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Supplementary appendix

This appendix formed part of the original submission and has been peer reviewed. We post it as supplied by the authors.

Supplement to: Montana F, Mueller N, Pereira Barboza E, et al. Building a Healthy Urban Design Index (HUDI): how to promote health and sustainability in European cities. *Lancet Planet Health* 2025; **9:** e511–26.

Building a Healthy Urban Design Index (HUDI): How to promote health and sustainability in European cities

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Supplementary Material

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Supplement 1) Cities boundaries and cluster division

City boundaries were obtained from the European Urban Audit 2018 (1). The original dataset includes 980 cities across 31 European countries (EU27, United Kingdom (UK), Norway, Switzerland and Iceland). We excluded Saint-Denis (Réunion) and Fort-de-France (Martinique) due to their location outside the European study area. We decided to include Greater London rather than the City of London, which is primarily an economic hub with only 8,600 inhabitants in 2021. Consequently, we excluded the 32 London boroughs within the Greater London area to avoid redundancy. We also excluded 29 cities whose data were missing from the analysis. We divided cities into clusters following the OECD definition (2), which defined cities based on population size (see Fig S1a). Fig S1b illustrates population distribution across clusters, showing that most people live in small cities (around 70 million) and medium cities (almost 50 million), compared to large metropolitan (30 million) and metropolitan cities (40 million). This highlights the importance of extending the study to medium and small cities as they cover an important European population proportion (120 million people), but are often excluded from studies and literature.

Fig S1a. Cities in Europe by cluster type

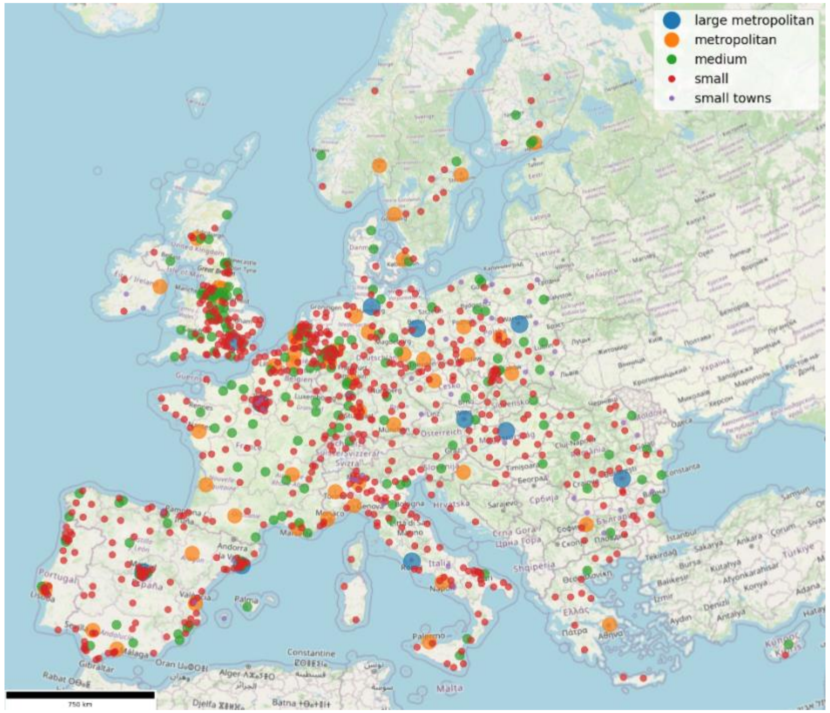
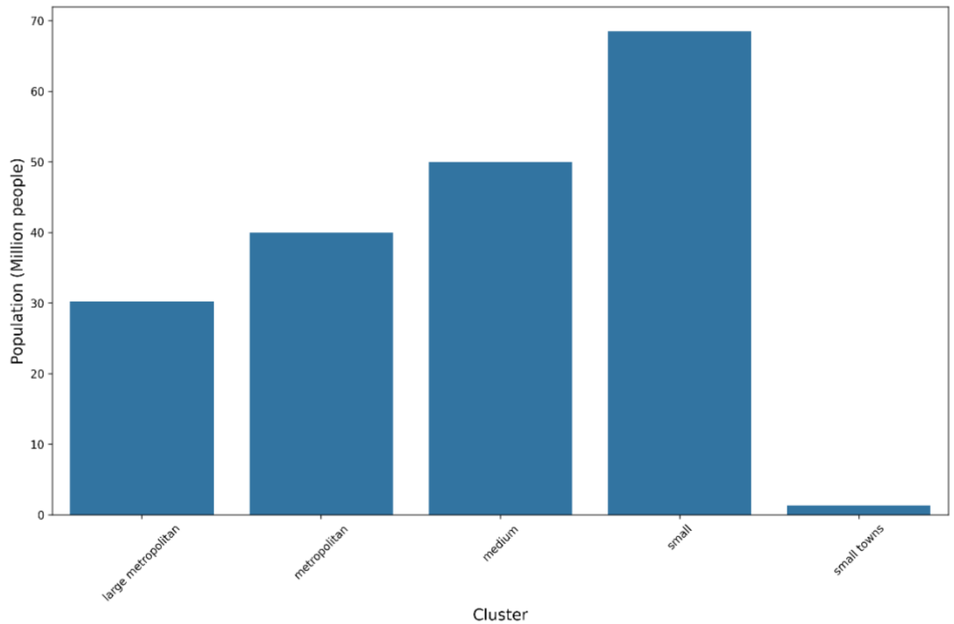


Fig S1b. Population distribution by cluster following the OE's definition



Supplement 2) Data and indicators

a. Optimal dwelling density

We refer to dwelling density as 'optimal' because both exceeding the appropriate density and having a density that is too low can be detrimental to achieving the right balance in an urban environment. This approach allows for variations in urban design while maintaining a density that supports the liveliness and functionality of the city (3). The optimal density has been suggested by previous studies (4,5) to be around 100 dwellings per hectare. To allow for more flexibility in accommodating diverse urban forms, a range of 45 to 175 dwellings per hectare is proposed (3). Specifically, dwelling values falling within the optimal range of [45 - 175] dwellings per hectare for the grid cells were transformed, using Gaussian interpolation, into the range of 6-10, with the values closer to 100 dwellings per hectare being closer to 10 and the value closer to 45 or 175 being closer to 6. The Gaussian interpolation was carefully executed, aligning the value nearest to 100 with the maximum value in the newly rescaled scale, 10. As one moves away from this peak (towards 45 or 175), values are gradually transformed into smaller numbers, ultimately converging to 6. Finally, a linear interpolation was utilized to convert the tails outside the optimal range within the 0-6 interval. In the linear interpolations, the upper and the lower thresholds were set based on considering the "best" and the "worst" within each city cluster.

As a grid of 250mx250m corresponds to 6,25ha, the same rescale method with the same target value was applied to the grid-cells. First, the grid population was divided by the household size. Then, the dwelling density for each grid cell was divided by the area of the grid in hectares to obtain the number of dwellings per hectare. The rescaling method used was the same as we explained above.

Data description

Fig S2a. Descriptive boxplots of the population dataset for all cities by cluster.

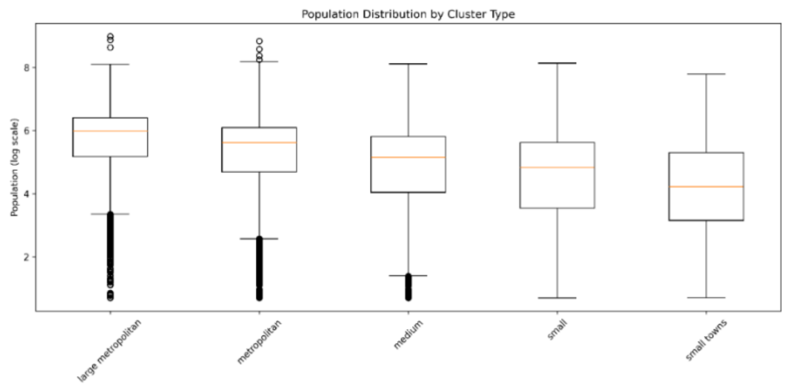


Table S2a. Descriptive of the Optimal dwelling density data at the city level for all cities by cluster.

Variable	**Cluster**	**Mean**	**Std**	**25%**	**75%**	**Max**	**Min**
Optimal dwelling density (dwellings/ha)	Large metropolitan	45.92	33.42	24.20	53.76	121.5	18.48
	Medium	19.62	14.66	12.89	21.60	124.13	4.94
	Metropolitan	26.34	12.57	17.34	32.00	74.65	10.43
	Small	16.26	10.30	10.43	18.81	93.55	2.87
	Small towns	14.79	18.73	4.28	16.83	113.08	1.168

b. Compactness

To compute the horizontal sprawl, we used the definition by Lopez et al. , who define the sprawl index as

$$SI_i = \left(\left(\frac{S\%_i - D\%_i}{100}\right) + 1\right) * 50$$

where:

- SI_i is the sprawl index for the city
- $D\%_i$is the percentage of the total population in the high-density cluster
- $S\%_i$ is the percentage of the total population in the moderate-density urban cluster.

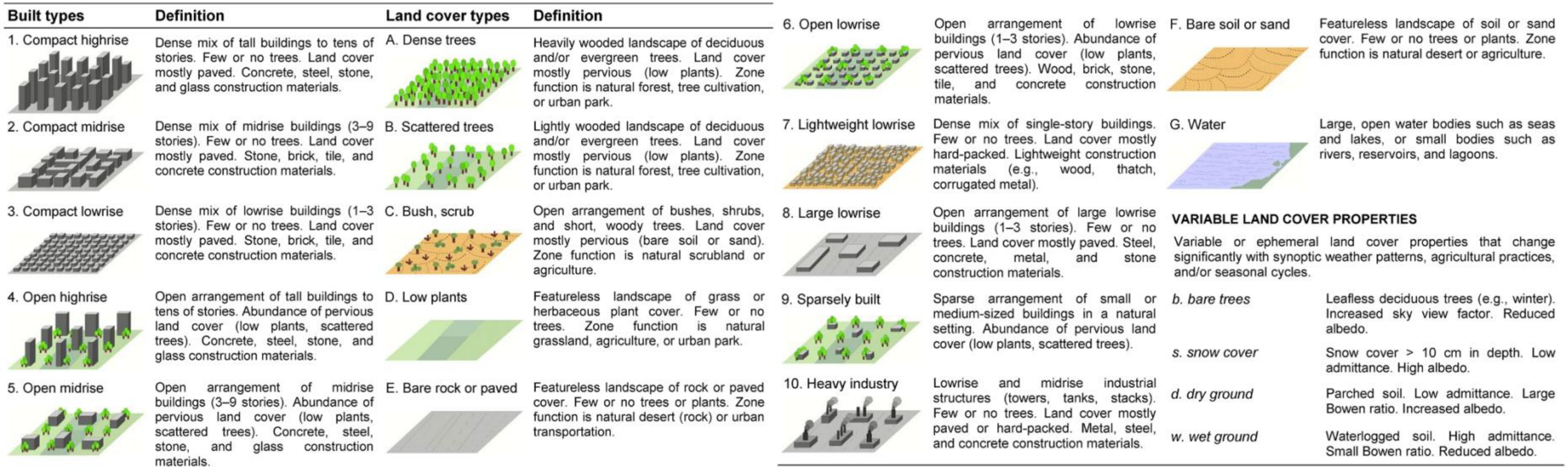
Values of SI_i range from 0 (no sprawl) to 100 (max sprawl). Compactness is computed as the inverse of SI_i : $C_i = 100 - SI_i$

Rural grid cells are those that do not meet the criteria for either urban centers or urban clusters. Our analysis of sprawl indices across European cities confirms that the results align well with known urban forms and development patterns.

c. Mid-rise development

The Low Climate Zone (LCZ) classification is based on satellite imagery and classifies urban landscapes considering building density and height, imperviousness, and vegetation parameters into 17 LCZs. Ten of these LCZs represent the built types, and seven LCZs represent the non-built or natural types of urban areas (6). The dataset (7), retrieved at 100m resolution for Europe, was overlaid with our 250m grid cell layer to estimate the proportion of area corresponding to each LCZ for each grid cell. We excluded grid cells with more than 80% of missing data.

Fig S2b. Description of Local Climate Zones (LCZs) categories from Demuzere et al. (6) .



Local climate zone data wasn't available for 14 cities: Portsmouth (United Kingdom), Las Palmas de Gran Canaria (Spain), Valletta (Malta), Tromsø (Norway), Santa Cruz de Tenerife (Spain), Telde (Spain), Ceuta (Spain), Melilla (Spain), Arrecife (Spain), Santa Lucía de Tirajana (Spain), San Cristóbal de La Laguna (Spain), Funchal (Portugal), Ponta Delgada (Portugal), Puerto de la Cruz (Spain), which were excluded from this work.

Data description

Table S2b. Descriptive of LCZs data for all cities by cluster.

Variable	Cluster	Mean	Std	25%	75%	Max	Min
Compact Midrise (%)	Large metropolitan	8.52	26.15	0	0	100	0
	Medium	2.18	13.24	0	0	100	0
	Metropolitan	5.32	20.84	0	0	100	0
	Small	1.5	10.8	0	0	100	0
	Small towns	1.81	11.61	0	0	100	0
Compact Lowrise (%)	Large metropolitan	0.2	3.49	0	0	100	0
	Medium	0.6	6.5	0	0	100	0
	Metropolitan	0.95	8.52	0	0	100	0
	Small	0.4	5.19	0	0	100	0
	Small towns	0.34	4.71	0	0	100	0
Open Midrise (%)	Large metropolitan	6	21.22	0	0.2	100	0
	Medium	1.33	9.77	0	0	100	0
	Metropolitan	2.45	13.24	0	0	100	0
	Small	0.91	7.95	0	0	100	0

	Small towns	2.01	11.72	0	0	100	0
Open Lowrise (%)	Large metropolitan	13.07	31.01	0	1	100	0
	Medium	14.54	32.15	0.05	1	100	0
	Metropolitan	14.76	32.5	0.05	1	100	0
	Small	13.56	31.01	0	1	100	00
	Small towns	15.18	32.3	0.21	1	100	0
Large Lowrise (%)	Large metropolitan	1.31	9.62	0	0	100	0
	Medium	1.36	10.06	0	0	100	0
	Metropolitan	1.59	10.92	0	0	100	0
	Small	1.16	9.26	0	0	100	0
	Small towns	1.04	8.5	0	0	100	0

Indicator

The mid-rise development metric was normalized to a 0-10 scale at two levels:

- Grid level: Values were rescaled based on the cluster's range, with the highest value scoring 10 and lowest scoring 0. Higher values were considered better.
- City level: A population-weighted average was calculated from the grid scores, using the same normalization approach.

Table S2c. Descriptive of the Mid-rise development indicator for all cities by cluster.

Variable	Cluster	Mean	Std	25%	75%	Max	Min
Mid-rise development	Large metropolitan	0.5	0.13	0.45	0.59	0.64	0.2
	Medium	0.52	0.1	0.45	0.58	0.72	0.16
	Metropolitan	0.54	0.08	0.5	0.57	0.69	0.32
	Small	0.49	0.11	0.42	0.56	0.72	0.1
	Small towns	0.52	0.08	0.46	0.58	0.64	0.28

d. Permeability

To compute Permeability we retrieved the data from EEA (8) and calculated the total area related to non-sealed and sealed based on the imperviousness layer 2018 - 10m. We computed the percentage of permeability in each grid cell by referring to the non-sealed and dividing by the total area of the grid cell.

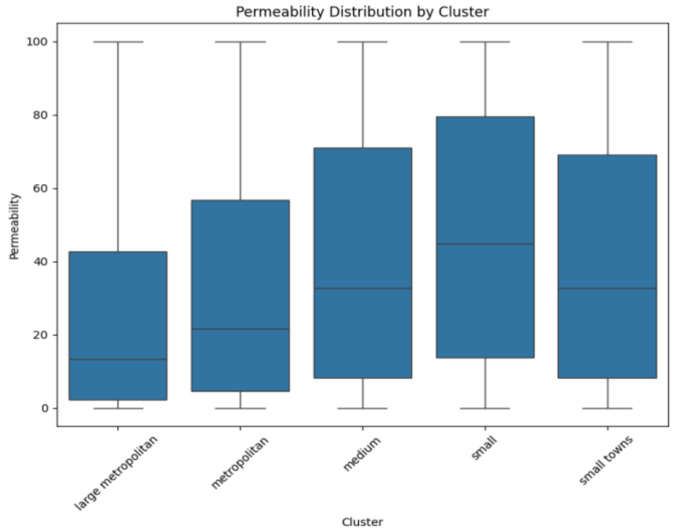
Data description

Table S2d. Descriptive of Permeability data for all cities by cluster at grid cell level.

Variable	Cluster	Mean	Std	25%	75%	Max	Min
Permeability (%)	Large metropolitan	26.03	29.15	2.4	42.84	100	0
	Medium	40.22	33.62	8.32	71.04	100	0
	Metropolitan	32.54	31.31	4.64	56.8	100	0

	Small	46.9	33.95	13.76	79.52	100	0
	Small towns	39.58	33	8.32	69.12	100	0

Figure S2c. Descriptive boxplot of the Permeability data for all cities by cluster.



Indicator

Building on previous studies (9,10) cite we established a threshold of 25% as the target for the grids. At the grid-cell level, this threshold was assigned a score of 6 on the 0–10 scale, with grid cells exceeding 25% receiving proportionally higher scores. The value of 6 identifies it as the minimum threshold for achieving sustainable and healthy urban design (4,9,10) . This approach allows flexibility for higher scores in cases where green space coverage exceeds the baseline target.

At the city level, we computed the percentage of the Population in Target-Meeting Grids: we identified which grid cells met the 25% target and then calculated the percentage of the city's population residing in those cells. This percentage was then divided by 10 to produce a city-level score on a 0–10 scale.

Table S2e. Descriptive of Permeability indicator for all cities by cluster at city level.

Variable	Cluster	Mean	Std	25%	75%	Max	Min
Permeability (%)	Large metropolitan	17.39	6.49	13.8	21	28.2	4.37
	Medium	30.35	11.24	23.96	36.15	83.06	7.01
	Metropolitan	25.37	9.08	18.48	32.01	45.1	9.23
	Small	36.06	12.77	26.84	42.79	84.7	7.73
	Small towns	32.66	14.54	23.26	40.59	65.46	6.53

e. Opportunity to walk, Opportunity to cycle and Public transport stops

In the context of this work walkability and cyclability refer to the ''Opportunity to walk'' and ''Opportunity to cycle'' as defined in (11), emphasizing the potential for individuals to walk within a city based on available infrastructure. To avoid outliers in the dataset and ensure a more reliable and consistent analysis across different geographic areas, we excluded grid cells if they contained values exceeding the 99.5th percentile within their respective categories.

Data description

Table S2f. Description of OSM road categories.

Grouping category	Included OSM categories	Category definition
Total road length	Primary	The next most important roads in a country's system (often link larger towns).
	Primary link	The link roads (slip roads/ramps) leading to/from a primary road from/to a primary road or lower-class highway.

	Secondary	The next most important roads in a country's system (often link towns).
	Secondary link	The link roads (slip roads/ramps) leading to/from a secondary road from/to a secondary road or lower-class highway.
	Tertiary	The next most important roads in a country's system (often link smaller towns and villages).
	Tertiary link	The link roads (slip roads/ramps) leading to/from a tertiary road from/to a tertiary road or lower-class highway.
	Unclassified	The least important through-roads in a country's system, i.e. minor roads of a lower classification than tertiary, but which serve a purpose other than access to properties (often link villages and hamlets).
	Residential	Roads which serve as an access to housing, without the function of connecting settlements. Often lined with housing.
Pedestrian	Pedestrian	Areas primarily intended for pedestrian use. Can include pedestrianized streets, squares, promenades, pedestrian zones, and other similar spaces where pedestrians have priority over vehicles.
	Living streets	Type of road or street design that prioritizes pedestrians and cyclists over motorized vehicles, speeds are kept very low, and where children are allowed to play on the street.
	Path	Paths or tracks that are designated for pedestrian or non-motorized use. These paths are typically narrower than roads and are intended for walking, hiking, cycling, or other similar activities.
	Footway	Represent paths or walkways that are primarily intended for pedestrian use.
	Steps	Represent stairs or staircases. These are typically features that facilitate pedestrian movement between different levels, such as changes in elevation in urban or natural landscapes.
Cycleways	Cycleway	Path for designated cycleways.
Public	Pubtrans	Refers to public transportation-related data or features. This can include information such as bus stops, train stations, tram lines, subway routes, ferry terminals, and other public transit infrastructure.

Cycling infrastructure was found to be absent in some cities belonging to the small and small town clusters . Specifically, Kavala (Greece), Chania (Greece), Xanthi (Greece), Rijeka (Croatia), Trapani (Italy), Gela (Italy), Bagheria (Italy), Valongo (Portugal), L'Aquila (Italy), Campobasso (Italy), Avellino (Italy), Giugliano in Campania (Italy), Potenza (Italy), Vidin (Bulgaria), Sliven (Bulgaria), Shumen (Bulgaria), Yambol (Bulgaria), Pazardzhik (Bulgaria), Blagoevgrad (Bulgaria), Veliko Tarnovo (Bulgaria), Vratsa

(Bulgaria), Ploieşti (Romania), Suceava (Romania), Drobeta-Turnu Severin (Romania), Târgu Mureș (Romania), Călărași (Romania), Giurgiu (Romania), Târgu Jiu (Romania), Slatina (Romania), Bârlad (Romania), Roman (Romania), Brașov (Romania), Buzău (Romania), Bacău (Romania), Botoșani (Romania), Bitonto (Italy). We conducted a city-by-city review using Google Maps and observed that the absence of cycling infrastructure was either due to a lack of available data or a genuine absence of infrastructure. For example, in some Italian cities, such as Bagheria, Trapani, L'Aquila, Campobasso, Avellino, and Potenza, isolated cycling paths were visible on Google Maps. However, these were predominantly located inside parks (not within residential grids) or represented wide roads marked as cycling-friendly but lacking dedicated cycling infrastructure. Since our analysis focuses specifically on cycling infrastructure within residential grids, we decided to include all these cities in the analysis, treating them as having zero cycling infrastructure. The analysis of public transport stop data revealed that Bisceglie (Italy) recorded zero values for transport stops across the city. A further inspection using Google Maps confirmed the absence of visible bus stops, indicating that the lack of stops was due to their nonexistence rather than lack of data. Consequently, we decided to include Bisceglie from our study. Finally, we excluded cities where total length data were not available (N=13): Panevėžys (Lithuania), Tartu (Estonia), Alytus (Lithuania), Klaipėda (Lithuania), Šiauliai (Lithuania), Tallinn (Estonia), Kaunas (Lithuania), Liepāja (Latvia), Narva (Estonia), Daugavpils (Latvia), Jelgava (Latvia), Riga (Latvia), Vilnius (Lithuania).

