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

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Summary

Background As global urbanisation accelerates, alongside declining environmental quality and increasing climate challenges, it is increasingly vital for urban planners and policy makers to integrate health and wellbeing considerations into urban planning. This study introduces the Healthy Urban Design Index (HUDI), a high-resolution spatial index developed for European cities. HUDI combines policy-relevant indicators related to urban design, sustainable transportation, environmental quality, and greenspace accessibility—key factors influencing human health and well-being. Unlike existing indices, which often focus on few or large metropolitan cities and lack spatial granularity, HUDI offers high resolution and extends its scope to small-sized and medium-sized cities, home to over 50% of Europe's population.

Methods We analysed 917 European cities in total, 916 cities and one larger city, on the basis of the 2018 Urban Audit database. Using open-source spatial data, we mapped cities at a fine 250 m grid cell scale. To compare cities effectively, we grouped them into five city clusters on the basis of population size, following the definition of the Organisation for Economic Co-operation and Development: large metropolitan (11), metropolitan (53), medium-sized (177) and small (638) cities, and small towns (38). A set of 13 indicators, across four overarching domains of urban design, sustainable transportation, environmental quality, and green space accessibility was calculated spatially at the 250 m grid cell scale and then aggregated to the city level. The 13 indicators were optimal dwelling density, compactness, mid-rise development, permeability, opportunity to walk, opportunity to cycle, public transport stops, air quality ($PM_{2·5}$ and NO_2), surrounding greenness (Normalized Difference Vegetation Index), lower urban heat islands, universal access to green spaces, and access to large green spaces. To ensure comparability, all indicators were standardised on a scale from 0 to 10, considering data quality, indicator target levels, and specific evaluation criteria. The HUDI was then calculated by applying different weights to these indicators, allowing us to rank cities within their respective city size cluster. We visualised overall city performance using spider plots and did Local Moran's *I* and Local Indicators of Spatial Association analyses to pinpoint areas with poor urban planning. We did sensitivity tests and correlation analyses, incorporating external datasets where available, to validate our findings.

Findings HUDI scores ranged from 2·9 to nearly 7 of 10, showing that there is still room for improvement in creating healthier urban environments across European cities. Larger metropolitan cities, particularly in northern Europe and parts of Spain, tended to score well in the urban design and sustainable transportation domains. In contrast, medium and smaller-sized cities did better in the environmental quality domain. However, smaller cities often struggled with the green space accessibility domain, as fewer parks and green spaces were accessible via walking or cycling, despite having plenty of surrounding greenery. A clear east–west divide exists, with cities in Western Europe, such as those in the UK, Spain, and Sweden, achieving the highest HUDI scores, whereas eastern European cities, particularly in Romania, Bulgaria, and Poland, scored lower. These findings highlight how city size and regional factors shape urban sustainability and public health outcomes.

Interpretation The HUDI is a large-scale, high-resolution, open-data tool that measures key urban health factors across nearly 1000 European cities of different sizes. As an open-source resource, HUDI provides valuable, data-driven insights to help cities identify strengths, weaknesses, and urban management areas needing improvement. By offering clear, measurable indicators, it helps policy makers and urban planners pinpoint problem areas and make informed decisions to improve public health and sustainability. HUDI is a dynamic tool, not a definitive ranking. By clustering cities by size, it enables comparisons, knowledge, and best practice sharing. Further research is needed to refine HUDI and expand its indicators and cities as better data become available. A key strength of HUDI is its ability to highlight data gaps and encourage better data collection. We call on researchers and urban planners to support HUDI development by sharing data and code on GitHub and Zenodo, helping track urban health and sustainability progress more effectively.

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Introduction

Over half the global population lives in cities, with Europe reaching almost 75%.[1] Urban living offers access to services, jobs, and culture but also poses challenges such as traffic, pollution, heat, and lack of green space, which affect health.[2,3] Integrating public health into city planning can mitigate these issues and foster sustainable, healthy urban development.[4] Governments worldwide are increasingly putting sustainability, liveability, and health on their agendas, as also called for in the UN Sustainable Development Goals (SDGs), particularly SDG 11,[5] and the New Urban Agenda.[6] European initiatives such as the Green City Accord,[7] European Green Capital Award,[8] and Mission Cities[9] promote community-driven, climate-resilient, and health-enhancing approaches to urban and transport planning. However, many cities struggle with localising policies, implementation, and tracking progress.

For more on **C40 Healthy Neighborhood Explorer** see https://healthyneighbourhood.c40.org

Existing urban indices assess health but often focus on few or large metropolitan cities and lack spatial granularity.[10–17] Although tools such as the Urban[11] and Global Livability Index,[15] the Human Development Index,[16] the C40 Healthy Neighborhood Explorer, or the Urban Environment and Social Inclusion Index[12] provide valuable insights, they do not capture local disparities, especially in medium and small-sized cities, where over 50% of Europe's urban population resides.[18]

Research in context

Evidence before this study

To build a strong evidence base for the Healthy Urban Design Index (HUDI), we reviewed urban health studies from the past 20 years (January, 2003–January, 2023) using the PubMed database. Our search focused on the links between urban form, transport, environment, and health, identifying large-scale studies that analysed multiple European cities. Our search terms were 'urbanisation' OR 'urban typology' OR 'urban type' OR 'urban studies' OR 'urban environment' OR 'built environment' OR 'urban morphology' OR 'urban configuration' OR 'urban form' OR 'urban areas' OR 'cities' OR 'sprawl' OR 'urban planning' OR 'urban development' OR 'urban design' OR 'urban factors' OR 'urban features' OR 'urban characteristics' OR 'urban density' OR 'urban land use' OR 'urban land cover' AND "indicator" OR "indicators" OR "index". After expert consultation, we narrowed down 94 initial studies to seven key studies and three relevant tools. These studies developed indicators for sustainable mobility, environmental quality, social infrastructure, housing, and services, ranking cities by economy, environment, society, and culture. They also assessed liveability, equity, and inclusion. However, existing indexes were often limited to few, particularly large metropolitan cities, relied often on local data, or lacked fine spatial detail. No study covered many cities (>200) of different sizes by use of only open data with high spatial resolution, which highlights the unique value of HUDI.

Added value of this study

To our knowledge, this is the first study to develop a granular, open data-driven tool that integrates urban design, transportation, environmental quality, green space accessibility, and health considerations across nearly 1000 European cities of varying sizes. Use of open-source data at a high spatial resolution (250 m grid cells), HUDI enables comparisons within and between cities, tracks progress over time, and can be updated as better data becomes available. Our findings show that large metropolitan cities in Europe generally do well in urban design and sustainable transportation but struggle with environmental quality, particularly air pollution and greenery (Normalised Difference Vegetation Index). In contrast, medium-sized and smaller cities do well in environmental quality but lag in urban design and sustainable transportation, especially in density, opportunities to walk and cycle, and public transport access. HUDI serves as a scientific tool to help cities better understand the links between urban planning, transport, environment, and health. By use of large-scale, open data with fine spatial detail, it facilitates urban health and sustainability comparisons, tracks improvements over time, and highlights data gaps—encouraging cities to enhance data collection for more informed and healthier urban planning decisions.

Implications of all the available evidence

We offer HUDI as an open, digital tool and invite cities, researchers, policymakers, and urban planners to contribute by sharing open city data, tracking progress over time, and integrating new indicators and cities worldwide in the future. By strengthening HUDI, cities can enhance evidence-based decision making and improve health and sustainability. Although HUDI provides a valuable starting point for developing urban strategies and comparing cities, we emphasise the importance of tailoring solutions to local challenges and context to create effective, healthy, and equitable urban policies. Our study makes a key contribution by offering an evidence-based, high-resolution, policy-relevant index that connects urban design, transportation, environmental quality, green space access, and health. It highlights urban strategies such as promoting sustainable mobility, reducing emissions, and expanding green spaces. The high spatial resolution of our data allows us to pinpoint within cities areas of poor urban quality, identifying hotspots where targeted interventions can improve equity. These findings underline the need for coordinated efforts to collect consistent, open, spatial data across European and global cities, enabling better urban planning and healthier communities.

Standardisation of indicators and definition of appropriate implementation scales remain challenging.

