{inhabitants_x} - \frac{\%\ Land\ Use_{x-1}}{inhabitants_{x-1}}\right)}{\frac{\%\ Land\ Use_{x-1}}{inhabitants_{x-1}}}$$

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