Figure S2d. Descriptive boxplots of OSM road typologies for all cities by clusters.

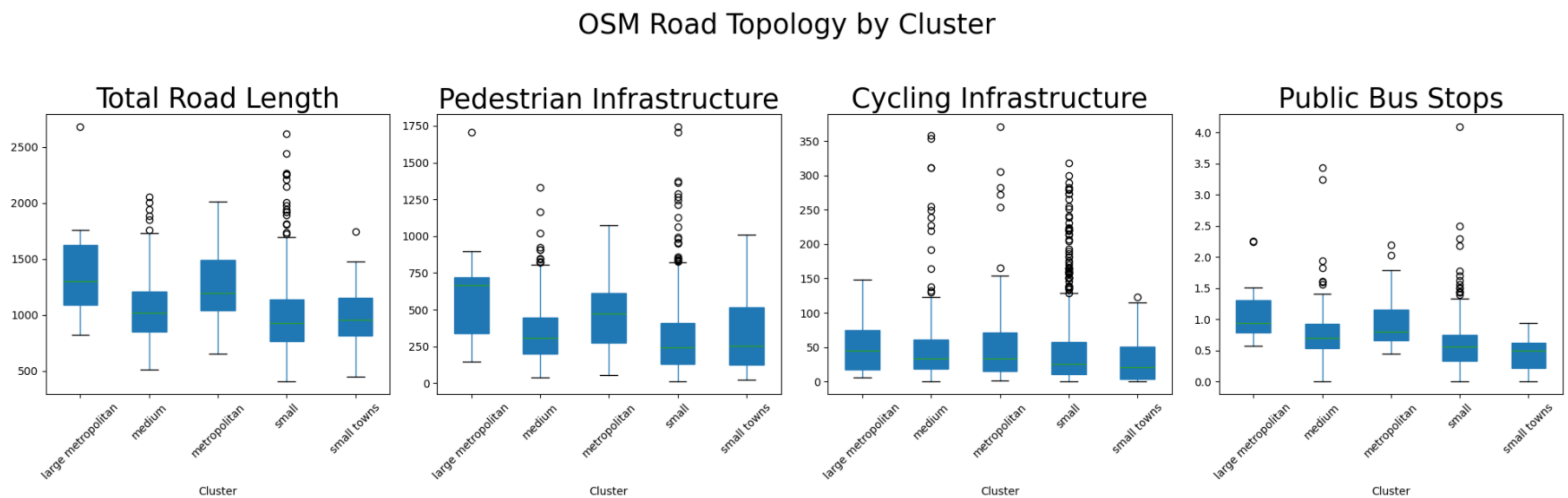


Table S2g. Descriptive of OSM road typologies for all cities by clusters.

Variable	Cluster	Mean	Std	25%	75%	Max	Min
Total road length (m)	Large metropolitan	1418.22	512.02	1085.74	1627.85	2678.17	827.11
	Medium	1068.13	294.46	852.01	1212.15	2052.22	513.6
	Metropolitan	1248.58	314.06	1040.99	1494.54	2014.14	654.27
	Small	983	321.4	763.91	1139.78	2620.53	406.44
	Small towns	988.78	272.1	814.9	1151.12	1743.4	447.72
Pedestrian roads (m)	Large metropolitan	634.75	427.56	338.12	718.67	1706.26	145.73
	Medium	364.3	236.42	197.52	443.86	1329.8	39.05
	Metropolitan	482.72	245.71	274.41	615.29	1074.02	56.62
	Small	304.48	238.59	132.54	410.14	1741.59	10.51
	Small towns	337.5	255.66	126.56	518.48	1010.12	20.2
Cycleway (m)	Large metropolitan	55.06	48.43	17.26	74.85	147.79	6.62
	Medium	52.82	63.01	18.51	61.5	357.97	0
	Metropolitan	66.27	85.16	14.99	70.87	370.22	1.11
	Small	46.11	56.41	10.49	57.82	317.49	0

	Small towns	32.4	34.42	3.89	51.05	122.61	0
Public transport stops	Large metropolitan	0.97	1.47	0	2	20	0
	Medium	0.7	1.22	0	1	20	0
	Metropolitan	0.86	1.43	0	2	20	0
	Small	0.53	1.06	0	1	20	0
	Small towns	0.45	0.95	0	1	19	0

Indicators

- **Opportunity to walk**

Similar to what was done by the Clean City Campaign project (11), the calculation for the opportunity to walk metric was conducted using the subsequent formula:

$$\%pedestrian\ roads = \frac{\sum pedestrian\ footways\ (m)}{total\ lengt\ of\ city\ road\ network\ (m)}$$

Where ‘pedestrian footways’ included the following map categories: ‘path’, ‘footway’, ‘steps’, ‘pedestrian’, and ‘living streets’. Total road length included ‘primary roads’, ‘secondary roads’, ‘tertiary roads’, and ‘residential roads’ (formed by “unclassified” and “residential”). A description of all the OSM categories is in Table S2g. This indicator was aggregated at the city level using population weighting and rescaled to a 0–10 scale through linear interpolation, where 0% corresponds to a score of 0 and 70% corresponds to a score of 10. Table S2h presents the top five cities with the highest "opportunity to walk" values. The upper threshold of 70%, derived from (18), aligns with the value observed in the city of Geneva.

Table S2h. Top 5-cities for the Opportunity to walk indicator

Indicator	City name	Value	Rescaled value	Cluster
Opportunity to walk	Geneve (CH)	69.02	8.52	Small
	Salamanca (ES)	66.45	8.15	Small
	Coslada (ES)	65.28	7.97	Small
	Burgos (ES)	65.21	7.96	Small
	Wroclaw (PL)	64.69	8.3	Metropolitan

- **Opportunity to cycle**

This indicator was calculated by using the formula below, similar to (11):

$$\%cycling\ roads = \frac{\sum cycling\ paths\ (m)}{total\ lengt\ of\ city\ road\ network\ (m)}$$

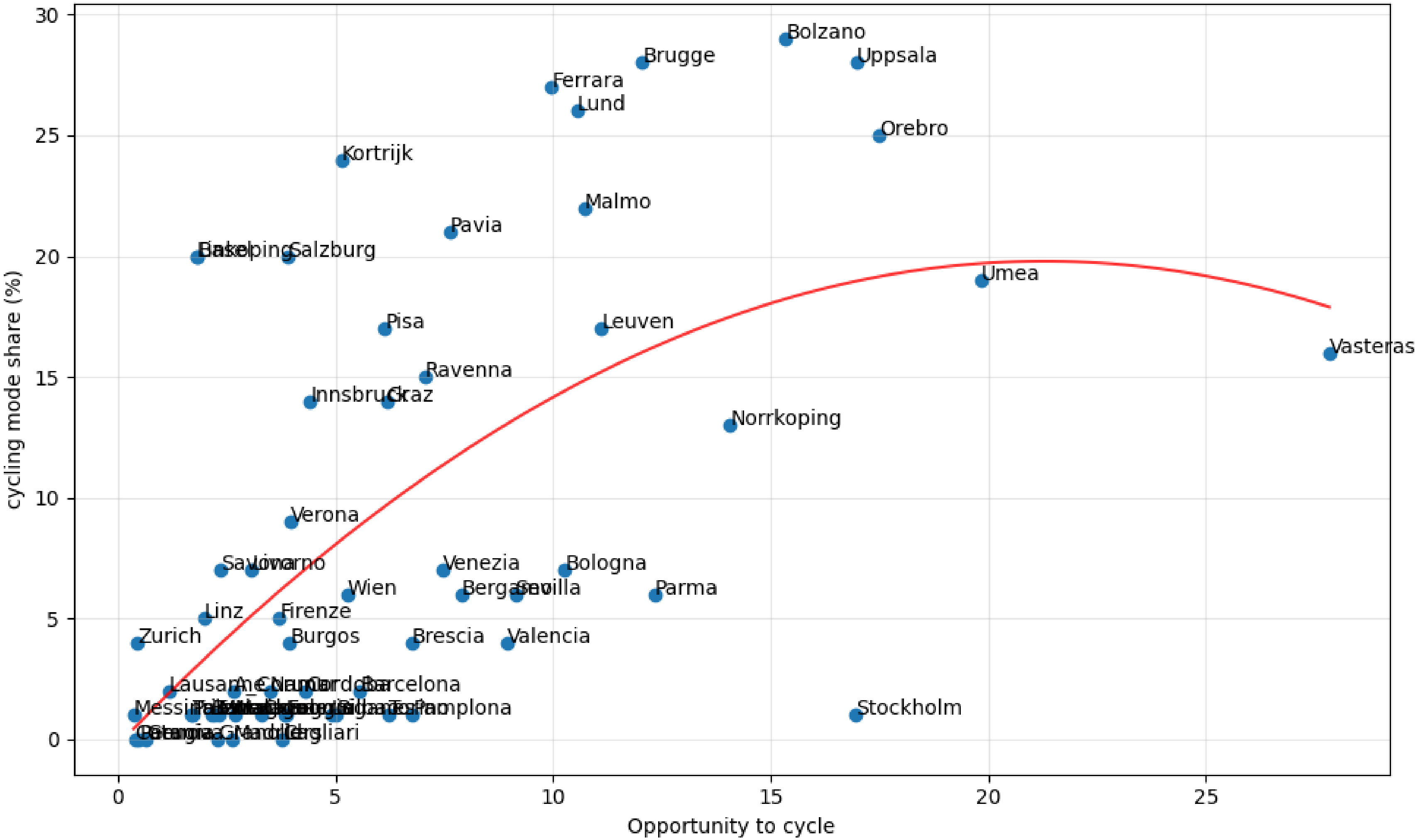
Table S2i. Top 5-cities for the Opportunity to cycle indicator

Indicator	City name	Value	Rescaled value	Cluster
Opportunity to cycle	Lahti	30.64	7.66	Small
	Espoo	30.62	7.65	Medium
	Vantaa	29.63	7.41	Medium

	Jyvaskyla	29.27	7.31	Small
	Oulu	28.620049	7.15	Small

We computed the score at the city level using different thresholds and we see that the andament of the score is stable over the clusters. We replicated the findings of Mueller et al. (12), which demonstrated a positive relationship between the length of the cycling network and cycling mode share. Using our city-level cyclability data, we validated these results, confirming a positive correlation between cycling infrastructure and cycling mode share. This further reinforces the reliability of this indicator as a suitable proxy (See Fig S2e).

Fig S2e. Comparison between Opportunity to cycle indicator and mode-share data.



- **Public Transport stops**

We established a maximum limit of 20 Public Transport Stops per grid (250m x 250m resolution), which corresponds to the 99.5^{th} percentile and aligns with the typical configuration of grids in a bus station.

Data description

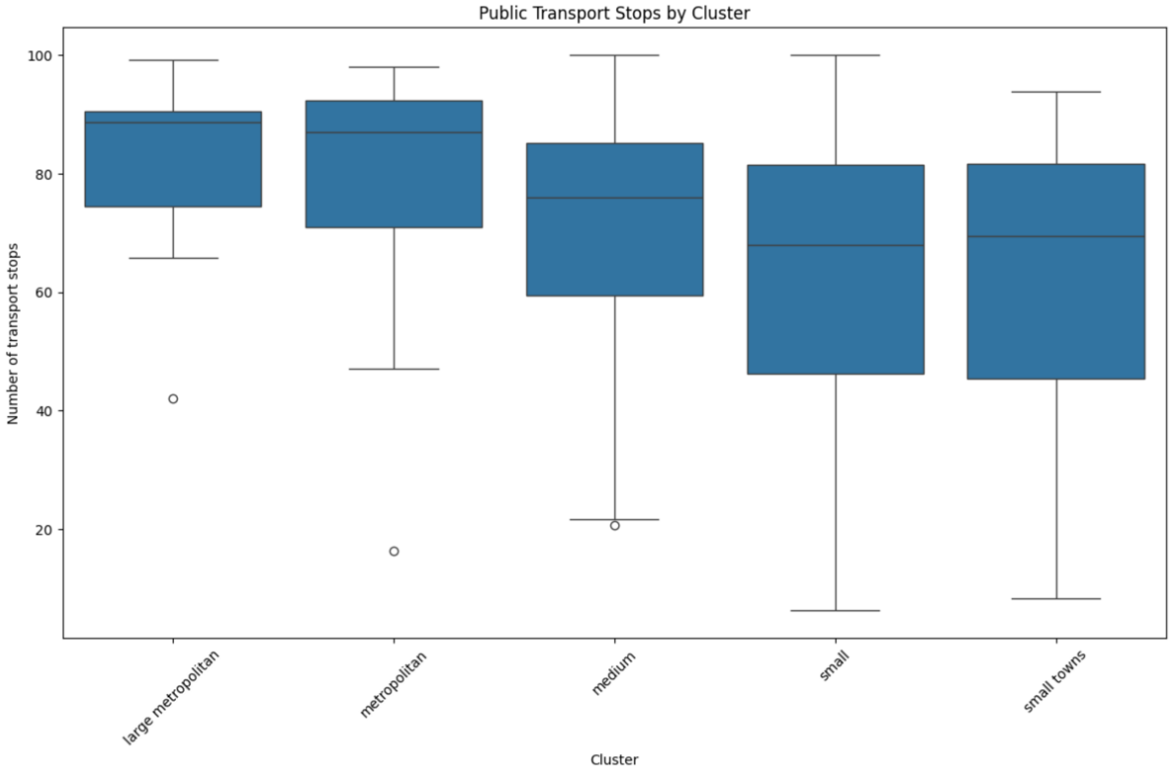
Table S2j. *Descriptive of public bus stops for all cities by clusters.*

Variable	Cluster	Mean	Std	25%	75%	Max	Min
Public transport stops	Large metropolitan	0.97	1.47	0	2	20	0
	Medium	0.7	1.22	0	1	20	0
	Metropolitan	0.86	1.43	0	2	20	0
	Small	0.53	1.06	0	1	20	0
	Small towns	0.45	0.95	0	1	19	0

Indicator

This indicator is based on the presence of at least one Public Transport stop per grid cell. We calculated the percentage of the city's population with access to such stops and rescaled it to a 0–10 scale by dividing the values by 10.

Fig S2f. Descriptive boxplot of Public transport stops indicator at city level for all cities by cluster.



f. Air Quality PM2.5 and NO2

To determine baseline average yearly concentrations of PM2.5 and NO2 at a resolution of 250-meter grid cells for the year 2015, we used estimates from land use regression (LUR) models. These models were created at a finer, 100-meter grid scale in 2010 as part of the Effects of Low-Level Air Pollution: a Study in Europe (ELAPSE) project. We applied these estimates to 802 cities and 46 larger urban areas. For additional details, please refer to the work by Khomenko et al. (13).

Data description

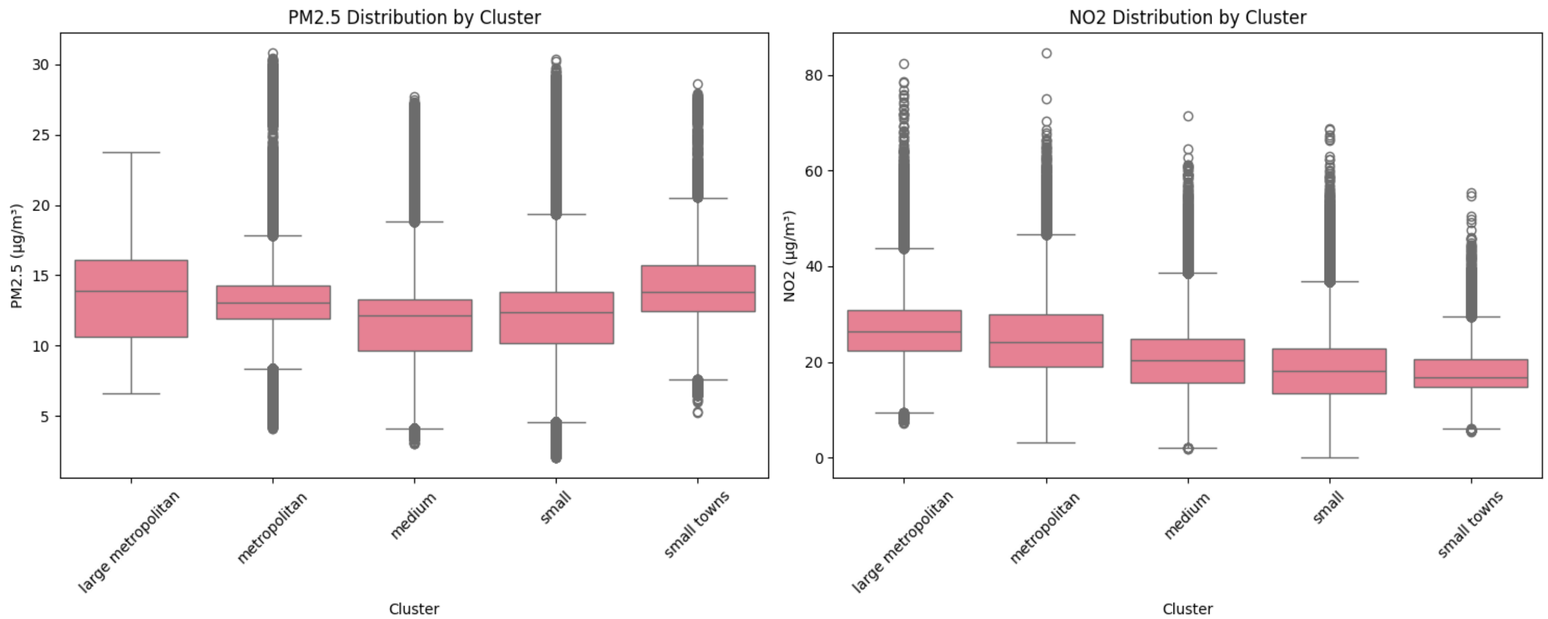
Table S2k. Descriptive of PM2.5 for all cities by clusters.

Variable	Cluster	Mean	Std	25%	75%	Max	Min
PM2.5	Large metropolitan	14.05	3.66	10.61	16.1	23.8	6.62
($\mu g/m^3$)	Medium	12.04	3.56	9.62	13.29	27.75	3.02
	Metropolitan	13.28	3.78	11.89	14.27	30.8	4.13
	Small	12.41	3.91	10.14	13.84	30.4	2.01
	Small towns	14.25	3.42	12.44	15.68	28.62	5.21

Table S2l. Descriptive of NO2 for all cities by clusters.

Variable	Cluster	Mean	Std	25%	75%	Max	Min
NO2	Large metropolitan	27.32	7.45	22.31	30.91	82.43	7.3
($\mu g/m^3$)	Medium	20.65	7.11	15.8	24.91	71.32	1.81
	Metropolitan	24.91	8.16	19.02	30.08	84.51	3.16
	Small	18.55	7.16	13.57	22.85	68.66	0
	Small towns	18.47	6.29	14.84	20.68	55.37	5.46

Fig S2g. Descriptive boxplot of PM2.5 and NO2 for all cities by cluster.



Indicators

Indicators at the grid-cell level were computed using the WHO recommended thresholds of 5 μg/m^3 for $PM_{2.5}$ and 10 μg/m^3 for NO_2 (14). Values reaching this threshold had assigned a score of 10 on the new scale. At the city level, we calculated a population-weighted average of the grid-cell values and then rescaled them according to the WHO thresholds.

Table S2m. Descriptive of absolute values of Air Quality (PM2.5) indicator at city level for all cities by clusters.

Variable	Cluster	Mean	Std	25%	75%	Max	Min
Air Quality (PM2.5) ($\mu g/m^3$)	Large metropolitan	15.58	3.44	13.51	17.19	23.24	10.28
	Medium	12.66	3.61	9.72	13.79	25.87	6
	Metropolitan	13.67	3.98	12.37	14.76	28.19	6.66
	Small	13.41	3.5	11.84	14.87	27.51	4.95
	Small towns	14.64	3.77	12.62	15.33	27.12	7.19

Table S2n. Descriptive of absolute values of Air Quality (NO2) indicator at city level for all cities by clusters.

Variable	Cluster	Mean	Std	25%	75%	Max	Min
Air Quality (NO2) ($\mu g/m^3$)	Large metropolitan	32.05	7.29	26.15	36.99	43.98	24.99
	Medium	24.29	5.07	20.8	26.74	42.09	12.46
	Metropolitan	28.33	6.05	24.3	33.51	42.19	18.6
	Small	22.53	5.43	18.61	25.68	42.72	9.51
	Small towns	21.5	6.41	17.37	26.07	35.45	11.81

g. Surrounding greenness (NDVI)

NDVI provides consistent, large-scale, and repeatable measurements of vegetation cover across different regions and time periods, making it a valuable tool for urban assessments. It serves as a proxy for green space availability, influencing urban resilience, air quality, biodiversity, and quality of life. High NDVI values indicate healthy vegetation, supporting temperature regulation, carbon sequestration, and mental well-being, while low values may signal environmental degradation or insufficient greenery. Data for NDVI were retrieved from 2015 MODIS Vegetation Indices (MOD13Q1) (15).

Table S2o. Descriptive of NDVI for all cities by cluster.

Variable	Cluster	Mean	Std	25%	75%	Max	Min
NDVI	Large metropolitan	0.49	0.13	0.41	0.58	0.84	0.08
	Medium	0.53	0.13	0.45	0.63	0.86	0.05
	Metropolitan	0.52	0.13	0.44	0.61	0.86	0.08
	Small	0.55	0.13	0.47	0.64	0.88	0.04
	Small towns	0.52	0.11	0.44	0.6	0.83	0.16

Fig S2h. Descriptive boxplot of NDVI for all cities by cluster.