To address these gaps, we developed the Healthy Urban Design Index (HUDI)—a granular, open-source tool tailored to European cities of all sizes on the basis of epidemiological evidence.[4,19] By use of open data from sources such as OpenStreetMap (OSM), Eurostat, Copernicus, the EU's Joint Research Centre, and government datasets, HUDI calculates at high resolution 13 spatial indicators across four key domains: urban design, sustainable transportation, environmental quality, and green space accessibility. HUDI is designed for transparency, adaptability, and intracity and intercity comparisons, and to integrate evidence into practice.[20] Although not a finalised index, HUDI serves as a starting point for linking urban development with sustainability and health, promoting open-data use, and guiding evidence-based policies. The tool is publicly available on our website, with source code, data, and documentation on GitHub[21] and Zenodo.[22]

Methods

The HUDI framework was developed collaboratively with researchers and city representatives, by use of expert consultation and evidence review. It builds on Mueller and colleagues' checklist[19] for integrating health into urban and transport planning. A literature review of existing indexes helped identify gaps.[10–17,23] HUDI balances scientific rigour with data availability, by use of grid-scale data for most indicators, except for the city-wide compactness indicator.

City definition, population, and data collection

We defined city boundaries using the European Urban Audit 2018,[24] covering 917 cities across 26 European countries. Cities were grouped into five clusters on the basis of OECD definitions[18] and population size, from large metropolitan cities (≥1·5 million, n=11), metropolitan cities (500 000–1·5 million, n=53), medium sized cities (200 000–500 000, n=177), small cities (50 000–200 000, n=638), to small towns (<50 000, n=38; appendix pp 3–4).

Data were collected at a 250 m grid cell resolution by use of the Global Human Settlement Layer (GHSL) dataset,[25] refined with Urban Atlas data for residential areas.[26] Population misassignments were corrected on the basis of density, as in previous studies,[27–31] resulting in 808 243 grid cells to analyse. HUDI indicators and scores were computed both spatially (grid level) to assess local inequities and at the city level for performance comparisons.

Indicator calculation

The HUDI covers four key domains: urban design, sustainable transportation, environmental quality and green space accessibility. These domains and their respective indicators have been previously shown to link to health.[19] Indicator selection was based on open data

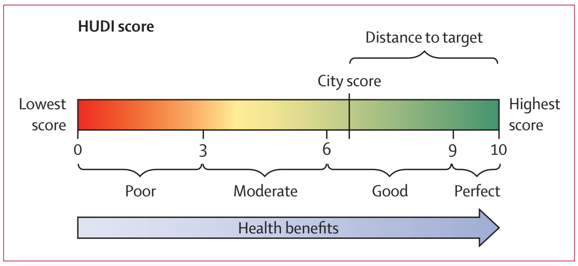

Figure 1: **Example of the rescaling method and range of HUDI scores**

For more on **OpenStreetMap** see https://www.openstreetmap.org

availability for the 917 European cities studied. Each indicator's data source, computation, and rescaling to a 0–10 scale were defined, with 10 as the best value and 0 the worst (figure 1). Indicator targets were set by means of epidemiological evidence or expert guidance, such as 25% green or permeable land,[19,32–34] optimal dwelling density of 45–175 dwellings per ha,[19,32,35] and WHO air quality limits.[36] Some indicators, such as mid-rise development, were benchmarked against top-performing cities in each cluster.

For more on **HUDI** see https://isglobalranking.org/hudi

Scores were categorised as poor (0–3), moderate (3–6), good (6–9), and perfect (10). All indicators were computed at the 250 m grid resolution before city-level aggregation, except for the compactness indicator. The table details sources, indicator targets, and health pathways. Analyses were done in Python (version 3.9.1, Python Software Foundation, USA), with some figures in QGIS (version 3.30.0, Open Source Geospatial Foundation).

City boundaries and city cluster divisions are shown in the appendix (pp 3–4). Data and indicator analysis are shown in the index (pp 5–32). Complementary main analysis results are shown in the appendix (pp 33–57). Correlation and sensitivity analyses, which ensure robustness of results, drawing on external datasets, different assumptions and data inputs, are shown in the appendix (pp 58–63). The indicator health links are evidenced in the appendix (pp 64–67).

Domain 1: urban design

See **Online** for appendix

The urban design domain highlights the importance of diverse, mixed land uses, compactness and higher population density in promoting access to services and community cohesion.[19] This domain score is the average of standardised scores from the following indicators (appendix pp 5–12).

Optimal dwelling density—this indicator measures housing unit compactness, focusing on apartment living. Optimal dwelling density balances urban functionality, avoiding both horizontal and vertical sprawl. Studies suggest an ideal range of 45–175 dwellings per hectare, with 100 as the optimal target.[32,35] Private household data for EU countries (2022) was sourced from Eurostat,[37] with missing data for Norway, England, Switzerland, and Iceland added manually.[38–41] Population data from GHSL[25] were used to calculate dwelling density. To compute the indicator, we divided total population by household size

	Description	Data source	Target	Absolute value description (before the rescaling)	Rescaling method (reference values in the new scale max=10, min=0)	Pathways to health (appendix pp 64–67)
Urban design						
Optimal dwelling density	The density of housing units in an area	2019 GHSL[25] and 2022 Eurostat household data by country[24]	45–175 dwellings per ha (grid and city levels)	Dwelling density (dwellings per ha), with an optimal range of 45–175 dwellings per ha	Gaussian interpolation was applied within the 45–175 dwellings per ha range on a 6–10 scale, with max=100 dwellings per ha (score 10);[32,35] linear interpolation was used outside this range, based on best-in-class and worst-in-class cities within the city cluster; this method was applied at both grid and city levels	↑ Mobility (↑ Active transport) ↑ Physical activity ↑ Access to services ↓ Environmental pollution ↓ CO_2 emissions per capita
Compactness	Horizontal urban sprawl or suburban expansion	2019 GHSL[25]	Higher values indicate better performance (grid and city levels)	Points (0–100) reflecting building density and urban development; higher scores indicate greater compactness	Computed by use of Lopez et al[42] (appendix p 6), with max=100 (score 10, compact), min=0 (score 0, sprawl); values were divided by 10 to rescale to 0–10 scale; city- level indicator only	↑ Mobility (↑ Active transport) ↑ Physical activity ↑ Social cohesion ↑ Access to services ↑ Livability– life satisfaction–quality of life ↓ Environmental pollution ↓ CO_2 emissions per capita
Mid-rise development	Refers to low-rise buildings and urban structures, typically 5–6 storeys high	2012 Local Climate Zone[45,46]	Higher values indicate better performance (grid and city levels)	Percentage of buildings with 5–6 storeys	Cluster-based linear interpolation at the grid level, by use of the highest (score 10) and lowest (score 0) values within each city cluster as references; city- level values were aggregated by use of a population-weighted average and linearly rescaled by use of the highest (score 10) and lowest (score 0) city-level values within each cluster as reference	↑ Mobility (↑ Active transport) ↓ Car dependence ↑ Physical activity ↑ Social cohesion ↑ Access to services
Permeability	Unpaved, permeable soil	2018 European Environment Agency[47]	At least 25% of the surface should be impermeable (grid level)	Percentage of people with access to the target level of permeable surfaces	Cluster-based linear interpolation at the grid level, by use of the highest (score 10) and lowest (score 0) values within each city cluster as references; a target score of 6 was assigned to 25%;[19,32] city- level values were aggregated as the percentage of people in grids meeting the target, then rescaled to 0–10 by dividing by 10	↑ Ecosystem services (↓ Air pollution, ↓ Noise, ↓ Heat, ↑ Green) ↑ Physical activity ↑ Mobility (active transport) ↓ Car dependence
Sustainable transportation						
Opportunity to walk	Percentage road network with pedestrian infrastructure	2022 OpenStreetMap data	70% of road network with pedestrian infrastructure (city level)	Percentage road network with pedestrian infrastructure	Cluster-based linear interpolation at the grid level, by use of the highest (score 10) and lowest (score 0) values within each city cluster as references; city- level values were aggregated by use of population-weighted averages and linearly rescaled by use of max=70% (score 10) and min=0% (score 0) as references[10]	↑ Mobility (↑ Sustainable transport) ↑ Physical activity ↑ Social cohesion– social capital ↑ Access to services ↓ Environmental pollution
Opportunity to cycle	Percentage of road network with cycling infrastructure	2022 OpenStreetMap data	35% of road network with cycling infrastructure (city level)	Percentage of road network with cycling infrastructure	Cluster-based linear interpolation at the grid level, by use of the highest (score 10) and lowest (score 0) values within each city cluster as references; city- level values were aggregated by use of population-weighted averages and linearly rescaled by use of max=35% (score 10) and min=0% (score 0) as references [10]	↑ Mobility (↑ Active transport) ↑ Physical activity ↓ Obesity ↑ Social cohesion ↑ Access to services ↓ Environmental pollution
Public transport stops	Number of public transport stops	2022 OpenStreetMap data	At least one bus stop (grid level)	Percentage of the population with access to a bus stop within 300 m of home	Cluster-based linear interpolation at the grid level, by use of max=20 (score 10) and min=0 (score 0); city-level values were aggregated by calculating the percentage of people in grids meeting the target of one bus stop, then rescaled to a 0–10 range by dividing by 10	↑ Mobility (↑ Active transport) ↑ Physical activity ↓ Obesity ↑ Social cohesion ↑ Access to services ↓ Environmental pollution