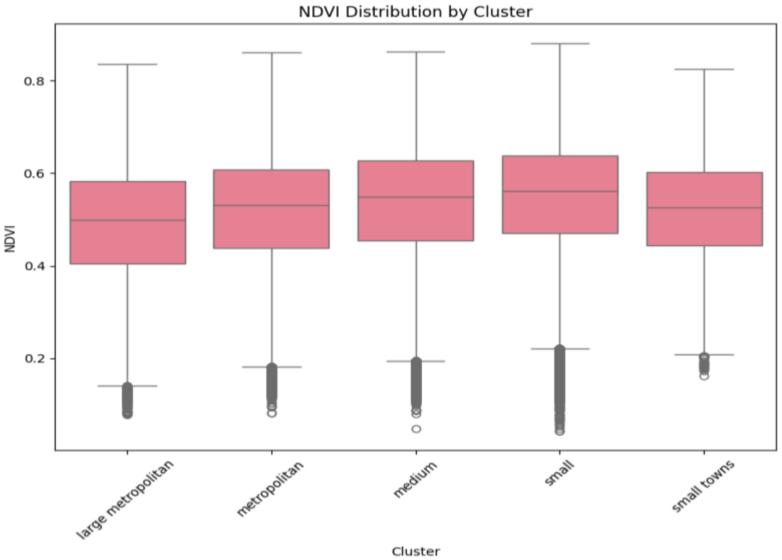


Table S2p. Descriptive of NDVI target for all cities by cluster.

Variable	Cluster	Mean	Std	25%	75%	Max	Min
target NDVI	Large metropolitan	0.45	0.1	0.39	0.52	0.6	0.31
	Medium	0.5	0.1	0.47	0.57	0.62	0.18
	Metropolitan	0.49	0.09	0.48	0.54	0.6	0.24
	Small	0.49	0.1	0.44	0.56	0.65	0.16

	Small towns	0.47	0.09	0.46	0.51	0.63	0.22

We calculated the indicator at the grid-cell level by first determining whether each cell met its city-specific target, as defined by Baraboza et al. (16). The target value was assigned a score of 6 on the new scale. Values above the target were rescaled within a 6–10 range, while values below the target were rescaled within a 6-0 range. We chose 6 as the target score to denote a 'good' value, ensuring room for cells with higher NDVI values to earn an even better score. At city level, we identified which grid cells met the target and then calculated the percentage of the city's population residing in those cells. This percentage was then divided by 10 to produce a city-level score on a 0–10 scale.

Table S2q. Descriptive of Surrounding greenness indicator by cluster, aggregated by target-meeting.

Variable	**Cluster**	**Mean**	**Std**	**25%**	**75%**	**Max**	**Min**
Surrounding greenness (%)	Large metropolitan	29.12	10.65	22.44	38.00	43.03	11.33
	Medium	39.16	11.06	32.12	47.10	79.81	13.97
	Metropolitan	35.35	11.49	25.48	44.33	55.87	7.78
	Small	42.57	12.53	34.74	50.39	85.24	0.68
	Small towns	42.06	13.15	31.04	49.26	67.54	15.96

h. Lower urban heat islands

The Lower Urban Heat Islands (LUHI) indicator measures a city's ability to mitigate heat by evaluating the temperature difference between urban and rural areas. It serves as a key metric for assessing urban resilience to heat stress, highlighting the effectiveness of green infrastructure, reflective surfaces, and sustainable urban design in reducing heat retention. LUHI contributes to creating cooler, healthier, and more livable urban environments, aligning with global sustainability goals.

For this indicator, we estimated the CUHI (Canopy Urban Heat Island) as the difference between the urban and non-urban Air Temperatures within the urban extent (17).

Data description

Table S2r. Descriptive of CUHI for all cities by clusters.

Variable	Cluster	Mean	Std	25%	75%	Max	Min
CUHI	Large metropolitan	0.24	0.54	-0.014	0.58	2.38	-3.17
	Medium	0.28	0.61	-0.006	0.6	2.95	-7.22
	Metropolitan	0.39	0.64	0.034	0.75	3.54	-3.85
	Small	0.34	0.68	-0.015	0.64	7.39	-8.33
	Small towns	0.321	0.58	0.02	0.57	4.01	-2.35

Indicator

The Lower Urban Heat Island (LUHI) indicator was rescaled at the grid cell level to a 0-10 scale, where lower values indicate better performance. This approach aligns with the principle that indicators are always positive, and lower values are desirable to mitigate the urban heat island effect. At the city level, the LUHI indicator was calculated as a population-weighted average of the grid-level values. The rescaling was consistently performed at both levels to ensure that lower values represent better outcomes.

Table S2s. Descriptive of Lower urban heat island indicator at city level for all cities by clusters.

Variable	Cluster	Mean	Std	25%	75%	Max	Min
Lower Urban Heat Islands	Large metropolitan	0.29	0.40	0.20	0.41	0.93	-0.67
	Medium	0.41	0.37	0.22	0.58	1.98	-0.64

	Metropolitan	0.53	0.45	0.31	0.65	2.23	-0.71
	Small	0.46	0.58	0.22	0.65	5.88	-1.76
	Small towns	0.41	0.50	0.17	0.49	2.98	-0.17

i. Universal access to green spaces and Access to large green spaces

Table S2t. Descriptive of accessibility to green of 0.5 ha within 300m for all cities by cluster.

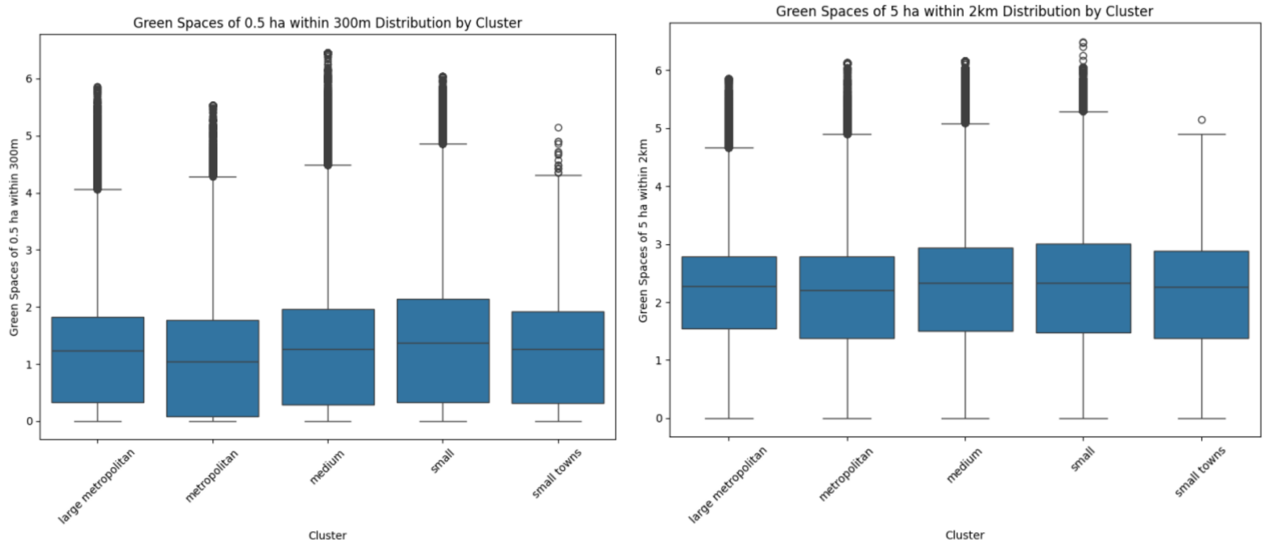
Variable	Cluster	Mean	Std	25%	75%	Max	Min
Green of 0.5 ha within 300m	Large metropolitan	1.21	0.97	0.34	1.83	5.86	0
	Medium	1.30	1.08	0.29	1.97	6.45	0
	Metropolitan	1.09	0.95	0.09	1.77	5.53	0
	Small	1.42	1.17	0.33	2.14	6.04	0
	Small towns	1.26	1.00	0.31	1.92	5.15	0

Table S2u. Descriptive of accessibility to green of 5 ha within 2km for all cities by cluster.

Variable	Cluster	Mean	Std	25%	75%	Max	Min
Green of 5 ha within 2km	Large metropolitan	2.12	1.08	1.54	2.79	5.86	0

	Medium	2.22	1.22	1.51	2.94	6.15	0
	Metropolitan	2.05	1.13	1.38	2.79	6.13	0
	Small	2.22	1.267	1.48	3.00	6.49	0
	Small towns	2.1	1.14	1.37	2.88	5.15	0

Fig S2i. Descriptive boxplot of Green Accessibility data for all cities by cluster.



Indicators at the grid level were rescaled by assigning a score of 10 to the highest value within the cluster and 0 to the lowest. At the city level. we first determined the proportion of the population meeting the grid-level target (as identified by Battiston et al.) and then converted this percentage into a 0–10 scale.

Table S2v. Descriptive of Universal access to green spaces indicator for all cities by cluster.

Variable	**Cluster**	**Mean**	**Std**	**25%**	**75%**	**Max**	**Min**
Universal access to green spaces	Large metropolitan	49.302	8.781	46.016	54.836	62.605	29.461
	Medium	46.131	10.667	39.544	53.394	72.123	12.383
	Metropolitan	48.129	8.811	44.026	54.536	70.375	25.412

	Small	44.486	12.507	36.697	53.23	81.877	0
	Small towns	45.414	13.776	33.225	54.729	83.291	23.916

Table S2w. Descriptive of Access to large green spaces indicator for all cities by cluster.

Variable	**Cluster**	**Mean**	**Std**	**25%**	**75%**	**Max**	**Min**
Access to large green spaces	Large metropolitan	63.574	8.239	58.344	68.474	78.678	50.3
	Medium	57.947	11.793	51.934	66.3	83.058	19.524
	Metropolitan	59.757	10.855	52.722	66.648	84.644	36.1
	Small	56.258	16.05	49.443	66.379	93.912	0
	Small towns	59.208	14.713	51.172	68.503	88.554	32.278

Supplement 3) Main Analysis

a. Indicators' analysis

Fig S3a. Descriptive boxplots of the absolute values indicators across different city clusters.

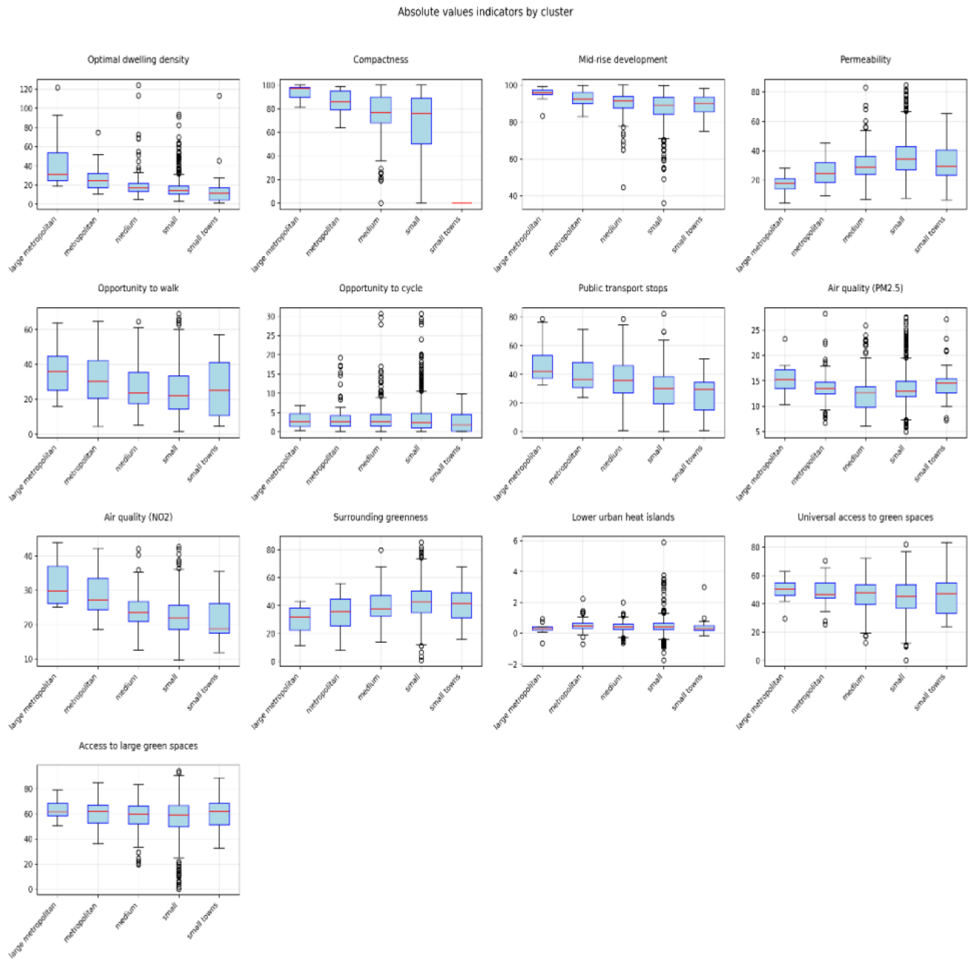


Fig S3b. Descriptive boxplot of the mean value of the domains (Urban Design, Sustainable Transportation, Environmental Quality and Green Spaces Accessibility) divided by cluster.

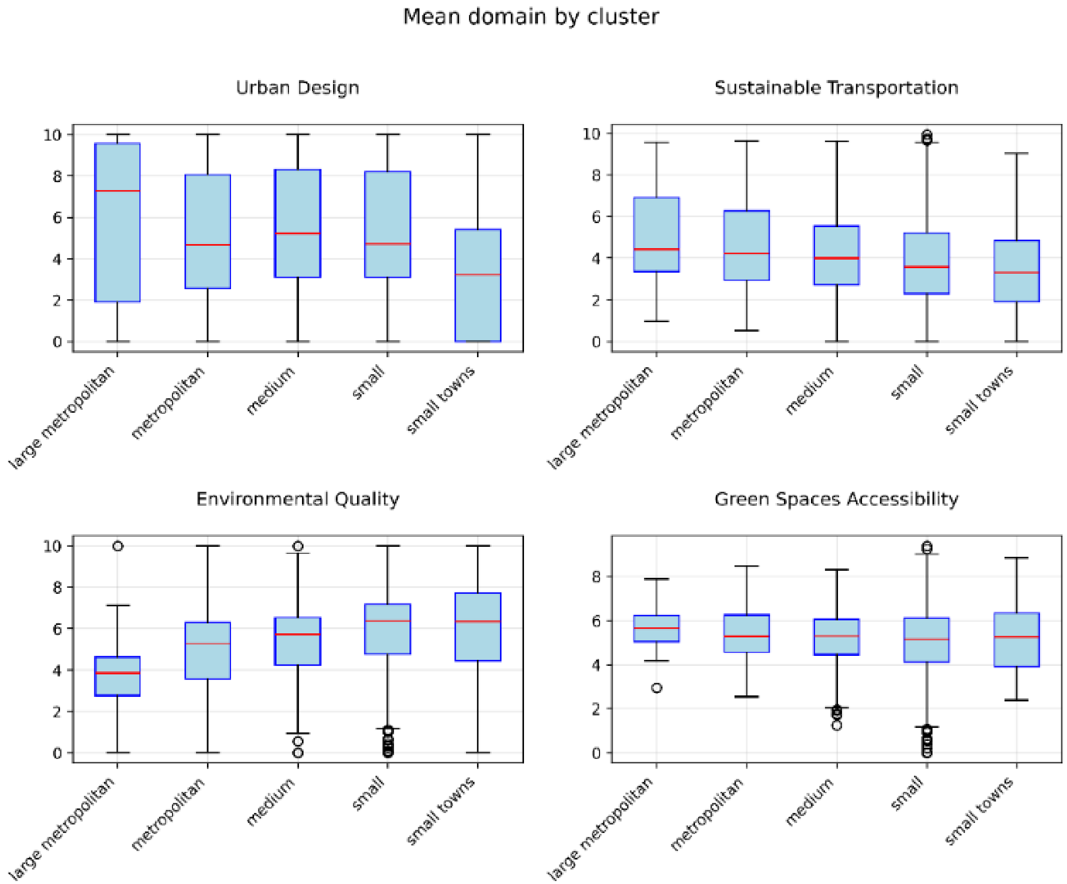
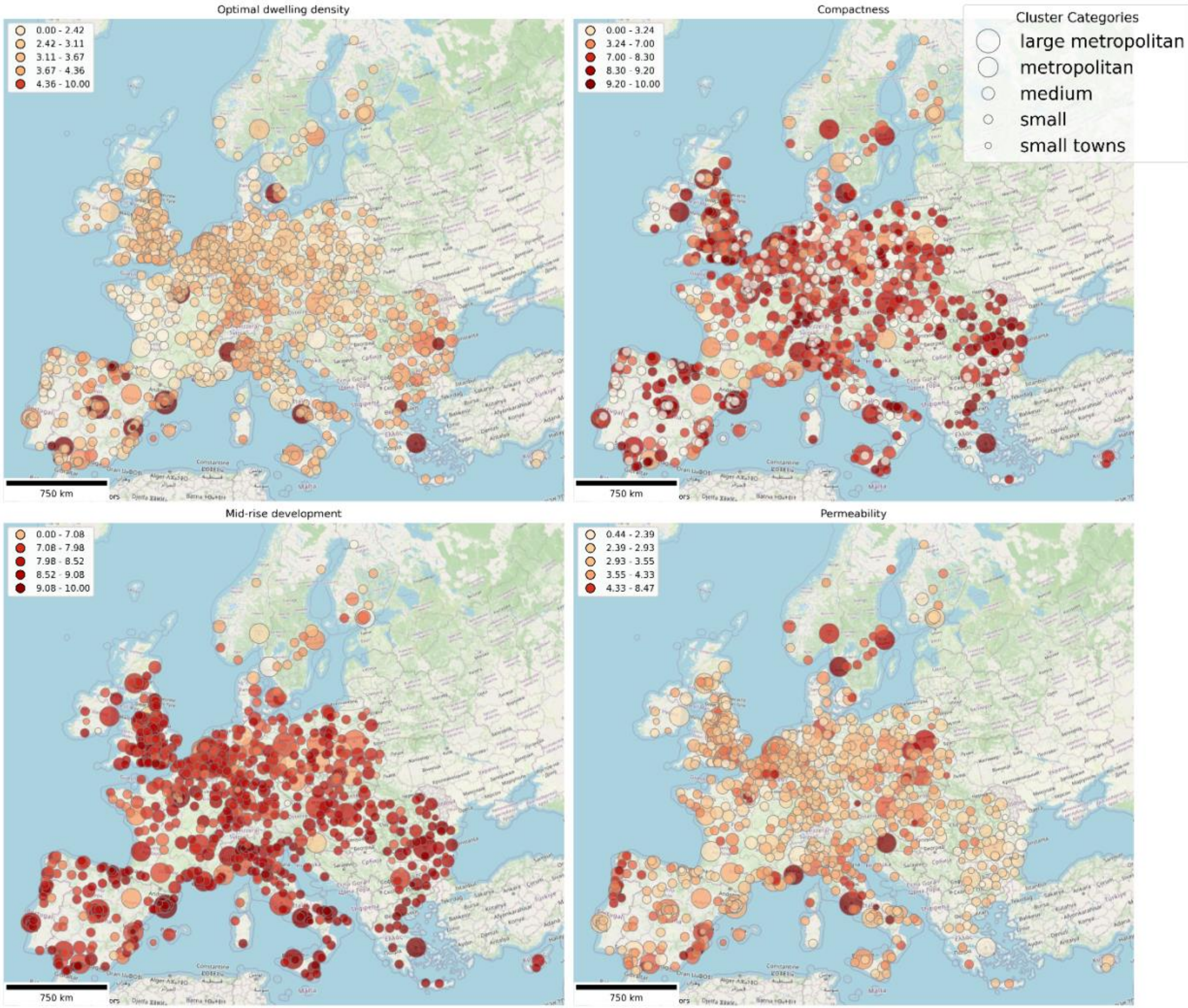
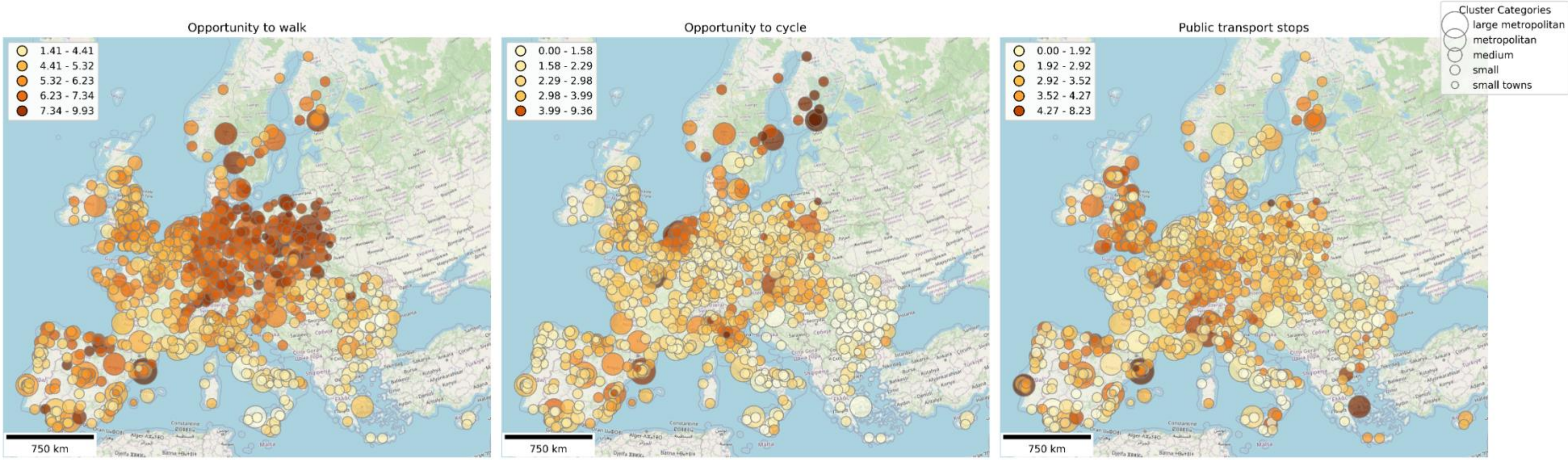


Fig S3c. Spatial distribution of the indicators across European cities. Larger rings correspond to large metropolitan cities and smaller rings indicate progressively smaller clusters.

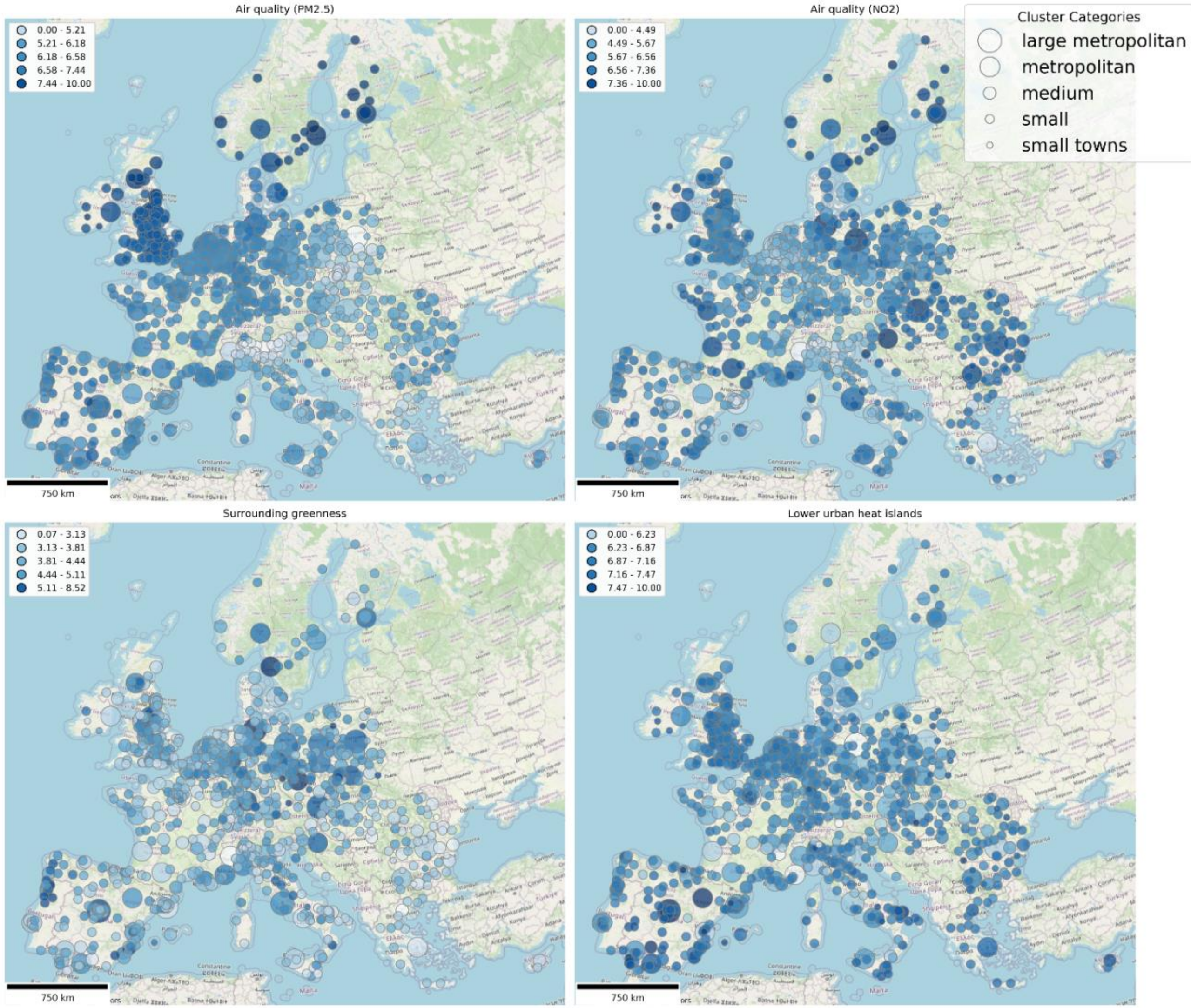
Urban Design



Sustainable Transportation



Environmental Quality



Green Spaces Accessibility

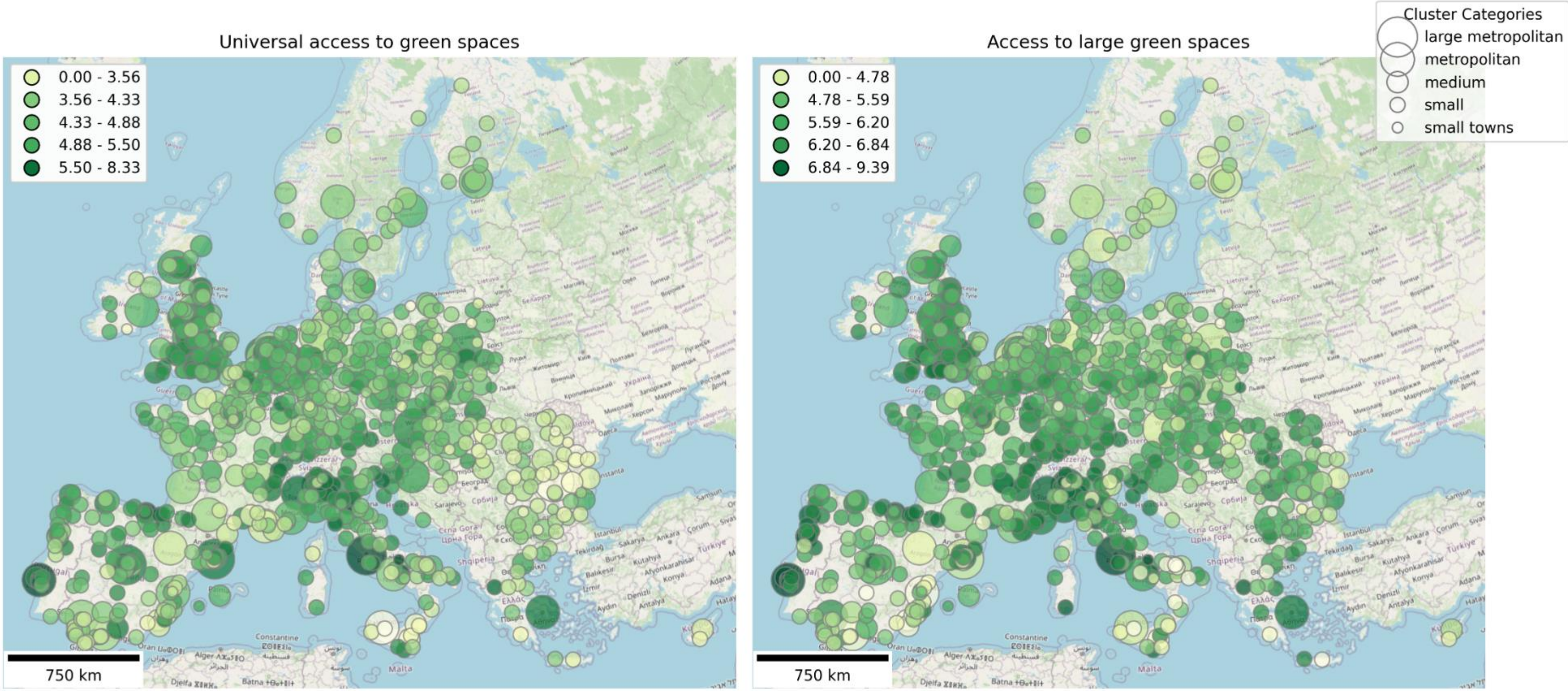
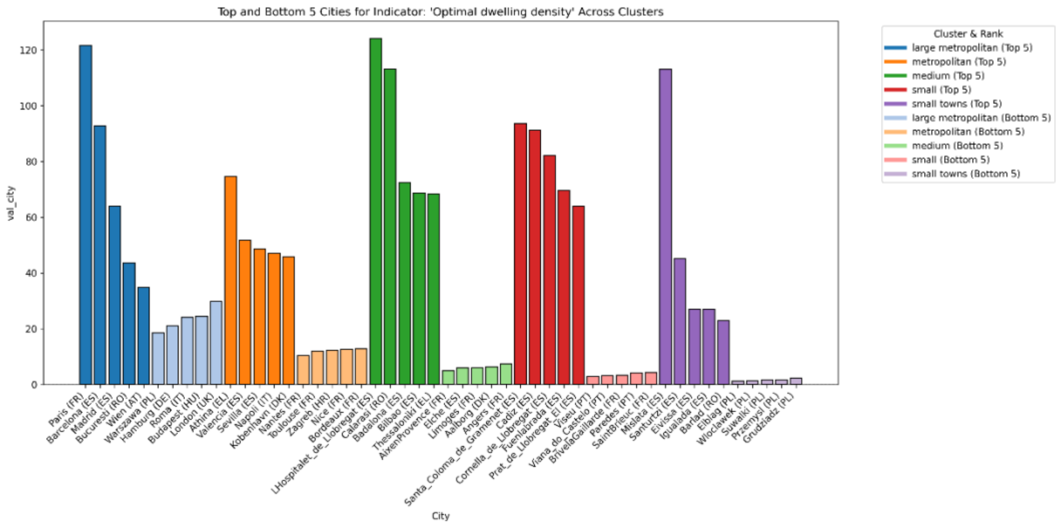
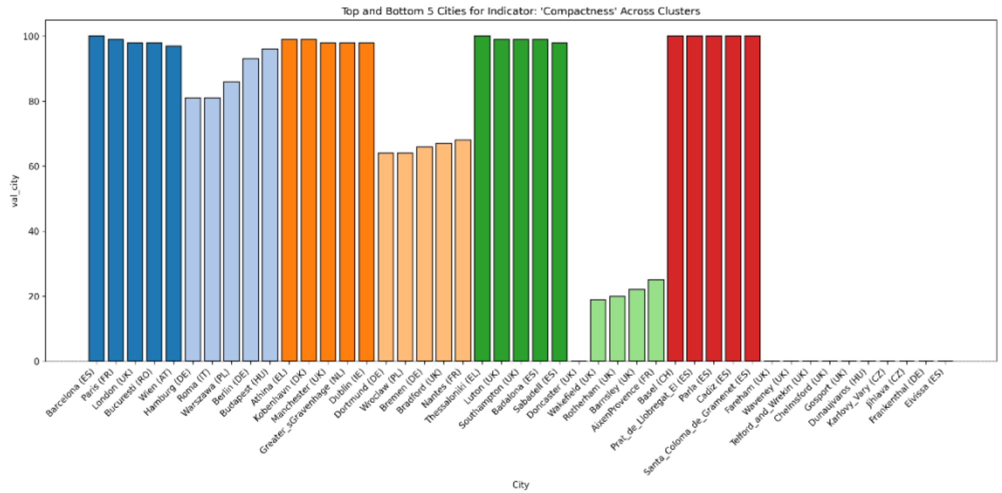
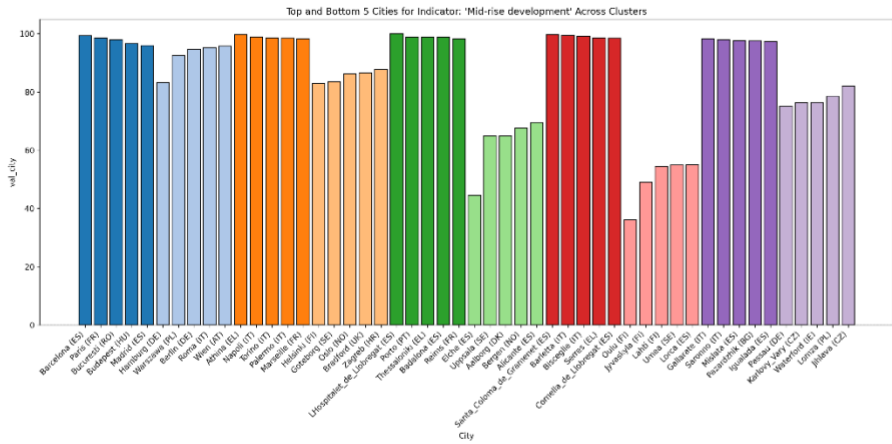


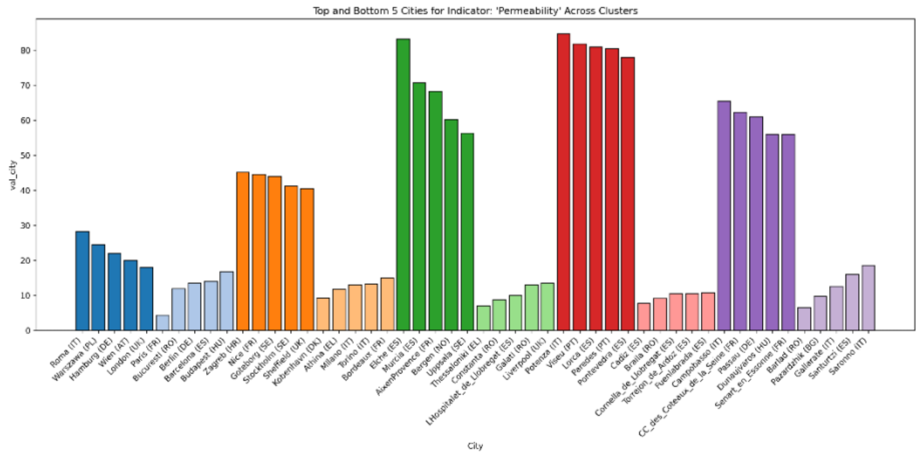
Fig S3d. The figures display the rescaled values for the 13 indicators, highlighting the top and bottom five cities across clusters.