(Table continues on next page)

	Description	Data source	Target	Absolute value description (before the rescaling)	Rescaling method (reference values in the new scale max=10, min=0)	Pathways to health (appendix pp pp 64–67)
(Continued from previous page)						
Environmental quality						
Air quality ($PM_{2.5}$)	Air quality indicator refers to the $PM_{2.5}$ pollutant	2015 ELAPSE and Ensemble models[54,55]	5 μg/m³ (grid and city levels)[36]	Micrograms per cubic metre annual mean	Cluster-based linear interpolation at the grid level, by use of max=5 μg/m³ (score 10) and min=highest grid level concentration (score 0); city- level values were aggregated by use of population-weighted averages and linearly rescaled by use of max=5 μg/m³ (score 10) and min set to highest city concentration (score 0)	↓ Air pollution
Air quality (NO_2)	Air quality indicator refers to the NO_2 pollutant	2015 ELAPSE and Global LUR models[54,55]	≤10 μg/m³ (grid and city levels)[36]	Micrograms per cubic metre annual mean	Cluster-based linear interpolation at the grid level, by use of max=10 μg/m³ (score 10) and min=highest grid-cell concentration (score 0); city- level values were aggregated by use of population-weighted averages and linearly rescaled by use of max=10 μg/m³ (score 10) and min set to highest city concentration (score 0)	↓ Air pollution
Surrounding greenness (NDVI)	Measures the difference between visible (red) and near-infrared light reflected by vegetation	2015 MODIS Vegetation Indices (MOD13Q1)[57]	Cities' thresholds as defined by Pereira Barboza et al[28] (grid level)	Percentage of people with access to the target NDVI value	Cluster-based linear interpolation at the grid level, by use of the highest (score 10) and lowest (score 0) values as references. A target score of 6 was assigned to the city-specific NDVI target derived from Pereira Barboza et al;[28] city-level values were aggregated as the percentage of people in grids meeting the target, then rescaled to a 0–10 range by dividing by 10	↑ Physical activity ↑ Restoration ↓ Stress ↑ Health perception ↑ Ecosystem services (improved air quality, noise reduction, heat mitigation, storm water runoff mitigation, etc)
Lower urban heat islands	Refers to phenomenon where urban areas are hotter than surrounding rural areas	2015 Chakraborty et al[58]	Higher values indicate better performance (city level)	Points on a scale from −8 to 7, where higher values indicate a stronger urban heat island effect	Cluster-based linear interpolation at the grid level, by use of the highest (score 10) and the lowest (score 0) values within each city cluster as references; city-level values were aggregated by use of a population-weighted average and linearly rescaled by use of the highest (score 10) and lowest (score 0) city-level values within each cluster as reference	↓ Heat ↑ Ecosystem services (Improved air quality, noise reduction, heat mitigation, and stormwater runoff mitigation, etc)
Green spaces accessibility						
Universal access to green spaces	Measures access to green spaces of at least 0·5 ha within 300 m	2022 Battiston et al[60]	Green space of at least 0·5 ha within a 300 m walking distance (grid level)	Percentage of people with access to a green space of at least 0·5 ha within a 300 m walking distance from home.	Cluster-based linear interpolation at the grid level, by use of the highest (score 10) and the lowest (score 0) values within each city cluster as references; city-level values were aggregated as the percentage of people in grids meeting the target by Battiston et al, [60] then rescaled to 0–10 by dividing by 10	↑ Physical activity ↑ Restoration ↓ Stress ↑ Social cohesion ↑ Livability/ life satisfaction/ quality of life ↑ Ecosystem services (improved air quality, noise reduction, heat mitigation, stormwater runoff mitigation, etc)
Access to large green spaces	Measures access to green spaces of at least 5 ha within 2 km	2022 Battiston et al[60]	Green space of at least 5 ha within a 2 km walking distance grid level)	Percentage of people with access to a green space of at least 5 ha within a 2 km walking distance from home	Cluster-based linear interpolation at the grid level, by use of the highest (score 10) and the lowest (score 0) values within each city cluster as references; city-level values were aggregated as the percentage of people in grids meeting the target by Battiston et al,[61] then rescaled to 0–10 by dividing by 10	↑ Physical activity ↑ Restoration ↓ Stress ↑ Social cohesion ↑ Livability/ life satisfaction/ quality of life ↑ Ecosystem services (improved air quality, noise reduction, heat mitigation, stormwater runoff mitigation, etc)

NDVI=Normalised Difference Vegetation Index.

***Table:* Description of indicators, data sources, target levels, rescaling methods used for indicator computation, absolute values description and pathways to health**

and city area. Scores (0–10) were assigned by use of Gaussian interpolation, mapping 45–175 dwellings per ha to 6–10 (with 100 as 10) and values outside this range to 0–6. The same method applied at the grid-cell level (appendix pp 5–6).

Compactness—this indicator measures city compactness, the inverse of horizontal sprawl, which is associated with poorer mental health, lower life satisfaction, and reduced community cohesion.[3] Using the GHSL population data,[25] we applied the OECD-EC definition[18] to classify areas. High-density clusters consist of adjacent 1 km² cells (excluding diagonals) with at least 1500 inhabitants per km² and a total population of 50 000 or more. Moderate-density urban clusters include adjacent 1 km² cells (including diagonals) with at least 300 inhabitants per km² and a total population of 5000 or more. Areas that do not meet these criteria are considered rural. Following Lopez and colleagues,[42] sprawl (S_i) was calculated by subtracting the percentage of the population in high-density and moderate-density clusters. Cities within the small towns cluster (with fewer than 50 000 inhabitants) were assigned a sprawl value of 100. Compactness (C_i) was then computed as $C_i=100-S_i$, where 100 represents a fully compact city and 0 a fully sprawled city.[42] Values were rescaled to a 0–10 range by dividing by 10. Since sprawl and compactness are city-wide measures, this indicator is not calculated at the grid-cell level (appendix p 6).

Mid-rise development—this indicator focuses on low-rise to mid-rise buildings (5–6 storeys), as studies suggest that they enhance comfort and wellbeing by maintaining clear sky visibility while preventing vertical sprawl.[3,43,44] To assess mid-rise development, we used the Local Climate Zone classification by Demuzere and colleagues,[45] which provides a standardised urban form description.[46] Since no specific target exists in the literature, the indicator was rescaled from 0 to 10 on the basis of cluster-specific maximum and minimum values, with higher scores reflecting better performance. At the city level, it was calculated as a population-weighted mean of grid values, maintaining the same rescaling method (appendix pp 7–10).