Urban Design

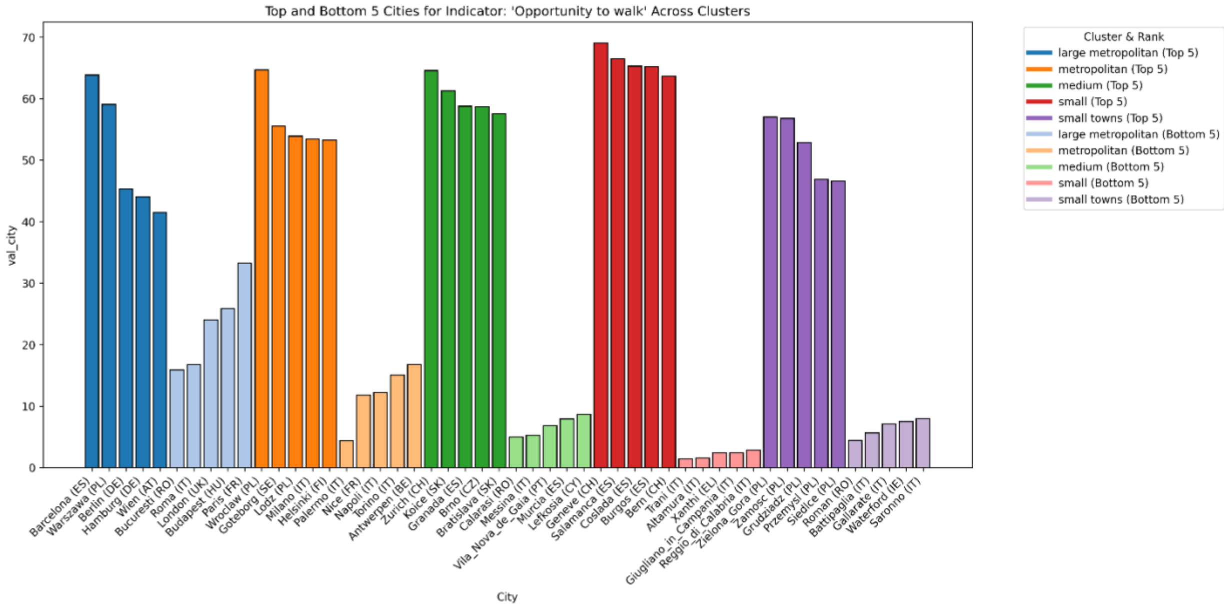


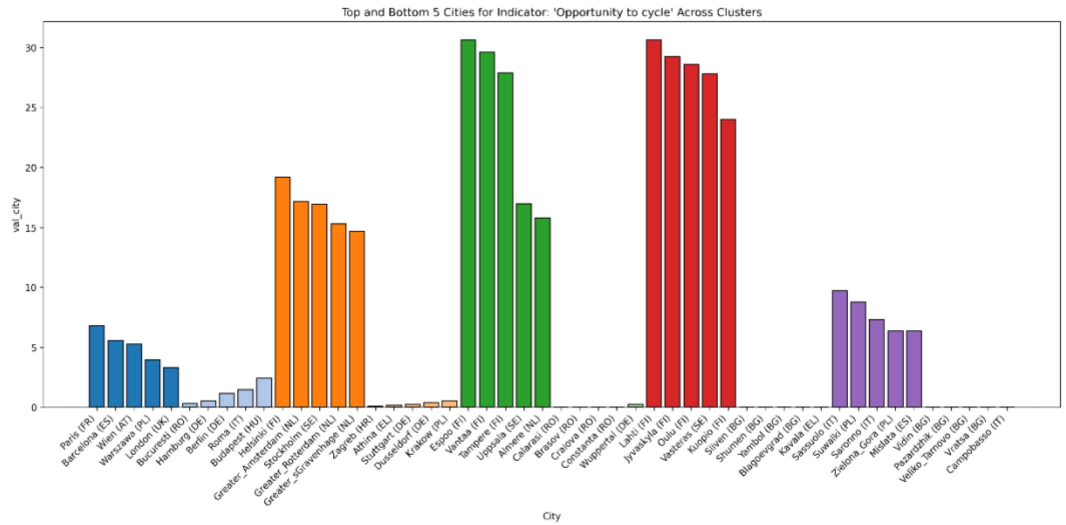


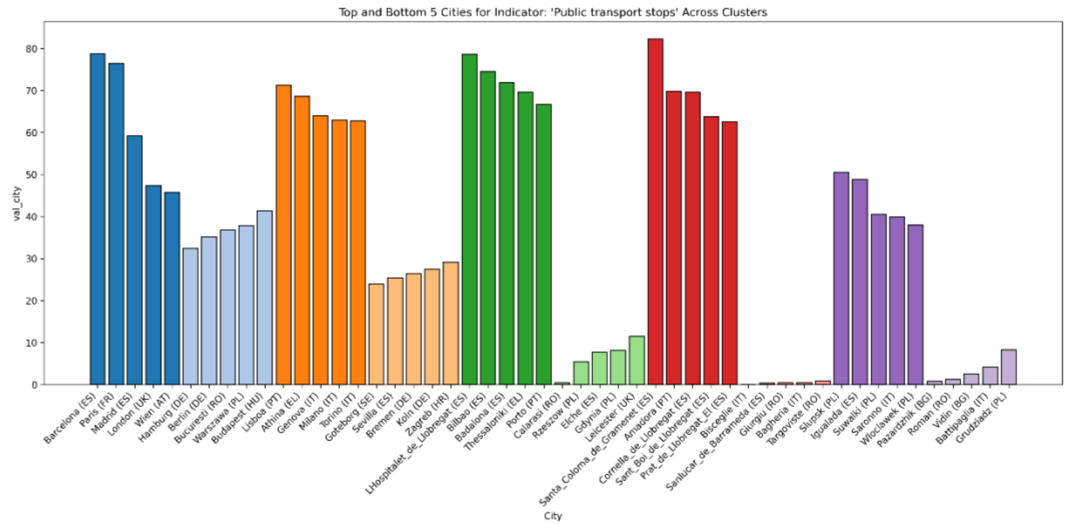




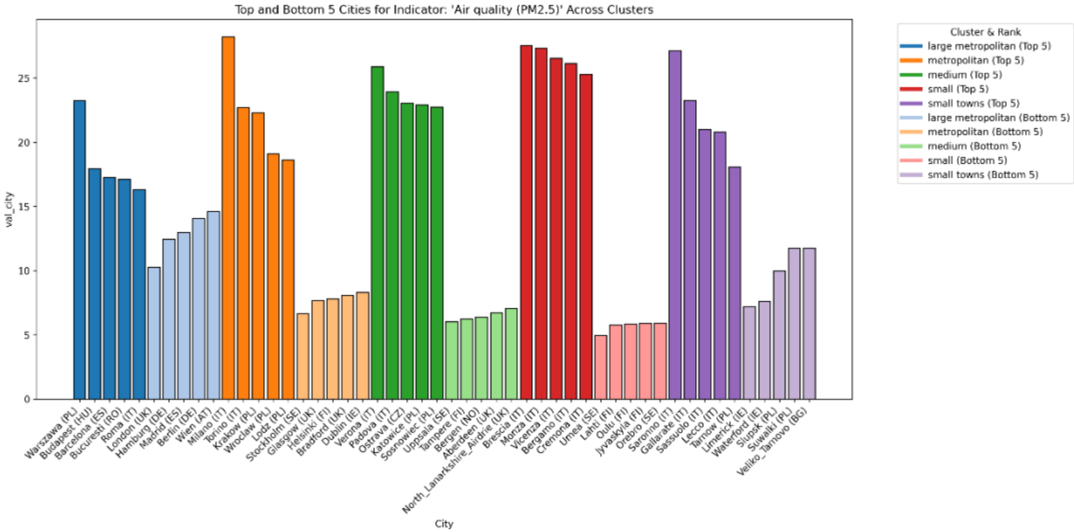
Sustainable Transportation

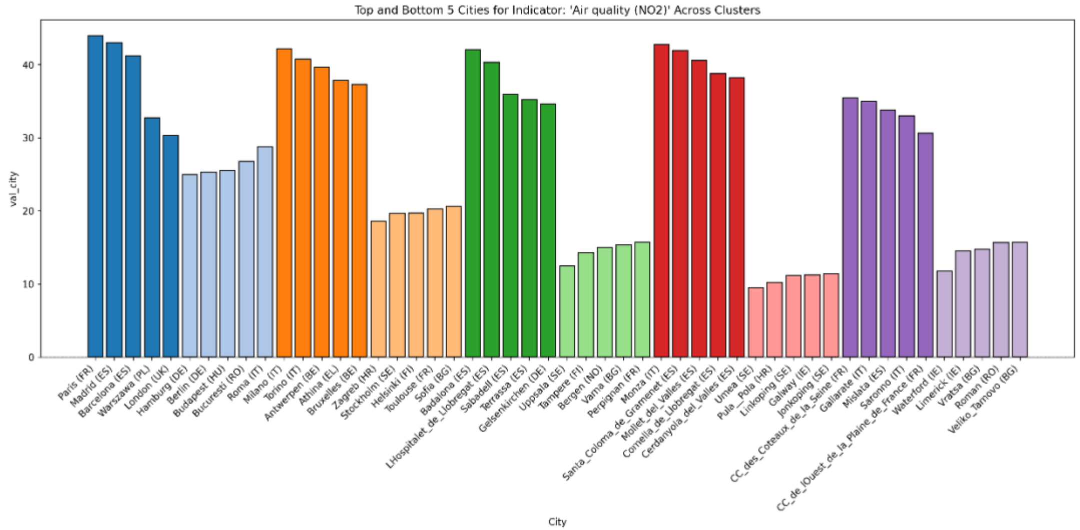


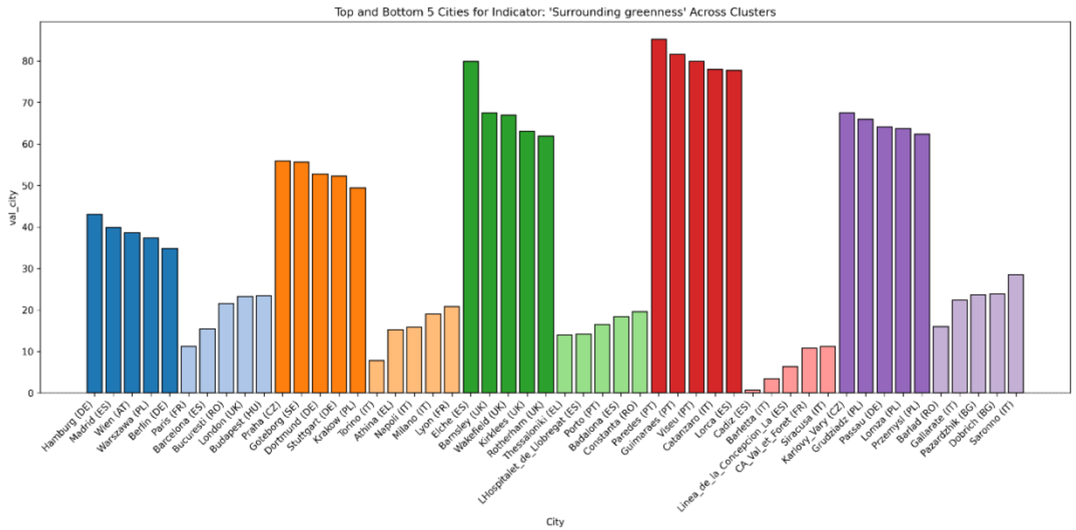


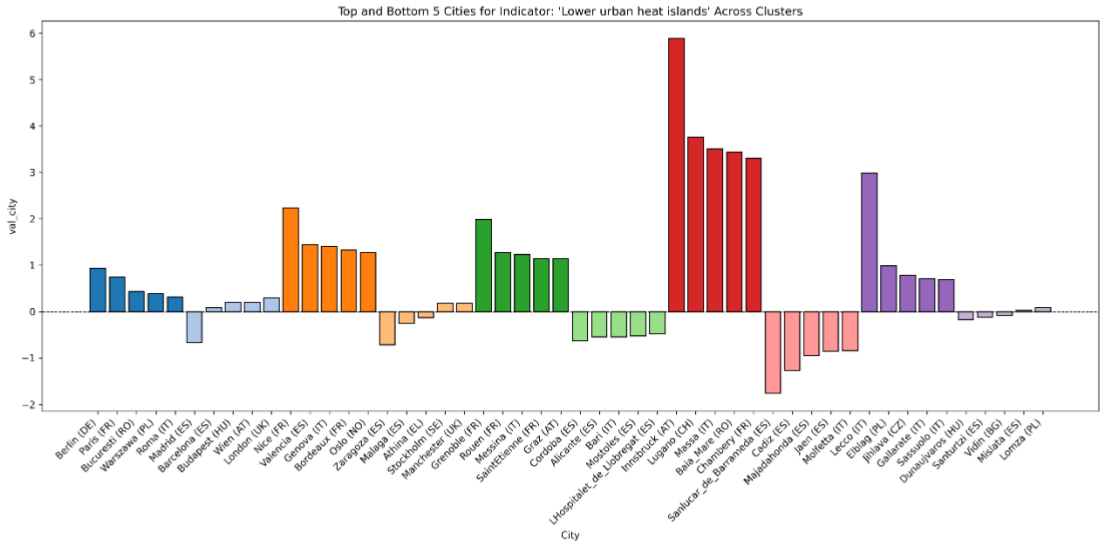


Environmental Quality

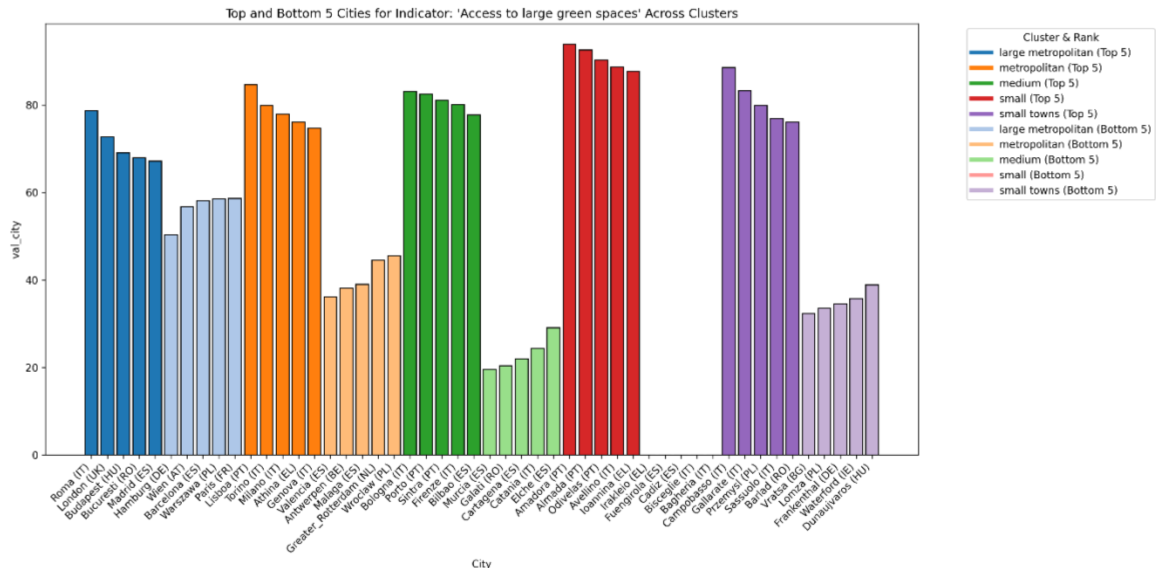








Access to Green Spaces



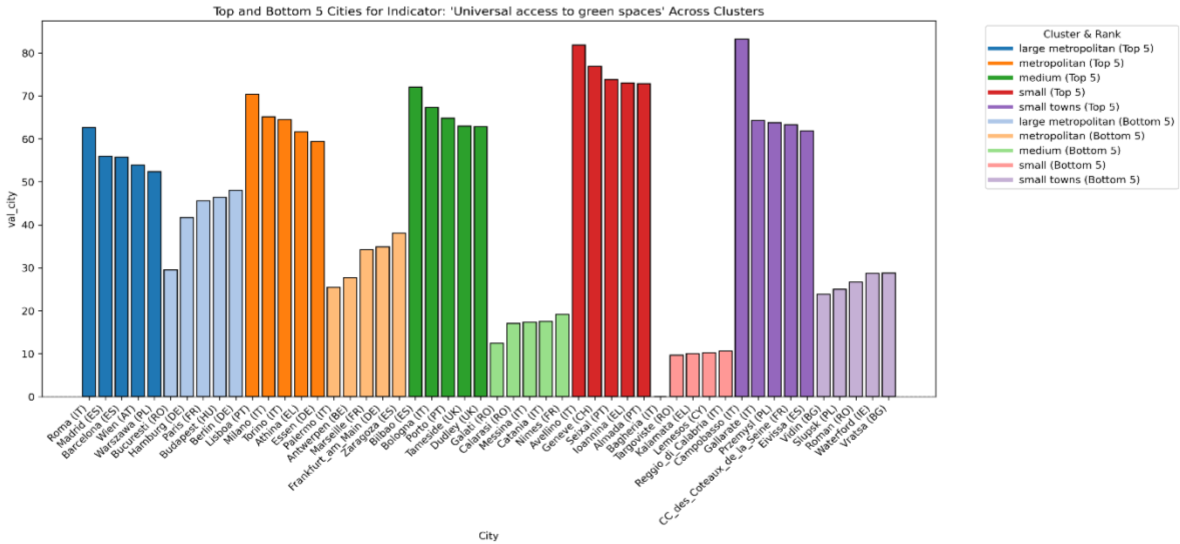


Fig S3e. Correlation Matrix of all the absolute values indicators at city level

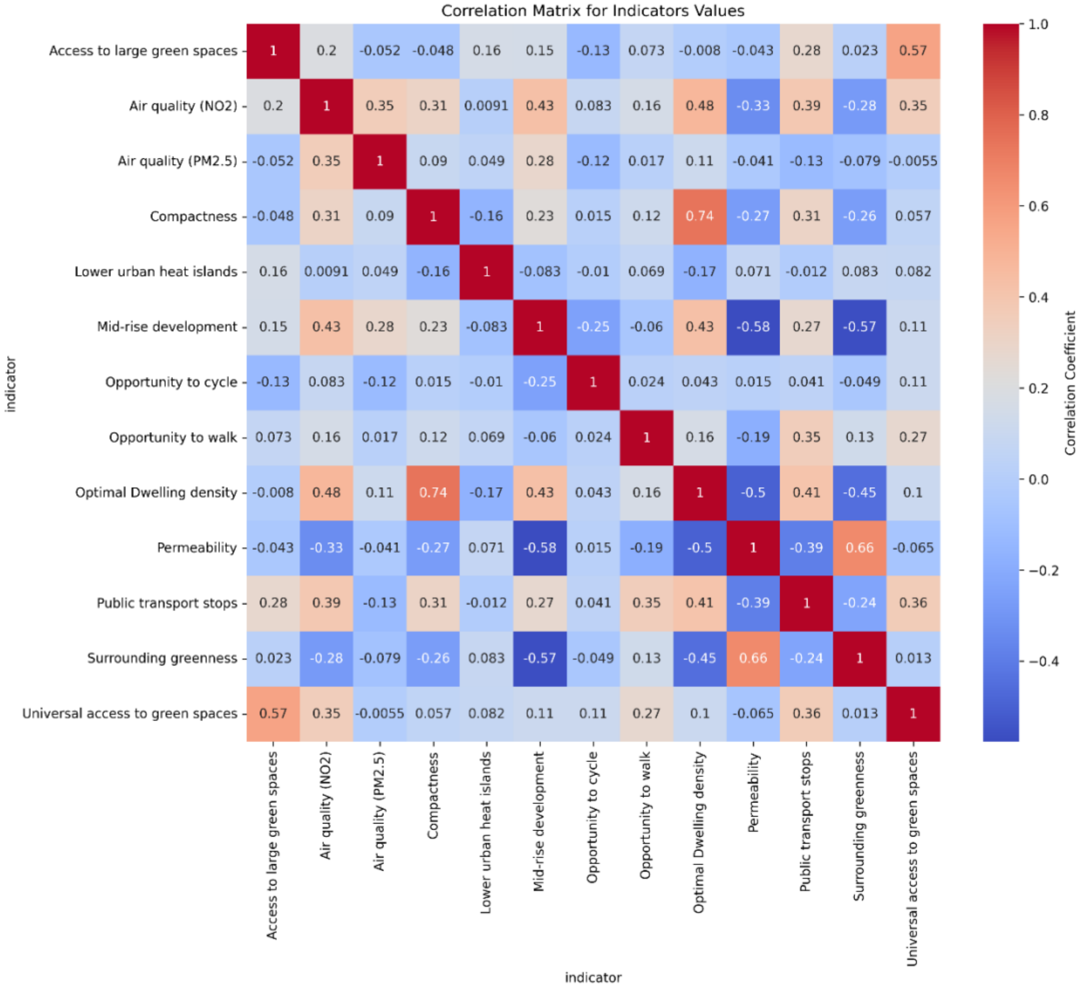


Table S3a. This table shows the statics of the indicators rescaled grouped by domain and cluster.

Domain	Cluster	Count	Mean	Std	Min	25%	50%	75%	Max
Urban Design	large metropolitan	44.0	4.32	3.56	0.00	1.67	2.65	7.77	10.00
	metropolitan	212.0	3.27	2.77	0.00	1.18	2.70	4.75	10.00
	medium	708.0	3.83	3.14	0.00	1.50	3.21	6.74	10.00
	small	2552.0	3.87	3.10	0.00	1.21	3.42	6.50	10.00
	small towns	152.0	3.34	2.93	0.00	0.00	3.20	5.42	10.00
Sustainable Transportation	large metropolitan	33.0	4.14	2.23	0.58	2.29	4.09	5.92	7.99
	metropolitan	159.0	3.81	1.95	0.31	2.06	3.69	5.33	8.04
	medium	531.0	3.52	1.81	0.00	1.98	3.52	4.81	8.04
	small	1914.0	3.12	1.79	0.00	1.64	3.00	4.39	8.31
	small towns	114.0	2.89	1.99	0.00	1.43	2.72	3.97	7.55
Environmental Quality	large metropolitan	44.0	3.65	1.97	0.00	2.76	3.84	4.63	10.00
	metropolitan	212.0	4.97	1.92	0.00	3.56	5.28	6.29	10.00
	medium	708.0	5.45	1.74	0.00	4.23	5.72	6.53	10.00
	small	2552.0	5.94	1.70	0.00	4.76	6.38	7.18	10.00

	small towns	152.0	5.87	2.32	0.00	4.43	6.35	7.73	10.00
Green Spaces Accessibility	large metropolitan	22.0	5.64	1.11	2.95	5.03	5.64	6.23	7.87
	metropolitan	106.0	5.39	1.14	2.54	4.56	5.27	6.24	8.46
	medium	354.0	5.20	1.27	1.24	4.44	5.29	6.05	8.31
	small	1276.0	5.04	1.55	0.00	4.12	5.16	6.11	9.39
	small towns	76.0	5.23	1.58	2.39	3.91	5.25	6.33	8.86

b. HUDI

Fig S3f. Descriptive boxplots of the HUDI by clusters

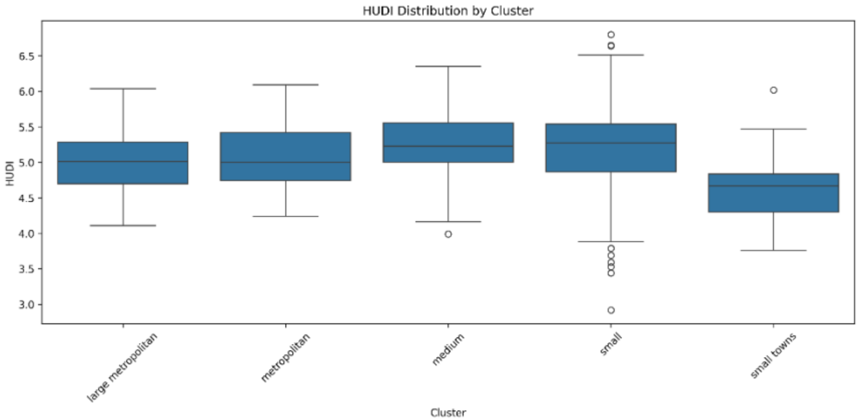
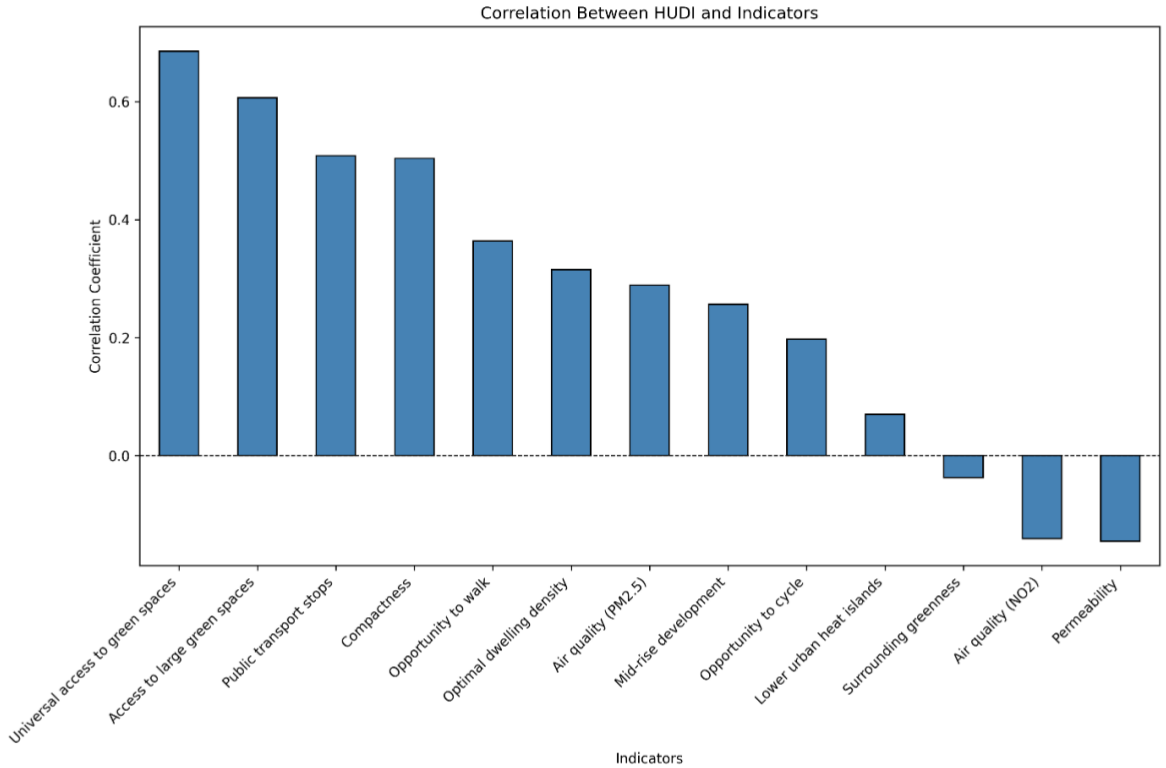


Table S3b. Description of the HUDI index.

Variable	Cluster	Count	Mean	Std	Min	25%	50%	75%	Max
HUDI	large metropolitan	11.0	5.01	0.56	4.11	4.70	5.01	5.28	6.04
	metropolitan	53.0	5.10	0.43	4.24	4.74	5.00	5.42	6.09
	medium	177.0	5.25	0.45	3.99	5.00	5.23	5.56	6.35
	small	638.0	5.21	0.53	2.92	4.86	5.28	5.54	6.80
	small towns	38.0	4.63	0.50	3.76	4.30	4.66	4.84	6.02

Fig S3g. Correlation analysis between HUDI index and its components.



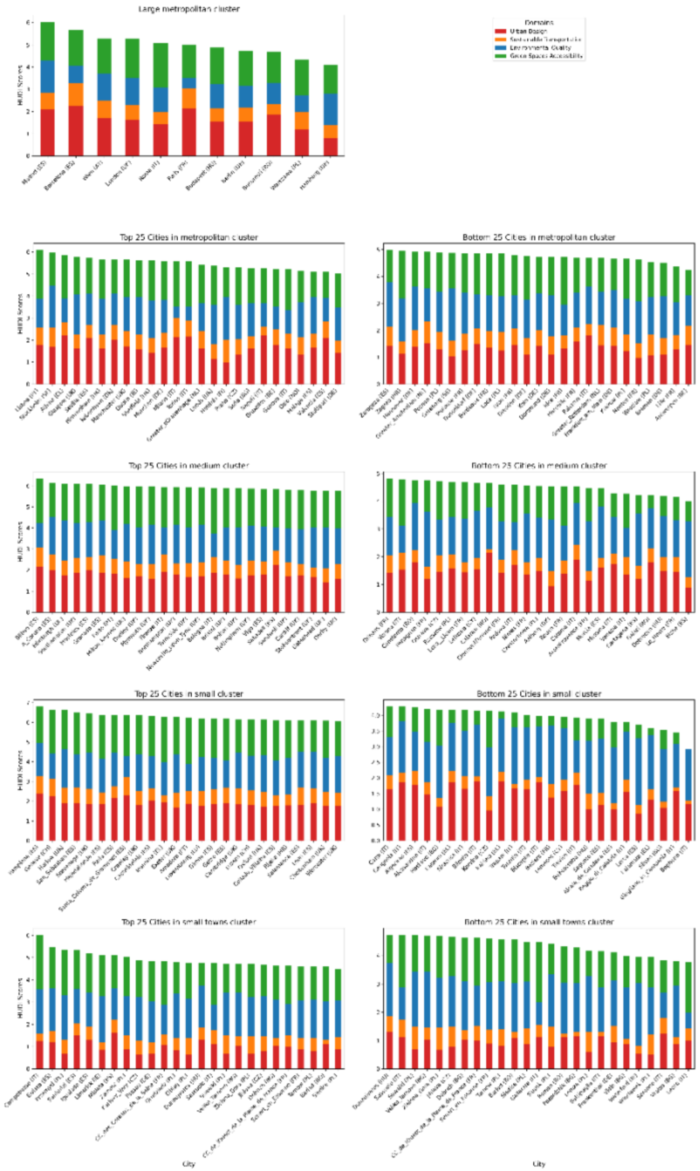


Fig S3h. Top and bottom 25 cities for each cluster, including the complete list of 11 cities in the large metropolitan cluster. Each bar represents the contribution of individual domains to the overall HUDI score. The domains—Urban Design, Environmental Quality, Sustainable Transportation, and Green Spaces Accessibility—are weighted equally (weight: 1), except for Sustainable Transportation, which is assigned a lower weight (0.5).

Fig S3i. Spatial clustering pattern of Local Moran's I correlation analysis across Europe. The map displays significant local spatial autocorrelation types where HH (High-High, red dots) indicates clusters of high values surrounded by high values, predominantly in the UK and Northern Europe; LL (Low-Low, blue dots) shows clusters of low values surrounded by low values, concentrated in Southern Europe and the Balkans; HL (High-Low, orange dots) and LH (Low-High, peach dots) represent spatial outliers where high/low values are surrounded by contrasting low/high values, scattered across Mediterranean coastal regions. Grey dots (ns) indicate non-significant spatial associations. Global Moran's I Results: Moran's I: 0.34, p-Value: 0.0010, Z-Score: 17.4

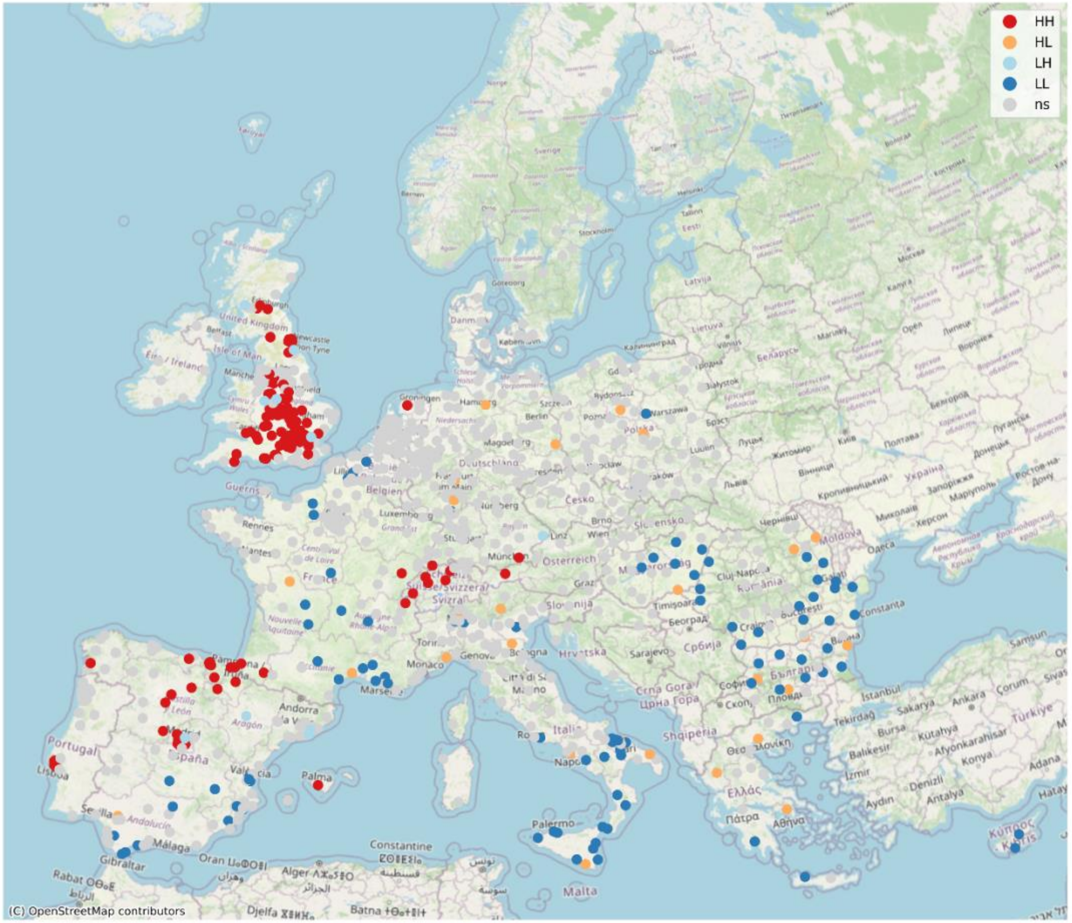
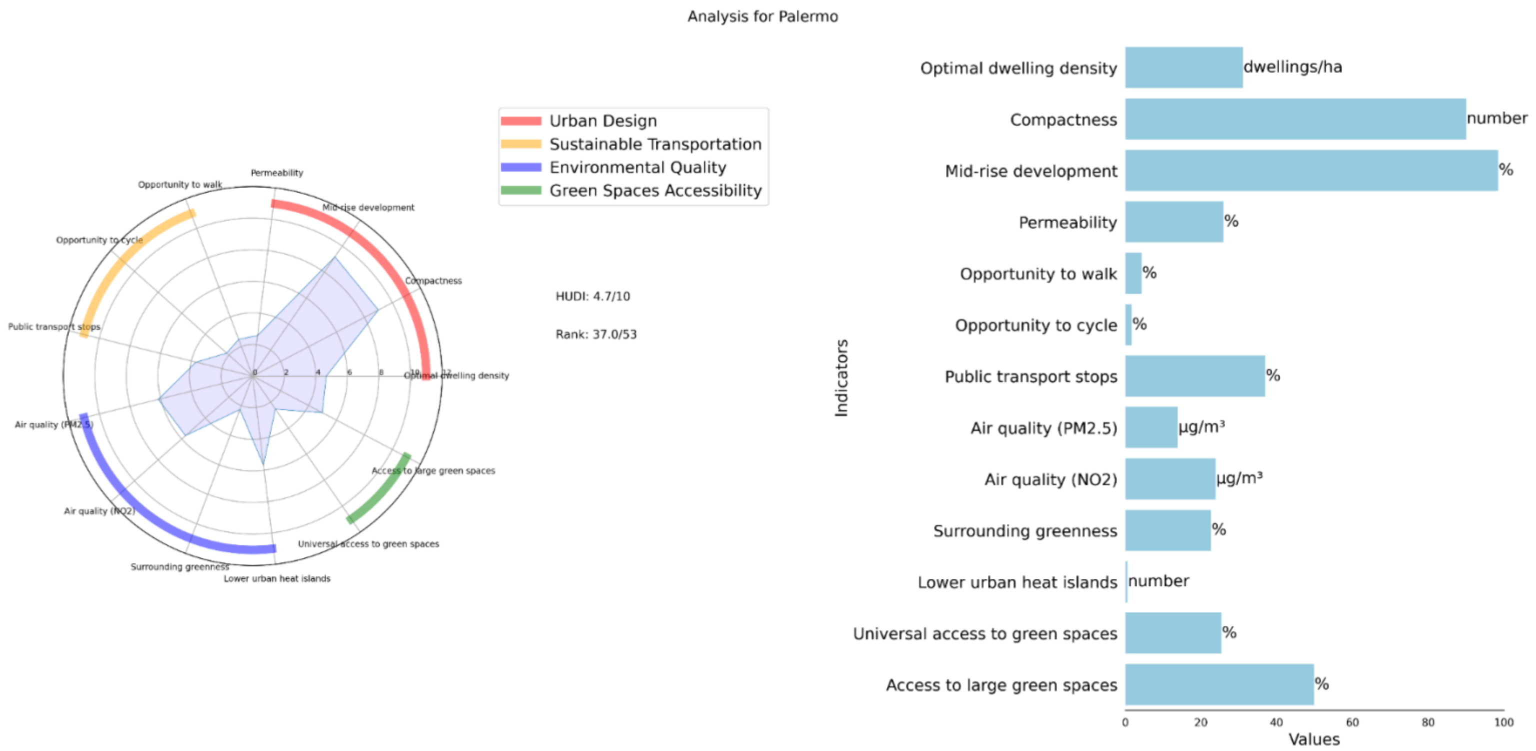
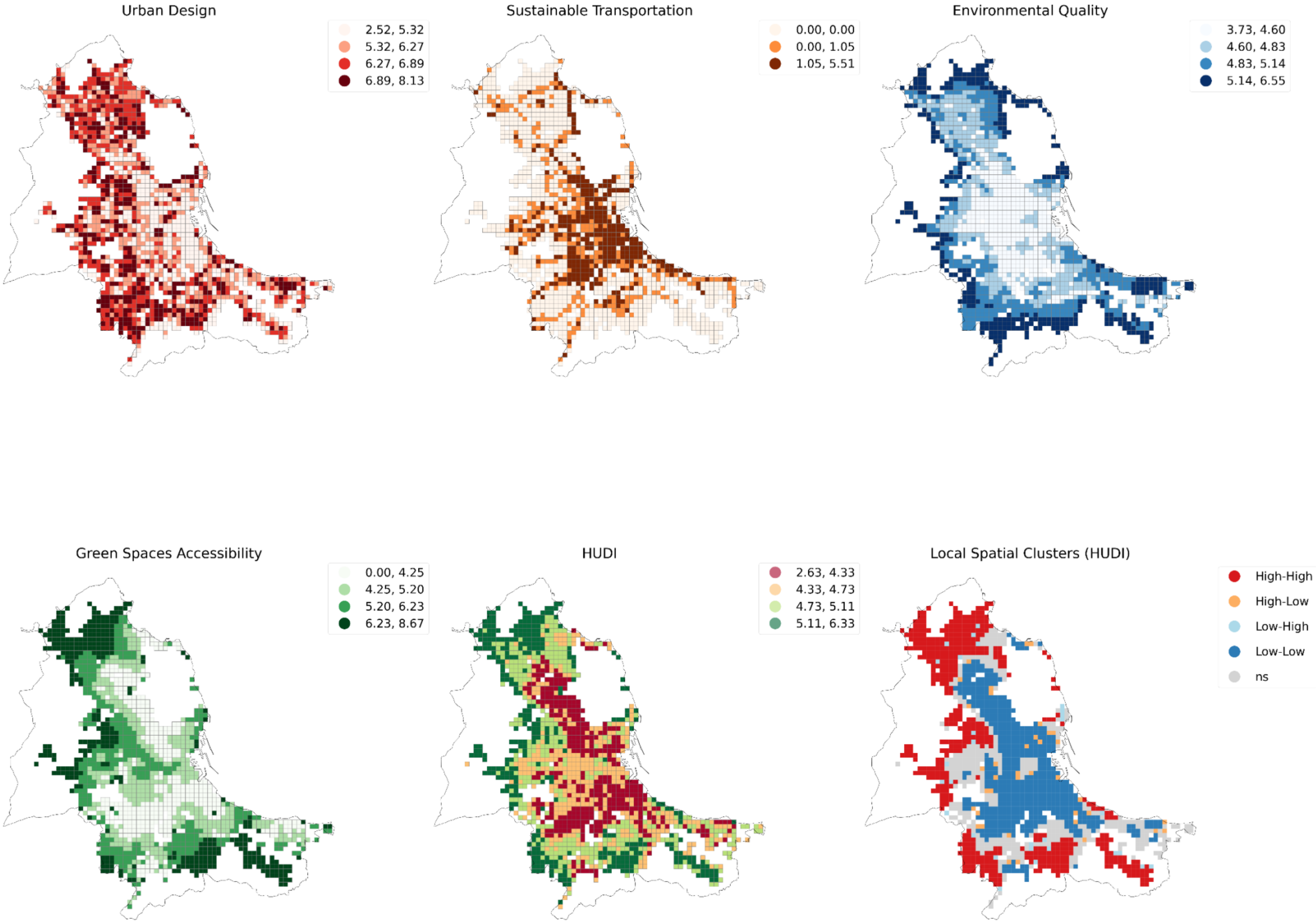


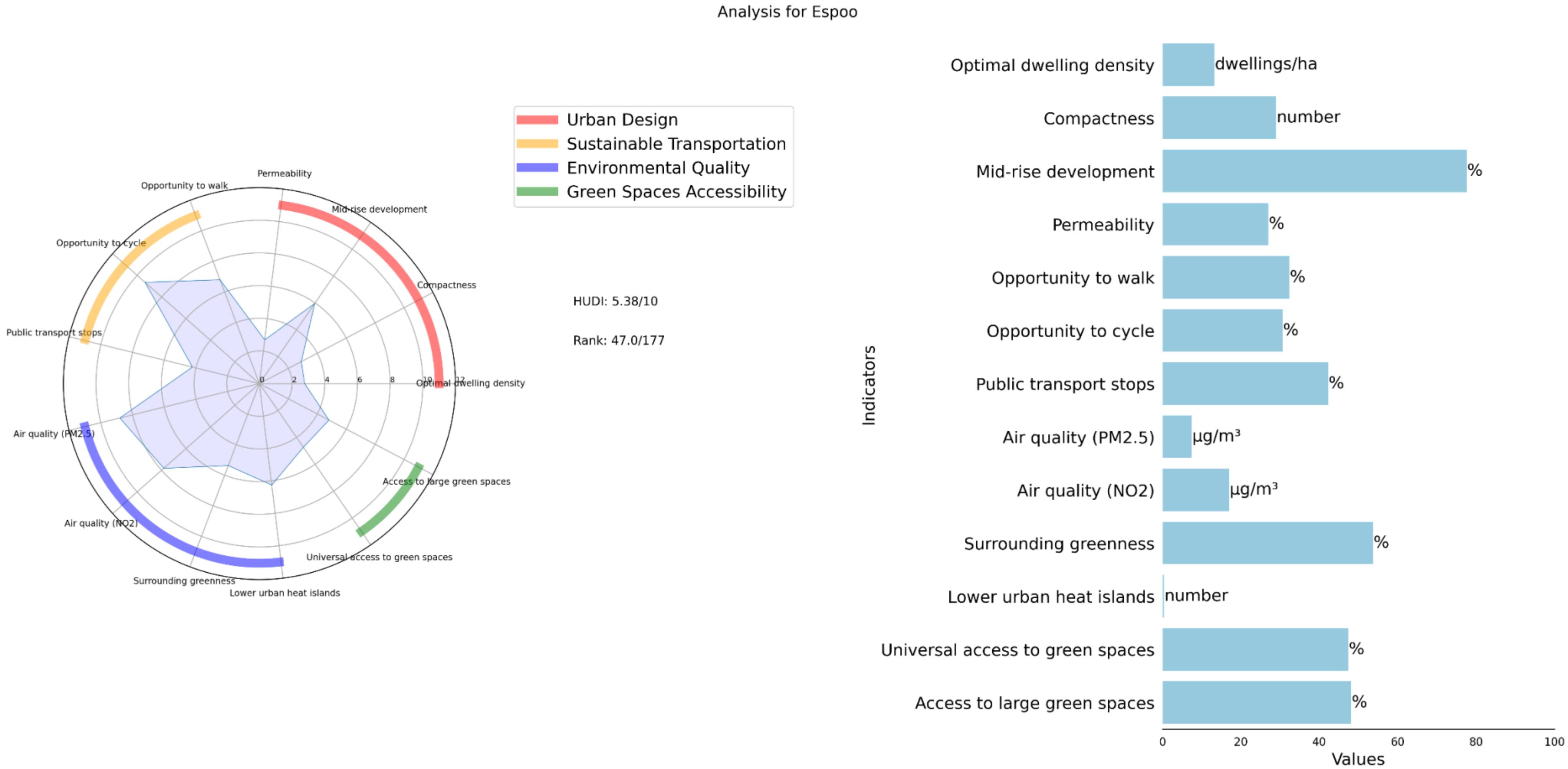
Fig S3j-S3m. Four representative cities—for metropolitan, medium, small and small towns clusters—along with the HUDI index at the city and grid level. The **spider plot** displays indicator values from 0 at the center to 10 at the outer ring, with higher extensions indicating better HUDI performance. An ideal city would have maximum scores across all indicators, resulting in a fully colored radial plot. The bar plot next to the spider plot displays the absolute values of the indicators before being rescaled to a 0–10 scale (refer to Table 1 for definitions of the absolute indicators values). At the bottom, a grid visualization highlights the spatial distribution of the HUDI domains and overall index at a 250m x 250m resolution, revealing detailed spatial patterns across the city. Additionally, a Local Moran's I plot identifies local clustering patterns, categorizing cities as High-High (HH, high HUDI values surrounded by high values), Low-Low (LL), High-Low (HL), or Low-High (LH), providing insights into spatial associations. A comprehensive overview of the performance of all cities is available at https://isglobalranking.org/hudi/

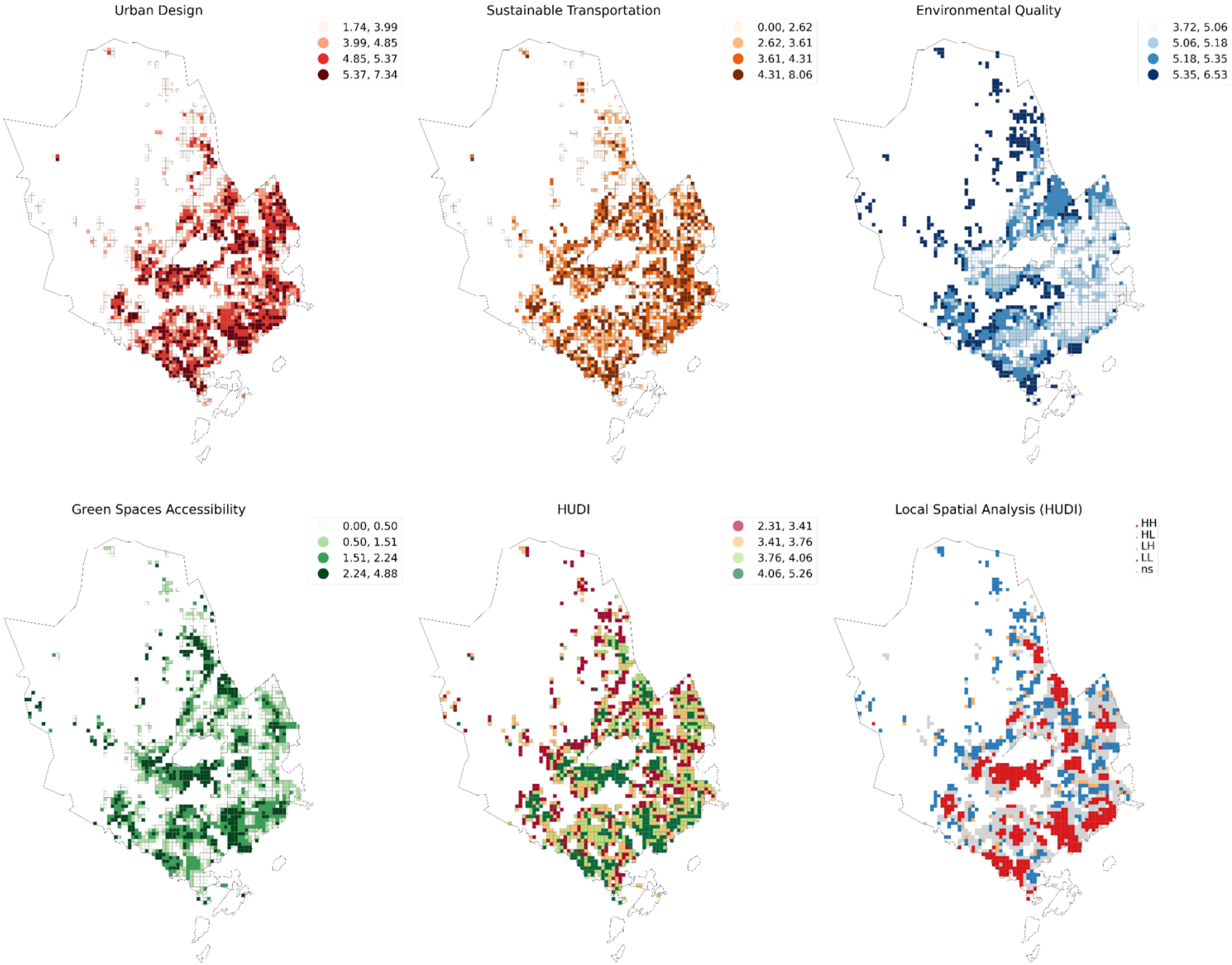
a. Metropolitan (Fig S3j)



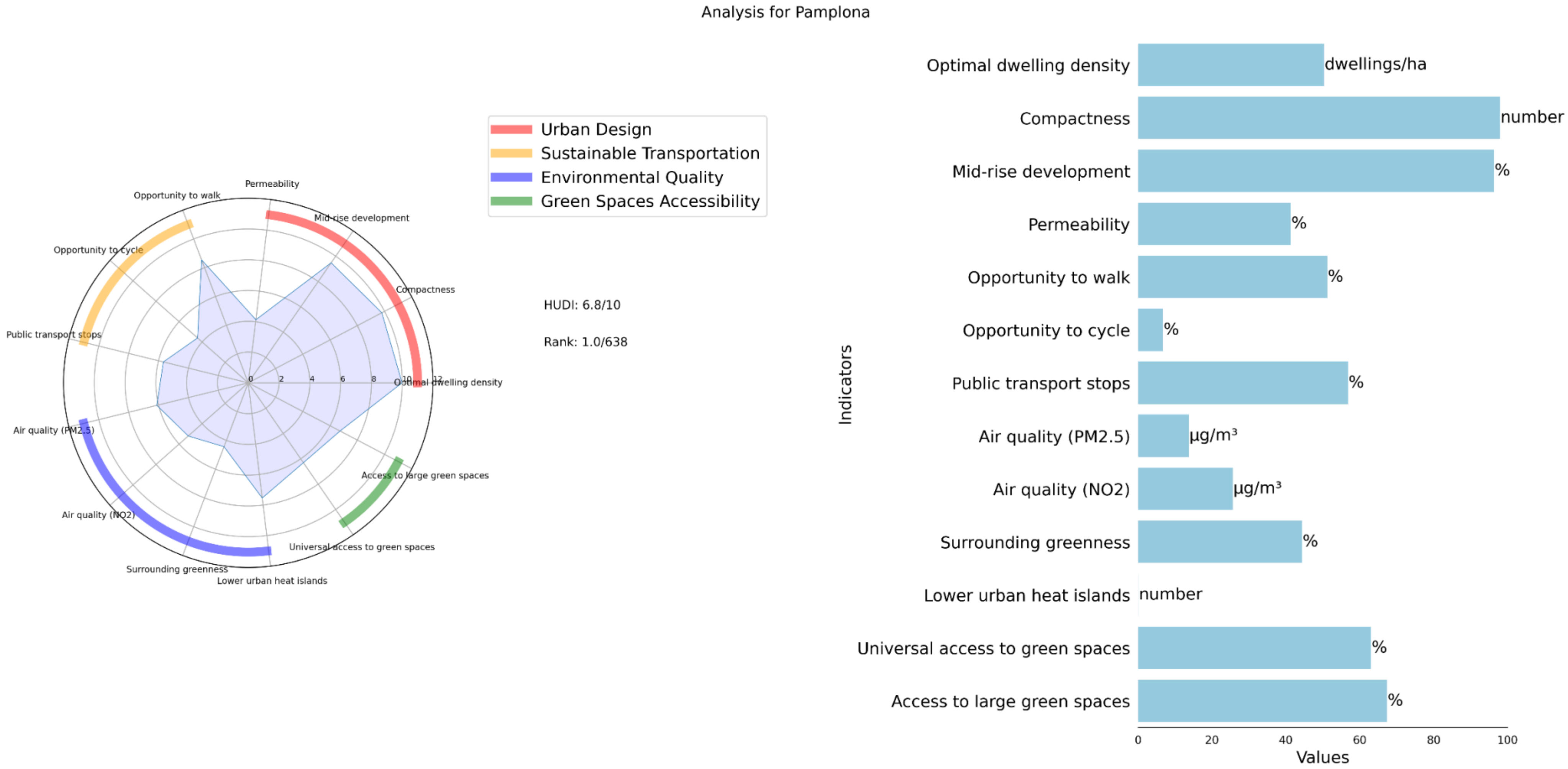

Urban Design
2.52, 5.32
5.32, 6.27
6.27, 6.89
6.89, 8.13
Sustainable Transportation
0.00, 0.00
0.00, 1.05
1.05, 5.51
Environmental Quality
3.73, 4.60
4.60, 4.83
4.83, 5.14
5.14, 6.55
Green Spaces Accessibility
0.00, 4.25
4.25, 5.20
5.20, 6.23
6.23, 8.67
HUDI
2.63, 4.33
4.33, 4.73
4.73, 5.11
5.11, 6.33
Local Spatial Clusters (HUDI)
High-High
High-Low
Low-High
Low-Low
ns