Permeability—the permeability indicator measures the land's ability to absorb water, reducing flooding, mitigating heat islands, and improving stormwater management. It is the inverse of imperviousness, reflecting the extent of built surfaces such as buildings and pavement. For healthy urban design, at least 25% of land should remain permeable.[19,32] Imperviousness data from the European Environment Agency geospatial data catalogue were downloaded at 10-m resolution and subsequently adapted to our 250-m² grid cells.[47] At grid-cell level, we rescaled the values using a threshold of 25%, corresponding to a score of 6 on the 0–10 scale. Grid cells exceeding 25% received proportionally higher scores. At the city level, we established the proportion of residents living in grid cells with over 25% permeability. This percentage was then scaled from 0 to 10 by dividing by 10 (appendix pp 10–12).

Domain 2: sustainable transportation

For a sustainable city, promoting active mobility (walking and cycling) and public transport is key to reducing car dependency, improving air and noise pollution, and encouraging physical activity.[19,48,49] Sustainable transportation was measured by averaging standardised indicator scores of the following indicators. We acknowledge that the sustainable transportation data, based on OSM data, have certain limitations and potential quality issues, as they lack systematic and globally consistent updates (appendix pp 12–21).[50] The data were downloaded at 10 m resolution and subsequently adapted to our 250 m² grid cells. For this reason, this domain was assigned a lower weight compared with the other domains in the calculation of the HUDI.

Opportunity to walk and opportunity to cycle—this metric quantifies the share of the road network dedicated to walking and cycling, by use of the most recent 2022 OSM data (appendix pp 12–19). The opportunity-to-walk and cycle indicators measure walking and cycling infrastructure as a percentage of the total street network (appendix pp 16–18) on the basis of definitions from the Clean Cities Campaign.[10] At the grid-cell level, both indicators were rescaled to a 0–10 scale by use of linear interpolation, with 0 and 10 representing the minimum and maximum values within each city cluster. Grid-level values were aggregated to the city level by use of population-weighted averages and rescaled similarly, where 0% equated to a score of 0 and 70% (pedestrian infrastructure) and 35% (cycling infrastructure), respectively, to a score of 10, according to Clean Cities Campaign infrastructure target levels for walking and cycling.[10] City-level scores remained stable across clusters under different thresholds. Consistent with Mueller and colleagues,[51] our analysis confirmed a strong correlation between cycling infrastructure and mode share, reinforcing the indicator's reliability as a proxy (appendix p 19).

Public transport stops—This indicator measures access to bus, metro, tram, and train stops within a city, aligning with SDG 11.2 for sustainable transport. Public transport stops 2022 OSM data were used. For optimal access, a public transport stop should ideally be located within a 300 m street network distance.[3,51,53] Grid cells were capped at 20 stops (99·5th percentile) and rescaled from 0 to 10 (20 stops). At the city level, we calculated the percentage of residents in grid cells with at least one public transport stop (target) and rescaled it to the 0–10 scale (appendix pp 20–21).

Domain 3: environmental quality

The environmental quality domain score was calculated as the average of standardised scores for air quality

($PM_{2·5}$, NO_2), surrounding greenness (Normalised Difference Vegetation Index [NDVI]), and urban heat island (UHI).

Air quality: $PM_{2·5}$ and NO_2—we assessed air quality using $PM_{2·5}$ and NO_2 given their well-established health effects and links to urban and transport planning (appendix pp 21–24). Baseline $PM_{2·5}$ and NO_2 concentrations (2015) were estimated at grid level by use of data from Khomenko and colleagues.[27] PM2·5 values were derived from the ELAPSE[54] and Ensemble models,[55], whereas NO_2 values combined ELAPSE with a Global LUR model.[56] Threshold concentrations were set at 5 μg/m³ annual mean for PM2·5 and 10 μg/m³ annual mean for NO_2, in line with WHO guidance.[36] Grid-cell values at the city level were aggregated by use of a population-weighted average. Scores were rescaled via linear interpolation, assigning 10 to cities meeting WHO guidance and 0 to the worst-performing city within the clusters. Grid cells complying with the WHO air quality guideline (≤ threshold) received a score of 10; the most polluted cell within the cluster scored 0.

Surrounding greenness (NDVI)—NDVI measures vegetation from satellite imagery (appendix pp 24–27). We used NDVI data from Barboza and colleagues,[28] retrieved via MODIS (MOD13Q1) from the US Geological Survey[57] for April–June, 2015, excluding blue spaces. Following Barboza and colleagues,[28] we assessed NDVI against biome-specific targets. The proportion of the population in grid cells meeting city-specific NDVI targets was rescaled to a 0–10 scale. At the grid-cell level, NDVI values were linearly interpolated, where 0 and 10 represented the lowest and highest observed values. The city-specific target NDVI values from Barboza and colleagues,[28] served as the threshold, corresponding to a score of 6 on the scale. This threshold represents a good NDVI value while allowing grid cells with higher values to achieve even better scores.

Lower urban heat islands (LUHI)—The lower urban heat islands (LUHI) indicator assesses cities' effectiveness in mitigating heat and is derived as the inverse of the canopy UHI (CUHI).[58] CUHI measures air temperature differences between urban and rural areas, capturing interactions between buildings, vegetation, and the atmosphere to evaluate green infrastructure, reflective surfaces, and sustainable design. We used the Simplified Urban Extent algorithm by Chakraborty and Lee[58] to estimate CUHI for the northern hemisphere summer (June–August, 2015), as it best reflects potential cooling benefits from urban greening (appendix pp 27–29). CUHI values were aggregated at the city level, weighted by population density, and rescaled to a 0–10 scale by use of linear interpolation. LUHI was then computed as its inverse, with grid-cell values similarly rescaled, setting the highest and lowest cluster values as benchmarks (scoring 0 and 10, respectively).

Domain 4: green space accessibility

Access to green spaces enhances quality of life, promotes health, and fosters social cohesion.[59] Using Battiston colleagues' methodology,[60] we computed two indicators of green space accessibility (appendix pp 29–32). Universal access to green spaces and access to large green spaces—these indicators measure walking time to the nearest public green space. The universal access to green spaces indicator targets a 0·5 ha green space within 300 m of residences;[61] the access to large green spaces indicator suggests a 5 ha green space within 2 km.[62] Green space data were retrieved by use of Battiston and colleagues' methodology[60] with 2022 OSM data at 9-arc resolution (WGS-84) and fitted into the grid cells. At the grid level, a logarithmic transformation addressed skewed data before rescaling, with the best grid scoring 10 and the lowest 0. At city level, indicators were calculated as the percentage of people meeting targets for each grids, then rescaled (0–10) by use of linear interpolation (0%=0, 100%=10).

Healthy Urban Design Index (HUDI) development

The table details all indicators, data sources, target levels, rescaling methods, and health pathways (appendix pp 64–67). A key challenge in composite indices is aggregating indicators effectively.[63] With no standardised method available, we tested two approaches for HUDI aggregation. First, we averaged indicators within each domain, then took an unweighted mean of the four domain scores. Second, following Hsu and colleagues,[12] we assigned a weight of 0·5 to the sustainable transportation domain (comprising opportunities to walk and cycle, and public transport stops) and 1 to the other three domains, reflecting data quality concerns. Unlike the other domains and their indicators, which rely on peer-reviewed or satellite data, sustainable transportation depends on OSM crowdsourced data. Although OSM land cover or land use data (like green space data) are often cross-validated with satellite imagery, transport-related data (eg, bus stops, and pedestrian and cycling infrastructures) are less complete and lack validation, especially in smaller cities.

To compare weighting methods, we calculated Kendall's rank correlation between the final rankings. We adopted the second approach, considering OSM data limitations in the sustainable transportation domain. HUDI was computed at both grid and city levels. City-level values were averaged from grids, excluding the compactness indicator. HUDI rankings identified the highest-scoring and lowest-scoring cities in each cluster. To enhance clarity for practitioners, we displayed both absolute and rescaled indicator values. We also included Local Indicators Spatial Associations (LISA) plots based on grid-level Local Moran's *I* statistics to highlight HUDI spatial clusters, helping practitioners identify areas of

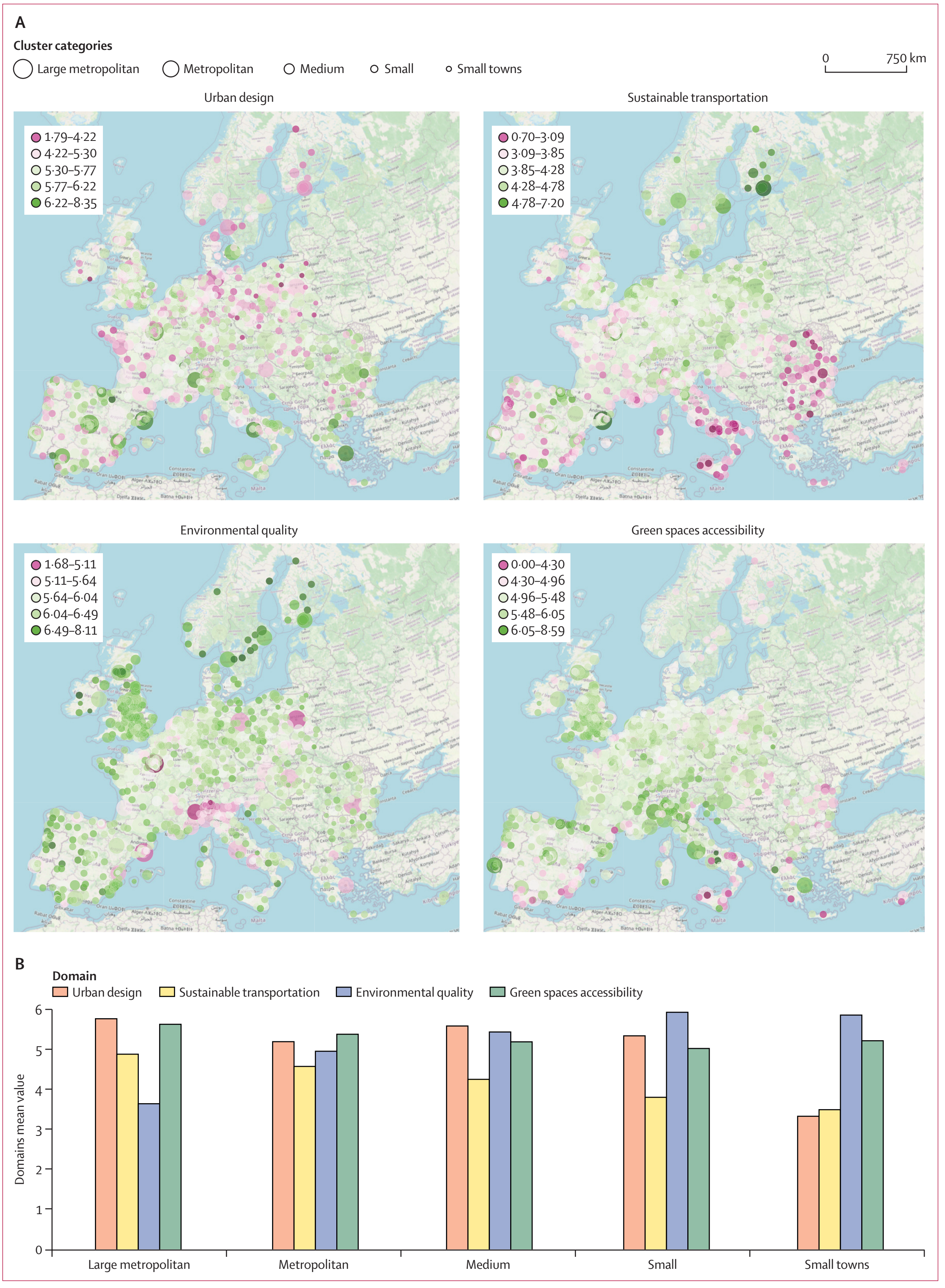

Figure 2: Map (A) showing the mean value for each domain (urban design, sustainable transportation, environmental quality, and green spaces accessibility) by city and cluster type (large metropolitan, metropolitan, medium, small, and small towns); ring sizes correspond to city cluster categories, with larger rings representing large metropolitan cities and smaller rings indicating smaller cities. The bar chart (B) summarises the average domain values across all cities within each city cluster type

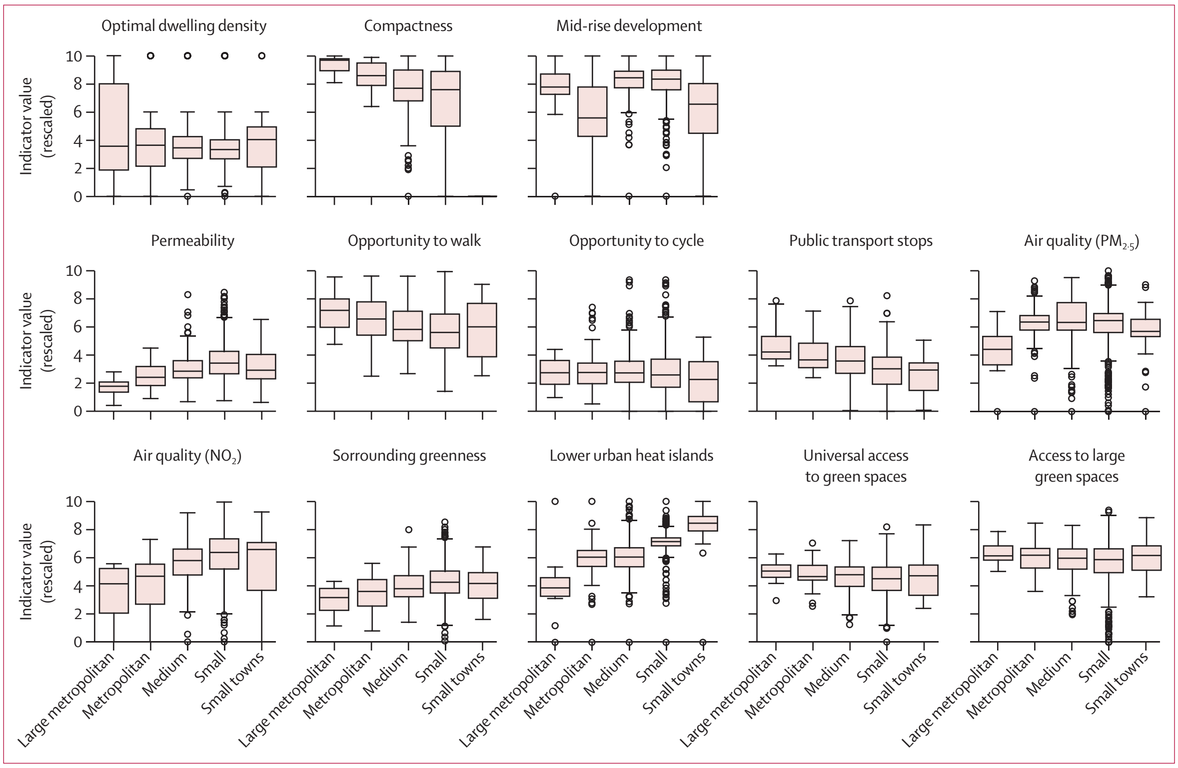

Figure 3: **Box plots showing the distribution of rescaled indicator values across the city cluster types**

weak and strong HUDI performance. LISA plots highlight areas where HUDI scores spatially correlate; including high–high (HH) clusters—high scores surrounded by high scores, low–Low (LL)—low scores surrounded by low scores; high–low (HL)—high scores surrounded by low scores; and low–high (LH)—low scores surrounded by high scores.

We used population-weighted aggregation for city-level indicators (opportunity to walk, opportunity to cycle) and those without specific target levels (mid-rise development, LUHI). For grid-level targets (surrounding greenness, permeability, green space accessibility, and public transport stops), we calculated the proportion of the population meeting them. A sensitivity analysis tested alternative thresholds and aggregation models for permeability, opportunity to walk, opportunity to cycle, and air quality ($PM_{2·5}$ and NO_2) to assess reliability (appendix pp 58–62).