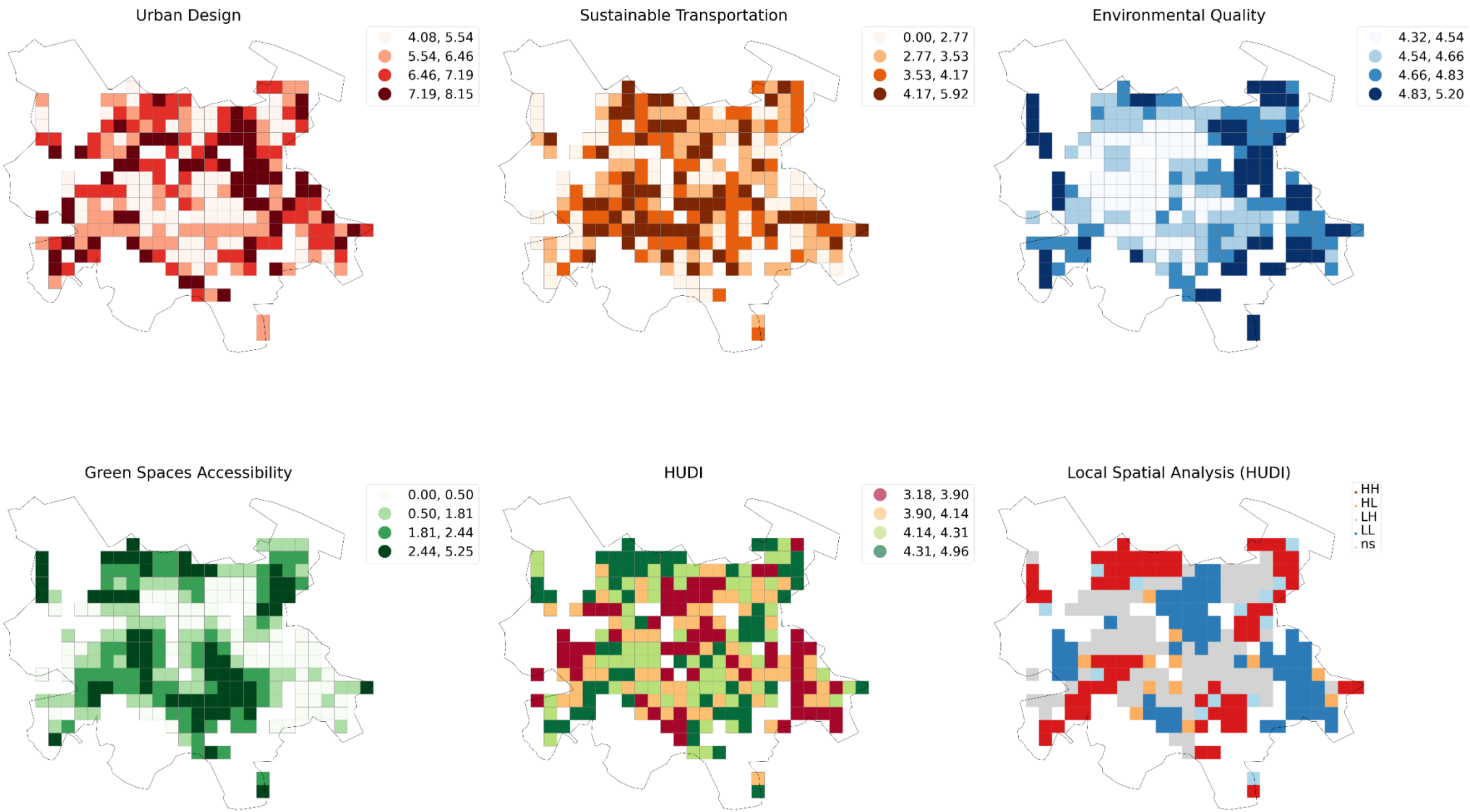
b. Medium cluster (Fig S3k)



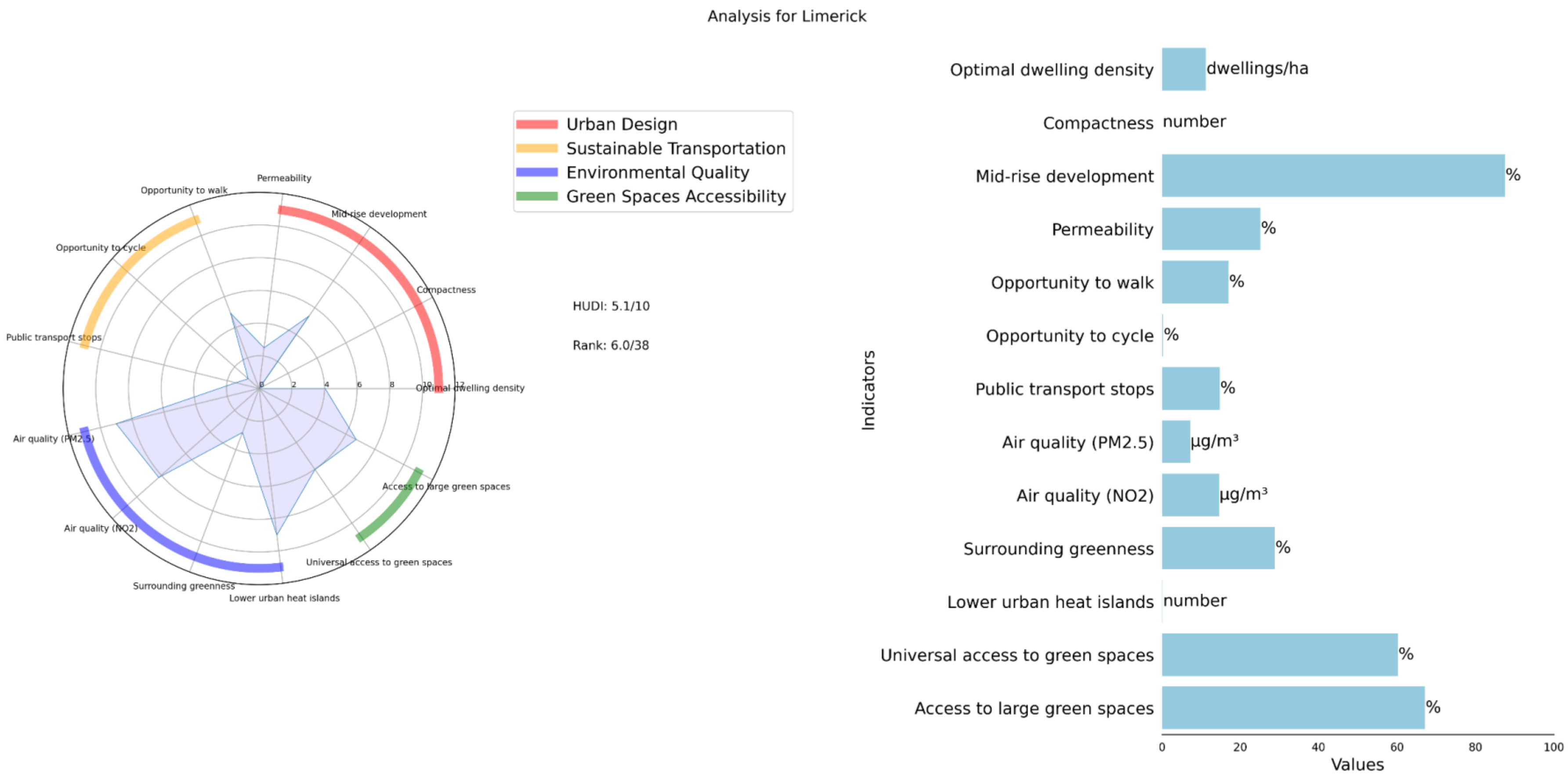

Urban Design
1.74, 3.99
3.99, 4.85
4.85, 5.37
5.37, 7.34
Sustainable Transportation
0.00, 2.62
2.62, 3.61
3.61, 4.31
4.31, 8.06
Environmental Quality
3.72, 5.06
5.06, 5.18
5.18, 5.35
5.35, 6.53
Green Spaces Accessibility
0.00, 0.50
0.50, 1.51
1.51, 2.24
2.24, 4.88
HUDI
2.31, 3.41
3.41, 3.76
3.76, 4.06
4.06, 5.26
Local Spatial Analysis (HUDI)
HH
HL
LH
LL
ns

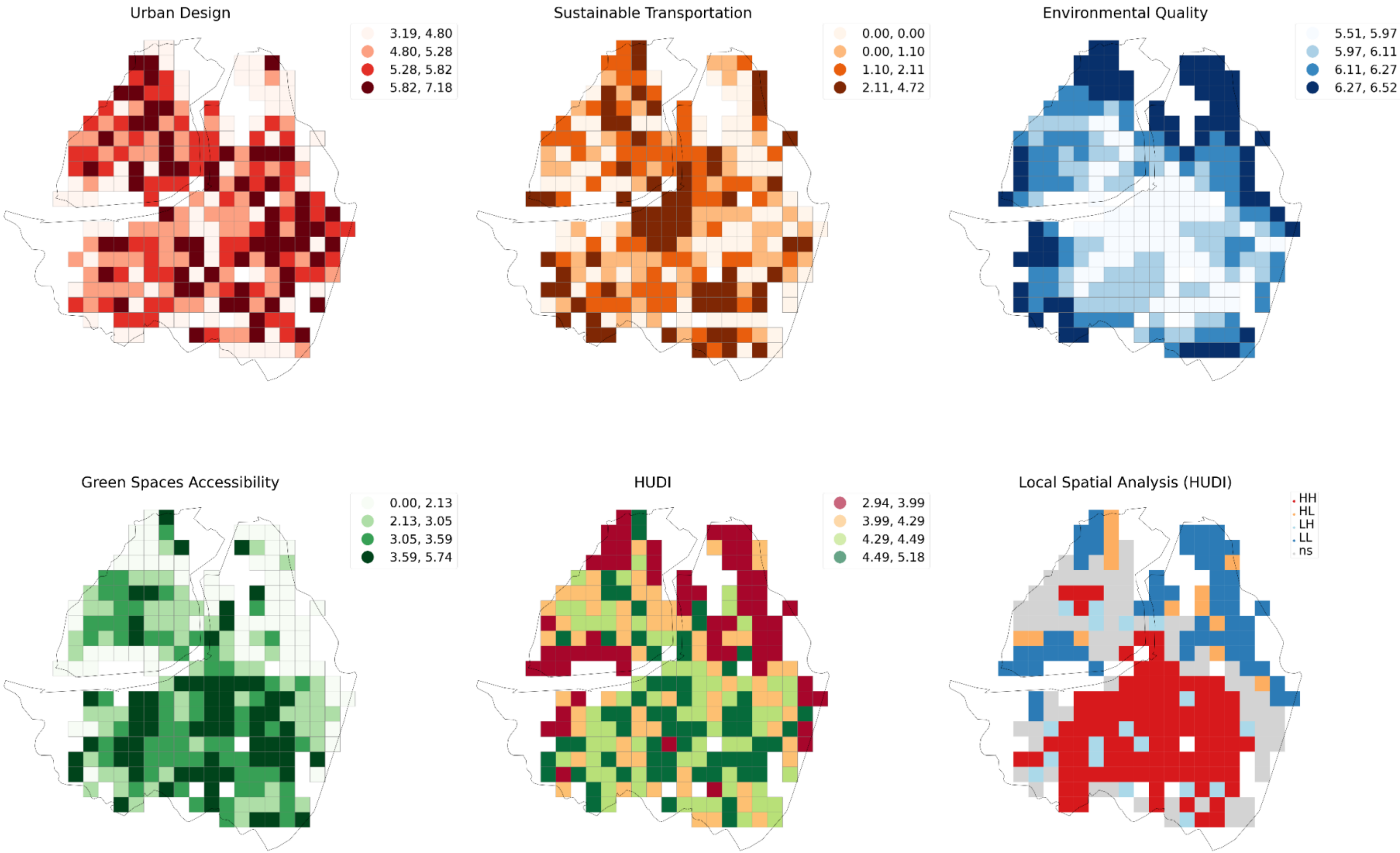
c. **Small (Fig S3l)**




Urban Design
4.08, 5.54
5.54, 6.46
6.46, 7.19
7.19, 8.15
Sustainable Transportation
0.00, 2.77
2.77, 3.53
3.53, 4.17
4.17, 5.92
Environmental Quality
4.32, 4.54
4.54, 4.66
4.66, 4.83
4.83, 5.20
Green Spaces Accessibility
0.00, 0.50
0.50, 1.81
1.81, 2.44
2.44, 5.25
HUDI
3.18, 3.90
3.90, 4.14
4.14, 4.31
4.31, 4.96
Local Spatial Analysis (HUDI)
HH
HL
LH
LL
ns

d. Small towns (Fig S3m)




Urban Design
3.19, 4.80
4.80, 5.28
5.28, 5.82
5.82, 7.18
Sustainable Transportation
0.00, 0.00
0.00, 1.10
1.10, 2.11
2.11, 4.72
Environmental Quality
5.51, 5.97
5.97, 6.11
6.11, 6.27
6.27, 6.52
Green Spaces Accessibility
0.00, 2.13
2.13, 3.05
3.05, 3.59
3.59, 5.74
HUDI
2.94, 3.99
3.99, 4.29
4.29, 4.49
4.49, 5.18
Local Spatial Analysis (HUDI)
HH
HL
LH
LL
ns

In the metropolitan city cluster (Fig S3j), Palermo (Italy) performs well in Urban Design (6.4/10), especially in Mid-rise development and Compactness, but scores low in Permeability (26%). Sustainable Transportation indicators score low (2.8/10), while Environmental Quality and Green Space Accessibility score moderately (4/10). With a HUDI score of 4.7/10, Palermo ranks 37th out of 53 cities. Granular grid level analysis shows higher HUDI scores in peripheral areas, except for Sustainable Transportation, which scores higher in centric areas. The HUDI and LISA plots highlight HH clusters in peripheral areas and LL clusters in central neighborhoods.

In the medium-sized city cluster (Fig. S3k), Espoo (Finland) excels in Environmental Quality and Sustainable Transportation (average score: 7/10), with PM2.5 averaging 7.5 $\mu g/m^3$ and high scores for Opportunities to walk and cycle (30%). However, Urban Design scores lag (3.6/10), particularly in Compactness (29/100). With a combined HUDI score of 5.38/10, Espoo ranks 47th out of 177 cities in its cluster. Granular grid cell analysis shows that Environmental Quality scores high in most areas, though central areas show moderate scores. Urban Design scores higher in the southern areas, where Environmental Quality scores lower. The LISA plot highlights well-performing clusters (HH), where Green Accessibility and Urban Design also score high.

In the small city cluster (Fig. S3l), Pamplona (Spain) performs well across all four domains, with a HUDI score of 6.8/10, ranking 1st out of 638 cities. Pamplona excels in Urban Design (8.4/10) and scores around 6/10 in other domains. The Urban Design indicators score well, except Permeability (41%). Opportunity to walk (51%) scores high and LUHI scores low (0.12/10). However, Opportunity to cycle sores low (6%). Granular grid level analysis for Pamplona show that Environmental Quality and Urban Design indicators show similar distribution in HUDI score patterns, with Green Space Accessibility performing best in Central-Western areas (60%). The grid-cell HUDI map highlights high-performing clusters in the central and western areas of Pamplona, while the LISA plot identifies HH clusters in the southern and northern areas, and the eastern areas struggling with Green Accessibility.

In the small towns cluster (Fig. S3m), Limerick (Ireland) scores 5.1/10 for the combined HUDI, ranking 6th out of 38 cities in its cluster. Limerick excels in Green Space Accessibility (6/10) and Environmental Quality (7/10), with low PM2.5 (7.1 $\mu g/m^3$) and NO2 (14.6 $\mu g/m^3$) levels and a low LUHI score (0.13/10). However, Limerick struggles with Sustainable Transportation (2.4/10) and Urban Design (3/10). Granular grid level analysis show that Environmental Quality is highest in the Northern and Eastern areas, while Green Space Accessibility peaks in central neighborhoods. The LISA plot shows HH clusters in the Southern and Eastern areas, with LL clusters in peripheral neighborhoods.

Supplement 4) Sensitivity Analysis and Correlation Analysis with External Datasets

a. Permeability indicator

We used green spaces data retrieved from European Urban Urban Atlas 2012 (18) (0·25 hectare resolution) and the Corine Land Cover (CLC) 2012 inventory (25 hectare resolution) (19) (25 hectare resolution) to verify whether its distribution aligned with that of the permeability data. The analysis reveals a strong positive correlation between permeability and green space percentage. The correlation is robust across different statistical measures (Spearman $\rho = 0.79$) and is clearly visible in Fig S4b. As permeability increases, there is a consistent and significant increase in green space percentage, with the relationship maintaining linearity across the full range of values. Fig S4a shows that when the Permeability Percentile increases (left to right), the Green Space Percentage also increases. This means that higher permeability areas tend to have more green space.

Table S4a. Descriptive of green spaces data for all cities by cluster at grid cell level.

Variable	**Cluster**	**Mean**	**Std**	**25%**	**75%**	**Max**	**Min**
Green spaces (%)	Large metropolitan	25.10	21.94	7.16	38.40	96.32	0.0
	Medium	37.16	25.27	14.93	57.40	100.00	0.0
	Metropolitan	31.12	23.54	11.10	48.05	98.20	0.0
	Small	42.15	26.42	18.60	64.53	100.00	0.0
	Small towns	37.09	24.37	16.00	56.50	96.50	0.0

Fig S4a. Relationship between permeability categories and green space distribution. The plot shows a clear positive relationship, indicating that higher land permeability is consistently associated with a greater percentage of green space within a 300m radius.