Additional analysis

We did additional tests to validate indicators (appendix pp 58–63). Using Urban Atlas 2012 (0·25 ha)[26] and Corine Land Cover 2012 (25 ha),[64] we confirmed city-level permeability alignment with green space data (appendix pp 58–60). We also compared air pollution $PM_{2·5}$ and NO_2 data with AirBase,[65] (appendix p 62), aggregating grid-level data using population-weighted averages. Strong correlations were found (Spearman: $PM_{2·5}$=0·73, NO_2=0·62), confirming reliability. Lastly, a sensitivity analysis tested alternative thresholds for opportunity to walk and opportunity to cycle, where no fixed thresholds exist (appendix pp 60–61).

Role of the funding source

The funders of the study had no role in the study design, data collection, data analysis, data interpretation, or writing of the report.

Results

Grid-level and city-level results for all 917 European cities, along with overall HUDI performance, are available on our website. Figure 2 shows the interplay among the four key domains of urban design, sustainable transportation, environmental quality, and green spaces accessibility and city clusters. Urban design and sustainable transportation have the highest scores in large metropolitan areas (mean values around 6 and 5 of 10, respectively), with scores gradually decreasing towards the small towns cluster. Sustainable transportation scores are higher in northern Europe and parts of Spain, and lower in eastern Europe and southern Italy. Environmental quality scores are higher in the smaller city clusters, especially in northern Europe, with a mean of around 6 of 10. Green spaces accessibility scores are consistent across clusters but slightly decrease in smaller cities. Indicator patterns can be seen in the appendix (pp 35–38), and the top and bottom five cities for each indicator by cluster are highlighted in the appendix (pp 39–42).

For more on **HUDI** see https://isglobalranking.org/hudi

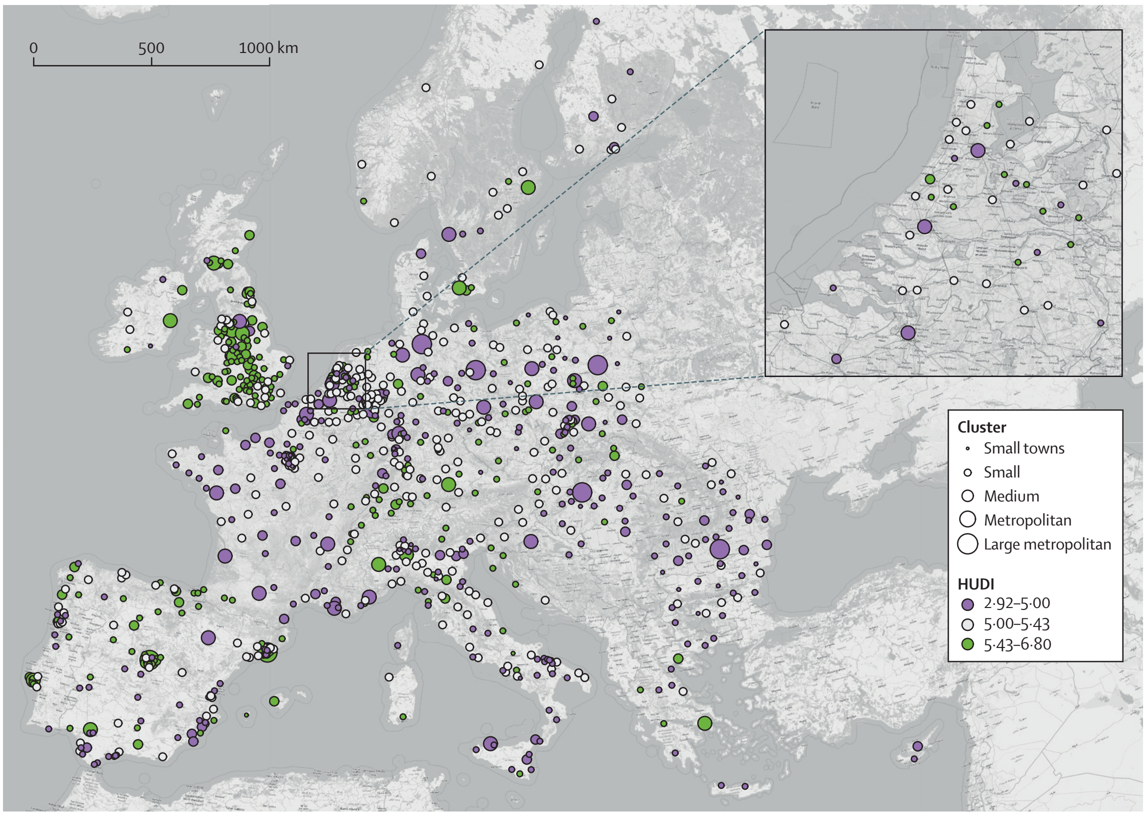

Figure 4: **Spatial distribution of European cities based on their performance in the HUDI. Cities are categorised into four city clusters—large metropolitan, metropolitan, medium-sized cities, and small towns—and further classified into HUDI score quintiles. The color coding and varying circle sizes reflect these classifications, providing a comprehensive overview of the HUDI across Europe**
HUDI=Healthy Urban Design Index.

Figure 3 shows boxplots of the indicators across the five city clusters. In the urban design domain, indicator scores decrease from large metropolitan areas to small towns, except permeability, which peaks in medium and small cities such as Elche (Spain) and Potenza (Italy), whereas large cities such as Rome score below 3 of 10 (appendix p 39). In the sustainable transportation domain, large metropolitan cities have less variability and score higher. The opportunity to cycle indicator scores high in northern cities such as Helsinki and Amsterdam, whereas southern cities (eg, Italy, Bulgaria, and Romania) score low (appendix p 40). In the environmental quality domain, larger cities score lower median values (approximately 4), with poor performance in air quality and UHI, especially in Warsaw, Paris, and northern Italian cities. Smaller northern cities (eg, Oulu, Lahti, and Umeå) score higher. Surrounding Greenness mirrors permeability, with mid-sized and small cities such as Elche (Spain) and Paredes (Portugal) scoring highest (appendix p 41). In the green space accessibility domain, large and medium cities score the highest median values, particularly in the universal access to green spaces indicator (appendix p 42).

Integrating the 13 indicators, the HUDI distribution across the city clusters shows distinct patterns (appendix p 46). Large metropolitan cities, with the smallest sample size (n=11), show the highest variability in HUDI scores, ranging from 4·11 to 6·04 (SD 0·56), with a mean of 5·01. Metropolitan cities (n=53) have a slightly higher HUDI mean (5·10) but lower variability (SD 0·43), whereas medium cities (n=177) show an even higher mean (5·25) and lower variability (SD 0·45). Small cities (n=638) have the highest mean (5·21) and larger variability (SD 0·53), influenced by a larger sample size. Small towns (n=38) have the lowest mean (4·63) and moderate variability (SD 0·50).

The correlation between the 13 indicators and the combined HUDI is shown in the appendix (p 47). Access to green spaces has the strongest positive correlation (0·7–0·6), which indicates that high HUDI scoring cities often provide good access to green spaces. Public transport stops and opportunity to walk show moderate correlations with HUDI scoring (approximately 0·5–0·4). Air quality correlations vary: $PM_{2·5}$ has a positive correlation (0·3), whereas NO_2 has a slight negative correlation with HUDI scoring, suggesting air quality challenges in high HUDI scoring cities. Permeability and surrounding greenness show weak correlations with HUDI scoring.

The spatial distribution of HUDI scores shows distinct patterns across European cities (figure 4). Higher HUDI scoring cities (5·35–6·8) are concentrated in western Europe, notably in the UK, Spain, and Sweden (eg, Edinburgh, Pamplona, and Stockholm), across the different city clusters, although metropolitan cities generally score higher than smaller cities. In contrast, eastern European cities, especially in Romania, Bulgaria, and Poland (eg, Bucharest, Dobrich, and Warsaw), consistently fall into the lowest HUDI score quintiles (2·92–4·74), highlighting an east–west HUDI scoring gradient. Mediterranean cities generally do worse than northern European cities in the same cluster. Local HUDI clustering patterns and Local Moran's I statistics LISA plots results are further explored in the appendix (p 49).

Figure 5 provides an example of Paris' city performance. In the large metropolitan cluster, Paris shows balanced performance in urban design (7·5 of 10) and sustainable transportation (6·3 of 10), but lower scores in environmental quality (2 of 10) and green space accessibility (5 of 10). Paris does well for public transport access (76%) and opportunity to walk (33%), whereas for opportunity to cycle (6·79%) and air quality ($PM_{2·5}$: 15·18 μg/m³, NO_2: 43·98 μg/m³) it does weakly. Paris has a HUDI score of 5·01 of 10, ranking 6th out of 11 in its cluster. Figure 6 shows granular grid level analysis highlighting strong urban design scores in central Paris areas, with environmental quality and green space accessibility scoring higher in Paris' affluent neighbourhoods, as shown in the HUDI map and LISA plot, which identifies HH clusters in central and LL clusters in peripheral areas. One representative city from each of the remaining city clusters that we explain hereafter is similarly illustrated in the appendix (pp 50–57).

In the metropolitan city cluster (appendix pp 50–51), Palermo (Italy) does well in urban design (6·4 of 10), especially in mid-rise development and compactness, but scores low in permeability (26%). Sustainable transportation indicators score low (2·8 of 10), whereas environmental quality and green space accessibility score moderately (4 of 10). With a HUDI score of 4·7 of 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 neighbourhoods.

In the medium-sized city cluster (appendix pp 52–53), Espoo (Finland) excels in environmental quality and sustainable transportation (average score 7 of 10), with $PM_{2·5}$ averaging 7·5 μg/m³ and high scores for opportunities to walk and cycle (30%). However, urban design scores lag (3·6 of 10), particularly in compactness (29 of 100). With a combined HUDI score of 5·38 of 10, Espoo ranks 47th of 177 cities in its cluster. Granular grid cell analysis shows that environmental quality scores high in most areas, although 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 (appendix pp 54–55), Pamplona (Spain) does well across all four domains, with a HUDI score of 6·8 of 10, ranking first of 638 cities. Pamplona excels in urban design (8·4 of 10) and scores around 6 of 10 in other domains. The urban design indicators score well, except permeability (41%).

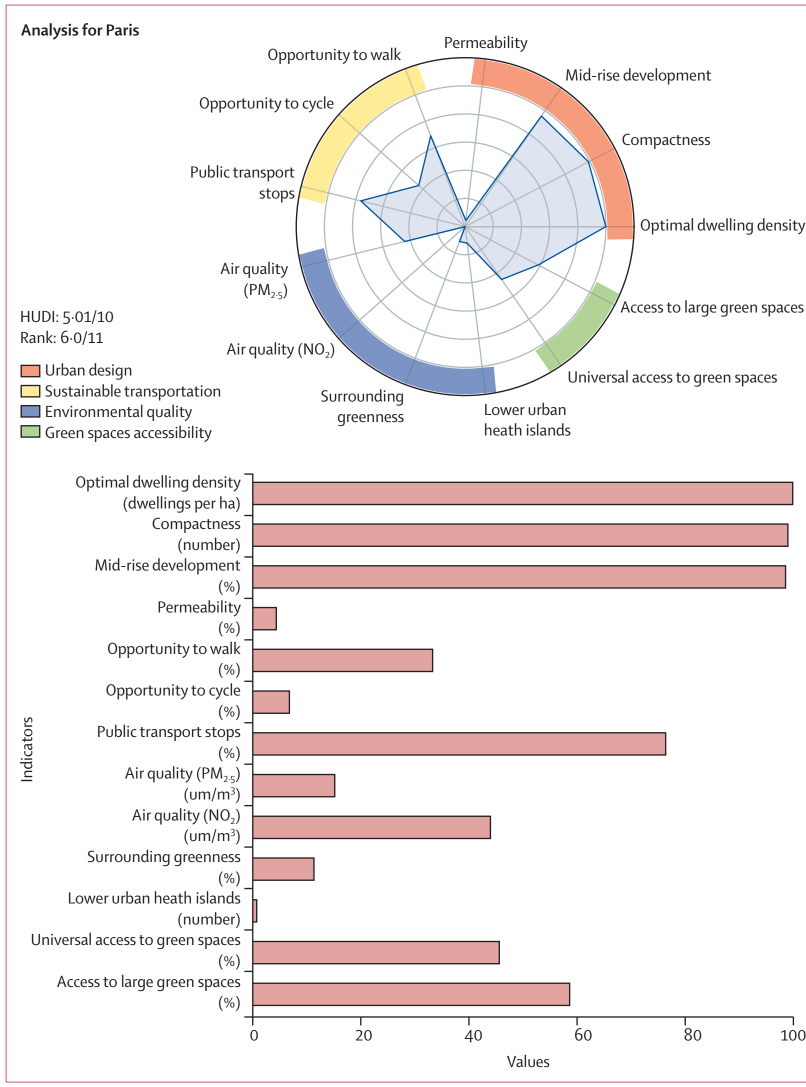

***Figure 5:* HUDI and indicator values for the city of Paris, classified within the large metropolitan cluster**
The spider plot displays rescaled indicator values, ranging from 0 at the centre to 10 at the outer edge, with greater radial extensions indicating stronger HUDI performance. An ideal city would score 10 on all indicators, resulting in a fully filled radial plot. Adjacent to the spider plot, a bar chart displays the absolute indicator values before rescaling to the 0–10 scale (see table for definitions of these absolute values). HUDI=Healthy Urban Design Index.

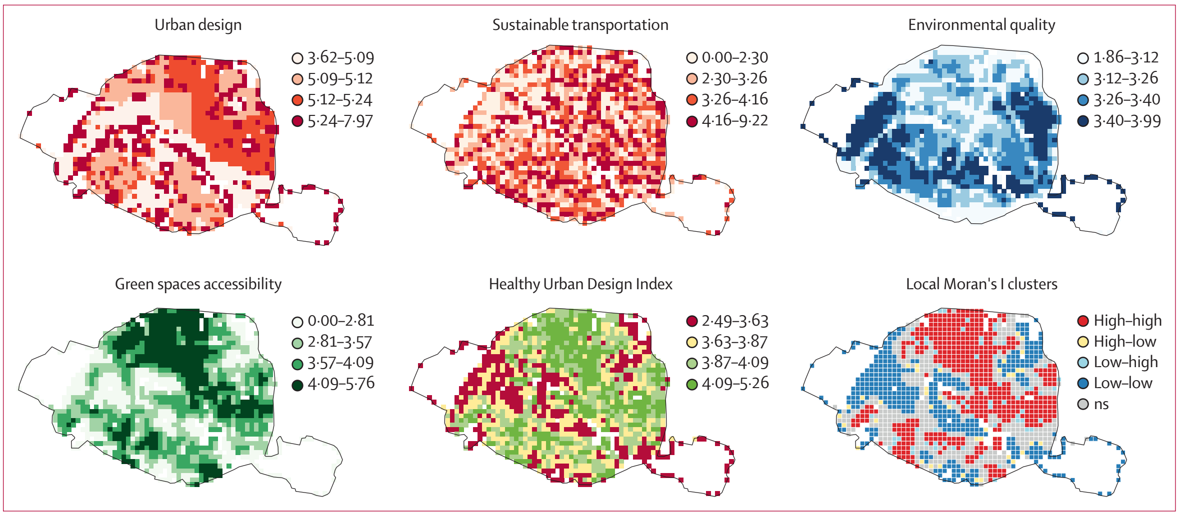

***Figure 6:* Grid level visualisation of Paris, which highlights the spatial distribution of HUDI domains and overall HUDI at a 250 m resolution, revealing detailed spatial patterns across the city**

A Local Moran's *I* LISA plot further identifies spatial clustering, classifying areas as high–high (high HUDI values surrounded by high values), low-low, high-low, or low-high, offering insights into local spatial associations. A comprehensive overview of the HUDI performance of all cities is available on the authors' website. HUDI=Healthy Urban Design Index. LISA=Local Indicators of Spatial Association.