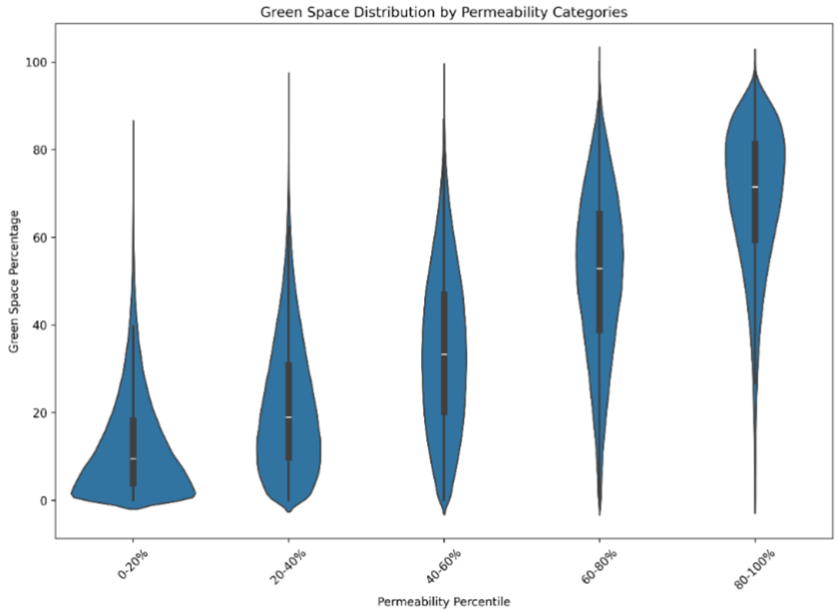
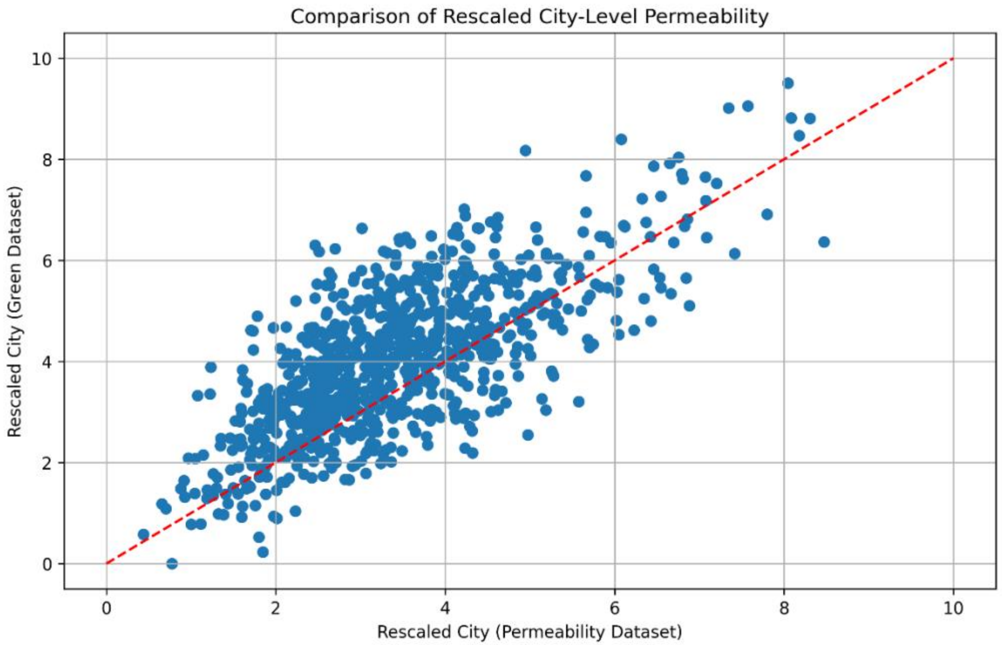
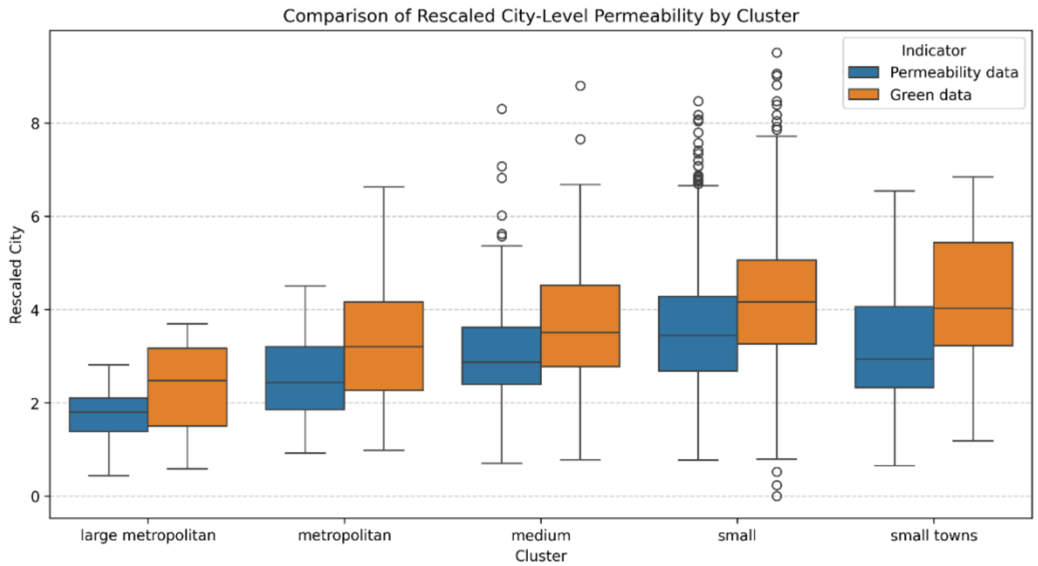


Fig S4b. Comparison of the Permeability Indicator rescaled to the [0-10] scale, at city level (scatter plot), and grids level (box plots), using two datasets, the permeability data, from the imperviousness dataset (20), and the green spaces data (18,19). The scatter plot compares city-level permeability values from the Permeability dataset (x-axis) and the Green dataset (y-axis), with the dashed red line indicating perfect agreement. The box plot displays the distribution of rescaled grid Permeability indicator across urban clusters (large metropolitan, metropolitan, medium, small, and small towns), highlighting differences between the two datasets (Permeability data in blue, Green data in orange).

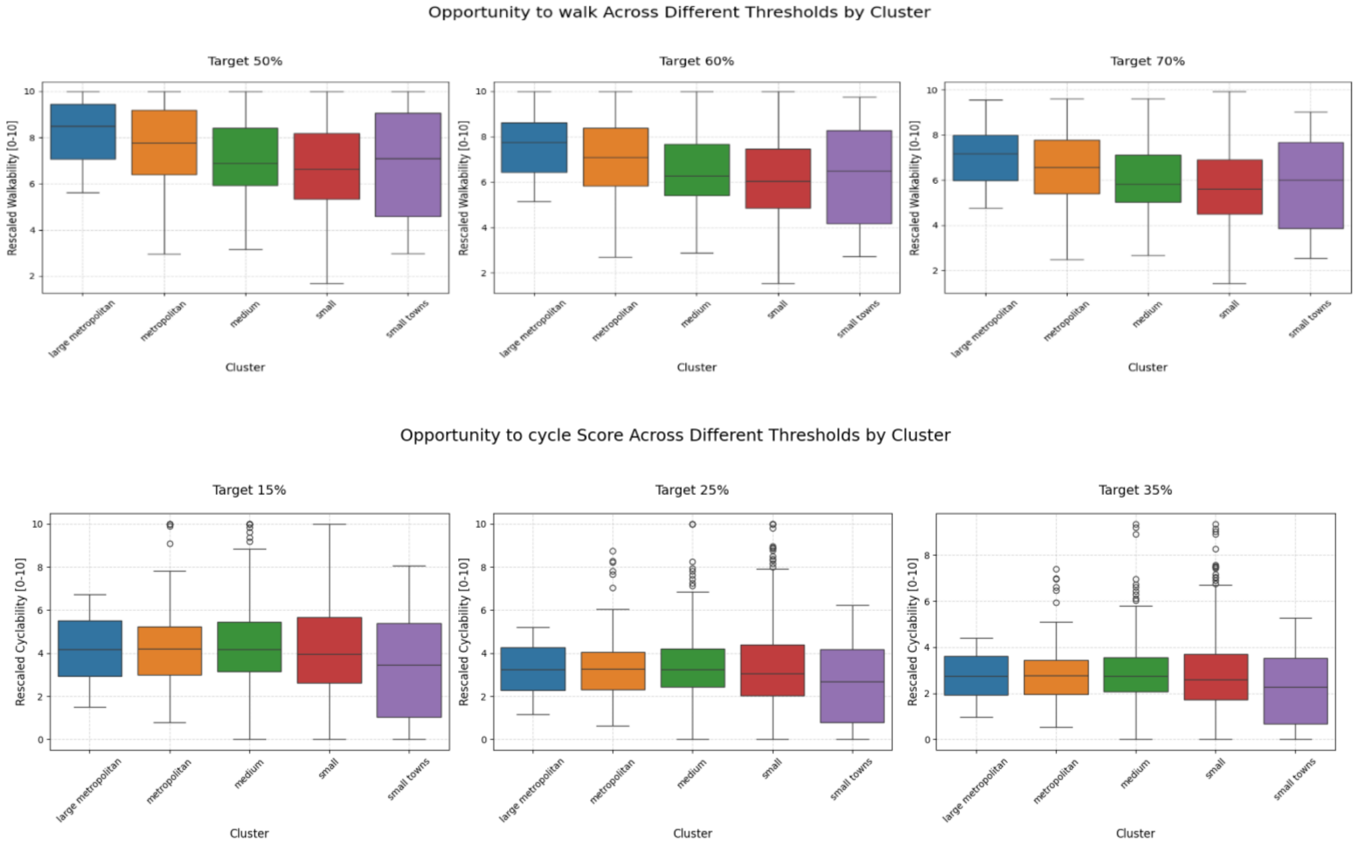




b. Opportunity to walk and Opportunity to cycle

We conducted a sensitivity analysis to examine how the scores varied across the clusters when adjusting the target thresholds. The selection of target thresholds for walkability and cyclability indicators was based on both statistical analysis and policy benchmarks. Walkability thresholds (50%, 60%, 70%) and cyclability thresholds (15%, 25%, 35%) were chosen based on two key reference points: the current 95th percentile distribution (50% for walking, 15% for cycling) and established policy targets from literature (11) (70% for walking, 35% for cycling), with an intermediate value included to assess the sensitivity of our scoring system. The analysis reveals distinct sensitivity patterns across thresholds. While walkability scores show consistent distributions from 50% to 70%, cyclability scores demonstrate higher sensitivity in the progression from 15% to 35%, especially in smaller urban areas. Large metropolitan areas maintain stable scores across both indicators, contrasting with the wider variability seen in smaller urban clusters. This pattern suggests that current cycling infrastructure has a more pronounced gap between existing conditions and policy targets compared to pedestrian infrastructure. The varying thresholds effectively differentiate between cities with advanced infrastructure while capturing the nuanced reality of infrastructure provision across different urban scales

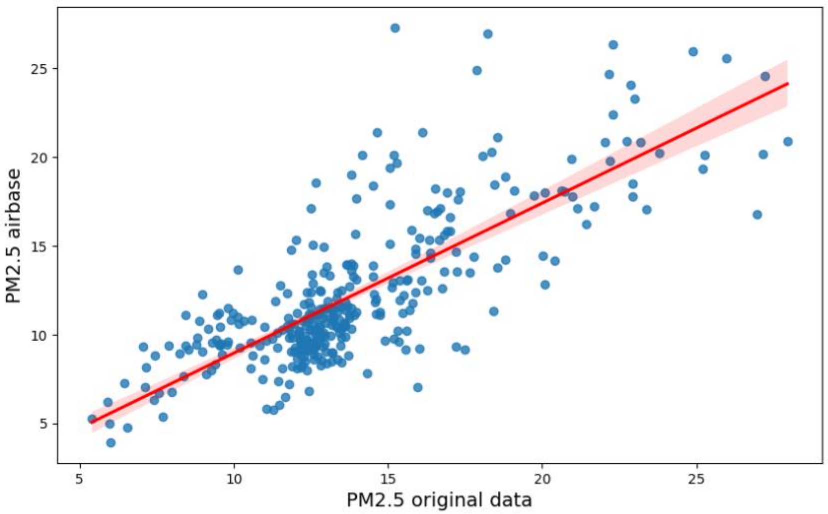
Fig S4c. Distribution of Opportunity to walk and cycle indicators scores across urban clusters under different maximum thresholds (50%, 60% and 70% for walking 15%, 25%, and 35% for cycling).

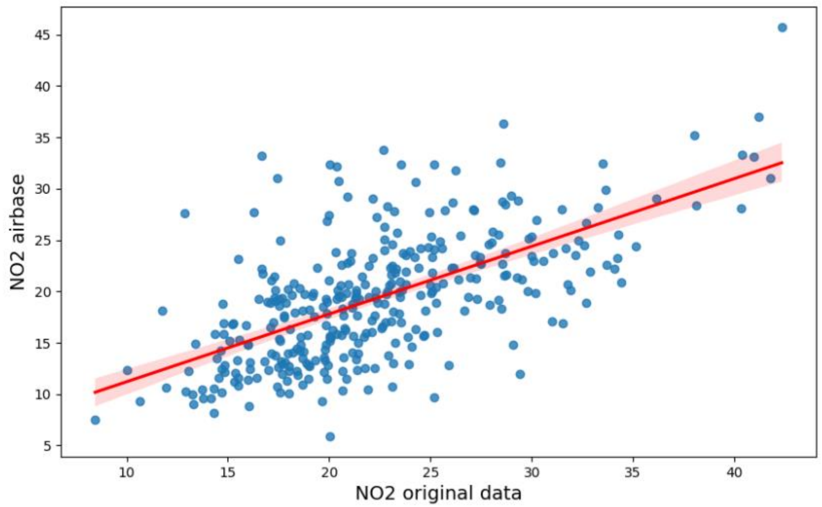


c. Air Quality – Correlation analysis with external dataset

We utilized an external dataset for PM2.5 and NO2 (Airbase dataset) (21)and observed a strong correlation with our dataset, further confirming the robustness and reliability of our data when validated against an independent source. Our data at the grid cell level were average at the city level to enable comparison with the Airbase dataset, which was available for 516 cities

Fig S4d. Scatter plot showing the ELAPSE dataset (x-axis) versus the Airbase dataset (y-axis). The red line indicates the fitted regression line, and the shaded areas represent the associated confidence intervals.

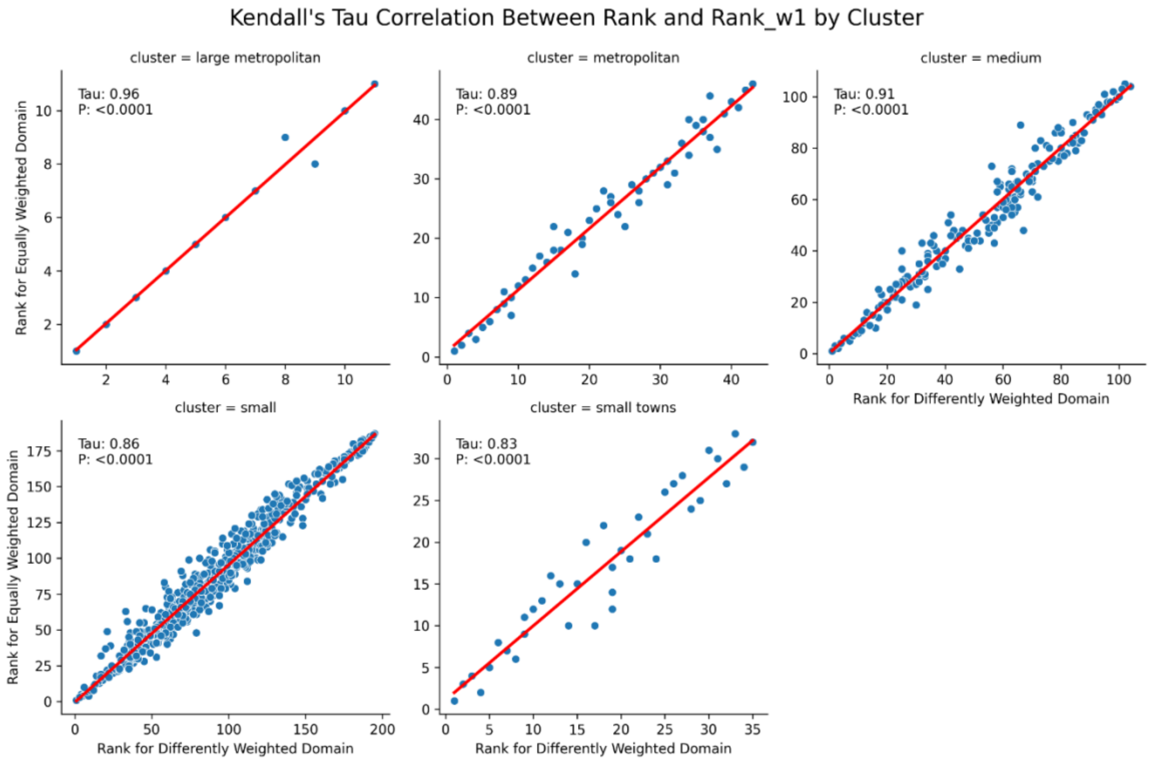




Correlation Analysis (PM2.5): Spearman correlation: 0.73, Spearman p-value: <0.0001. Correlation Analysis (NO2): Spearman correlation: 0.36, Spearman p-value: <0.0001

d. HUDI

Fig S4e. Detailed Kendall Rank Correlation



Supplement 5) Indicators-domains and Health links

Table S5a. HUDI indicators pathways to health (For the full bibliography please refer to Mueller et al. (4))

Domain	HUDI Indicator	Suggested thresholds	Health mecanism	Direct and indirect health pathways	Scientific references for HUDI indicator-health links	Health outcome
URBAN DESIGN	Optimal Dwelling Density	dwellings/ha [45-175] dwellings/ha is the optimal range	Density defines human activity within given land base. Higher dwelling or population density is encouraged.	↑ Mobility (↑ Active transport) ↑ Physical activity ↑ Access to services ↓ Environmental pollution and CO_2 emissions (per capita)	(Cerin et al., 2018; Christiansen et al., 2016; Frank et al., 2008; Giles-Corti et al., 2016; Glazier et al., 2014; Hooper et al., 2015; Iungman et al., 2024; Udell et al., 2014)	**↑ Physical and mental health**
	Compactness	points (out of 100) based on the concentration of buildings and urban development. Higher scores indicate more compact cities	Defines human activity within given land base. A good mix of diverse, local destinations, services and amenities is encouraged.	↑ Mobility (↑ Active transport) ↑ Physical activity ↑ Social cohesion ↑ Access to services ↑ Livability/ life satisfaction/ quality of life ↓ Environmental pollution and CO_2 emissions (per capita)	(Bahadure and Kotharkar, 2018; Cerin et al., 2018; Gascon et al., 2019; Glazier et al., 2014; Gunn et al., 2017; Hooper et al., 2018, 2015; Iungman et al., 2024; Knuiman et al., 2014; Koohsari et al., 2016; Liao et al., 2017; McCormack and Shiell, 2011)	
	Mid-rise development	% of buildings with 5-6 stories	Mid-rise, 5-6 storey walk-up buildings are desirable, allowing sky visibility and human scale for mental health and well-being. Horizontal and vertical sprawl (i.e., high-rise buildings) should be avoided	↑ Mobility (↑ Active transport) ↓ Car dependence ↑ Physical activity ↑ Social cohesion ↑ Access to services	(Crowhurst Lennard, 2018; Giles-Corti et al., 2016; Udell et al., 2014)	
	Permeability	% of people with access to the target level of permeable surfaces	At least 25% permeable surfaces	↑ Ecosystem services (↓ Air pollution, ↓ Noise, ↓ Heat, ↑ Green) ↑ Physical activity ↑ Mobility (active transport) ↓ Car dependence	(Barcelona Urban Ecology Agency, 2018; Khomenko et al., 2020; Mueller et al., 2017; Mueller et al., 2018)	

Domain	HUDI Indicator	Explanation	Description	Direct and indirect health pathways	Scientific references for HUDI indicator-health links	Health outcome
SUSTAINABLE TRANSPORTATION	Public transport	% of walking infrastructure (versus total road length)	Accessibility of public transport requires individuals to walk or cycle to and from stops or stations, encouraging daily moderate physical activity.	↑ Mobility (↑ Sustainable transport) ↑ Physical activity ↑ Social cohesion/ social capital ↑ Access to services ↓ Environmental pollution	(Cerin et al., 2018, 2007; Florindo et al., 2018; Hooper et al., 2015; Knuiman et al., 2014)	**↑ Physical and mental health**
	Opportunity to walk	% of cycling infrastructure (versus total road length)	Facilitate segregated pedestrian infrastructure to support walking. Ideally all streets provide pedestrian infrastructure.	↑ Mobility (↑ Active transport) ↑ Physical activity ↓ Obesity ↑ Social cohesion ↑ Access to services ↓ Environmental pollution	(Carlin et al., 2016; Casey et al., 2014; D'Haese et al., 2015; Dunton et al., 2009; Florindo et al., 2018; Simon D S Fraser and Lock, 2011; Gomez et al., 2015; Grasser et al., 2013; Hajna et al., 2015; Krizek and Johnson, 2006; Larouche et al., 2012; Liao et al., 2017; Mayne et al., 2015; McCormack and Shiell, 2011; Mueller et al., 2015; N Mueller et al., 2018; Song et al., 2017; Van Cauwenberg et al., 2011; Van Holle et al., 2012; Wanner et al., 2012; WHO, 2007; Xu et al., 2013)	
	Opportunity to cycle	% of population with access to at least one bus stop within a 300 m buffer from home	Facilitate segregated cycling infrastructure to support cycling. Ideally a well-connected segregated cycling network exists.	↑ Mobility (↑ Active transport) ↑ Physical activity ↓ Obesity ↑ Social cohesion ↑ Access to services ↓ Environmental pollution	(Beard and Petitot, 2010; Carlin et al., 2016; D'Haese et al., 2015; Simon D.S. Fraser and Lock, 2011; Gomez et al., 2015; Grasser et al., 2013; Hajna et al., 2015; Larouche et al., 2012; Mayne et al., 2015; McCormack and Shiell, 2011; Mueller et al., 2015; Van Cauwenberg et al., 2011; Van Holle et al., 2012; Wanner et al., 2012; WHO, 2007)	

Domain	HUDI Indicator	Explanation	Description	Direct and indirect health pathways	Scientific references for HUDI indicator-health links	Health outcome
E N V I R O N M E N T A L Q U A L I T Y	Air quality	$PM_{2.5} \leq 5$ µg/ m^3 annual mean $NO_2 \leq 10$ µg/m^3 annual mean	Keep air pollution levels below WHO guidelines and where possible reduce further	↓ Air pollution	(WHO, 2021)	**↑ Physical and mental health**
	Surrounding greenness	% of people with access to the target value of NDVI	Provide surrounding greenness as NDVI (green corridors, street trees and other types of vegetation)	↑ Physical activity ↑ Restoration ↓ Stress ↑ Health perception ↑ Ecosystem services (Improved air quality, noise reduction, heat mitigation, storm water runoff mitigation, etc.)	(Bahadure and Kotharkar, 2018; Gascon et al., 2015; Hooper et al., 2015; Kardan et al., 2015; Triguero-Mas et al., 2015; WHO, 2016; Wolf and Robbins, 2015)	
	Lower urban heat islands (LUHIs)	points on a scale between -8 and 7 based on the urban heat island effect, where higher values indicate higher urban heat island effect.	Refers to the phenomenon where urban areas experience higher temperatures than surrounding rural areas	↓ Heat ↑ Ecosystem services (Improved air quality, noise reduction, heat mitigation, storm water runoff mitigation, etc.)	(22–24)	

Domain	HUDI Indicator	Explanation	Description	Direct and indirect health pathways	Scientific references for HUDI indicator-health links	Health outcome
GREEN SPACES ACCESSIBILITY	Universal access to green space	% of people with access to a green space of at least 0.5 ha within 300m walking distance of their home	Easy access to green spaces encourages walking, jogging, cycling, and other forms of exercise, reducing stress and the risk of obesity, cardiovascular diseases, and diabetes.	↑ Physical activity ↑ Restoration ↓ Stress ↑ Social cohesion ↑ Livability/ life satisfaction/ quality of life ↑ Ecosystem services (improved air quality, noise reduction, heat mitigation, storm water runoff mitigation, etc.)	(Annerstedt et al., 2012; Christian et al., 2017; Christiansen et al., 2016; Coombes et al., 2010; Gascon et al., 2019; Hooper et al., 2018, 2015; Kaczynski et al., 2016; WHO, 2016)	**↑ Physical and mental health**
	Access to a larger green space	% of people with access to a green space of at least 5 ha within 2 km walking distance of their home			(Hooper et al., 2018)	

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