For more on **HUDI** see https://isglobalranking.org/hudi

Opportunity to walk (51%) scores high and LUHI scores low (0·12 of 10). However, opportunity to cycle scores low (6%). Granular grid level analysis for Pamplona shows that environmental quality and urban design indicators have similar HUDI score patterns, with central-western areas doing best in green space accessibility (60%). The HUDI map highlights high-performing clusters in the central and western areas of Pamplona, whereas 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 (appendix pp 56–57), Limerick (Ireland) scores 5·1 of 10 for the combined HUDI, ranking 6th of 38 cities in its cluster. Limerick excels in green space accessibility (6 of 10) and Environmental quality (7 of 10), with low $PM_{2·5}$ (7·1 μg/m³) and NO_2 (14·6 μg/m³) concentrations and a low LUHI score (0·13 of 10). However, Limerick struggles with sustainable transportation (2·4 of 10) and urban design (3 of 10). Granular grid level analysis shows that environmental quality is highest in the northern and eastern areas, whereas green space accessibility peaks in central neighbourhoods. The LISA plot shows HH clusters in the southern and eastern areas, with LL clusters in peripheral neighbourhoods.

We present additional analyses to strengthen our results in the appendix (pp 58–63). We compared the two HUDI weighting methods, with Kendall's correlation consistently high (0·77 to 0·89) across all clusters, especially in large metropolitan cities. All p values were less than 0·0001, indicating similar results between the two methods.

We also did a sensitivity analysis on the permeability indicator using alternative datasets,[26,64] closely aligned with the original permeability indicator (appendix pp 58–60). This analysis reveals a strong positive correlation between permeability and green space data (Spearman ρ=0·68; appendix pp 58–60), confirming the robustness of our permeability indicator. The grid-level analysis revealed consistent patterns across the city clusters, validating the overlap between both indicators regardless of data input source (appendix pp 58–60).

Finally, we assessed how scores varied across clusters with different target thresholds for opportunity to walk (50%, 60%, and 70%) and cycle (15%, 25%, and 35%; appendix pp 60–61). Large cities showed stable scores, whereas smaller cities displayed more variability. Higher thresholds better identified cities with advanced pedestrian and cyclist infrastructure, whereas lower ones offered a more detailed view of current active mobility conditions. Results (appendix p 61) indicate that cycling infrastructure developments lag behind pedestrian infrastructure developments in meeting policy targets.

Discussion

The HUDI framework assesses urban health and sustainability across 917 European cities, from large metropolitan cities to small towns. Developed through research and expert input, HUDI provides granular grid-cell and city-level indicators, helping policy makers to analyse urban design, transport, environment, and health interconnections, drawing exclusively on open data. HUDI aids in identifying hotspots for intervention and shaping effective strategies. It connects urban design, transport, environment, and green space to health by addressing upstream determinants of pollution, heat, stress, physical activity, restoration, social cohesion and wellbeing.[4,19,66] Its open data framework enables cities to refine and expand insights for better urban planning and management.

Our findings highlight how city size and geography shape HUDI performance. Large metropolitan cities, especially in Northern Europe and parts of Spain, score higher in urban design and sustainable transportation domains. Smaller cities, particularly in Northern Europe, excel in environmental quality, with better air quality and lower LUHI effects. Green space accessibility, however, declines in smaller cities, probably because of poor accessibility via walking or cycling routes despite high surrounding greenness. No city scored more than 6·8 on HUDI, indicating room for improvement across Europe. A clear east–west gradient persists, with western cities—especially in the UK, Spain, and Sweden—ranking highest (5·35–6·80), whereas eastern cities, notably in Romania, Bulgaria, and Poland, score low (2·92–4·74). Even top-performing cities (ie, Stockholm, Pamplona, and Amsterdam) show intra-city variability, underscoring the value of high-resolution data for addressing urban equity. These findings emphasise the role of city size and consideration of local city context in shaping urban design, transport, environment, and health outcomes.

HUDI is a dynamic tool, not a fixed ranking, offering cities open-data insights on urban health. By clustering cities by size, it enables comparisons, knowledge, and best practice sharing. Combined with local city data and the grid-cell level granular insights, it helps policy makers to identify priorities and integrate improvements into urban planning and management. Below, we outline recommendations for healthier, more sustainable cities.

The correlation between HUDI and its indicators (appendix p 43) highlights the need to balance urban development with environmental quality. HUDI helps identify targeted strategies for improvement. In urban design, cities can enhance health and sustainability by promoting mid-rise (5–6 storey) developments,[35,44] smaller block sizes and increased connectivity,[67] and mixed-use zoning with permeable surfaces.[32] Sustainable transportation can be improved through complete streets with protected bike lanes and well-connected pedestrian networks,[19] low-traffic neighbourhoods, traffic calming and tactical transport planning,[68,69] and accessible and quality public and active transport. [19] Environmental quality can benefit from low emission zones,[69] congestion charging, green walls, urban heat sensors, cool roofs, and green corridors with native species.[31,73] To improve green space accessibility, cities can convert vacant lots into pocket parks, connect green areas via corridors and create linear parks,[70,71] and implement green space impact fees and maintenance programmes,[73] ensuring equitable, active mobility-friendly accessibility.

The strength of this study lies in its extensive data analysis, integrating open data and open-source methods to assess urban design, sustainable transportation, environmental quality, and green space accessibility across 917 European cities of all sizes at a high spatial resolution. This approach enables detailed intracity and intercity comparisons, supports replication and long-term monitoring, and allows cities to adapt HUDI to their contexts by integrating local data. Rather than definitely ranking cities, HUDI provides insights for benchmarking progress toward health and sustainability. By refining local indicators and considering specific challenges and context, cities can develop tailored interventions. Although it is designed for Europe, HUDI's framework can be adapted to other cities worldwide with adjusted threshold levels.

Despite its strengths, HUDI has limitations. A key challenge is the variability in data quality and availability across cities, particularly from open sources such as OSM. As a user-generated dataset, OSM lacks standardised protocols, affecting data accuracy and coverage. Consequently, we avoided using OSM for health-related points of interest such as access to food markets or hospitals in this first HUDI version. However, OSM data on land use (eg, green space), roads, and public transport is more reliable and was used for the sustainable transportation indicators, although we assigned them a lower weight (0·5) in the HUDI construct to account for data uncertainty. Additionally, owing to data limitations, we excluded other important urban health indicators such as socioeconomic factors, transportation modal share, CO_2 emissions, environmental noise, and other social and health-related data, which were often not available or spatially distributed.

Several methodological considerations need to be addressed. First, HUDI uses thresholds for 13 indicators, although the strength of epidemiological evidence varies. Some indicators, such as $PM_{2·5}$ and NO_2, have robust, evidence-based WHO-led thresholds,[38] whereas others, such as opportunity to walk and cycle, need further evidence support. Establishment of optimal thresholds for urban design indicators is less straightforward. For example, compactness and mid-rise development thresholds were set by analysing top and bottom-performing cities within each cluster. For opportunity to walk and cycle, we adopted more ambitious policy targets. Indicators such as optimal dwelling density, permeability, and surrounding greenness rely on established thresholds with epidemiological backing. However, some of these indicators would benefit from clearer guidance on the appropriate spatial scale—city, neighbourhood, or grid cell level.

Despite its limitations, this work offers great value and novelty. HUDI is a first attempt to systematically organise health-relevant urban development indicators by use of open, large-scale city data for almost 1000 European cities of different sizes at high resolution. By consolidating threshold values, we provide a clearer framework for their application and interpretation, bridging fragmented data sources and helping urban planners, policy makers, and researchers to identify benchmarks for healthier, more sustainable cities.

Further research is needed to refine HUDI and integrate additional indicators excluded owing to data limitations. A key value of HUDI is its ability to highlight data gaps and encourage cities to improve data collection and access. We envision continued development of HUDI as better open, spatial datasets become available, allowing for the inclusion of more urban health and sustainability indicators. We urge the research community and urban sectors to support these efforts, making data, code and documentation accessible on GitHub[21] and Zenodo[22] to improve HUDI and use it as a tool for tracking cities' urban health progress.

By making HUDI widely accessible, we aim to promote its use, encourage better open-data practices, and strengthen local stakeholders' capacity to support evidence-based and equitable urban health policies. We hope local governments will use and adapt HUDI to set tailored targets and guidelines, especially for smaller cities for which evidence is lacking, helping to foster healthier, more sustainable urban planning and providing a solid framework for monitoring progress.

We call for urgent action to build healthy, sustainable cities for all by improving how we measure and guide urban development. We urge the UN, WHO, and EU to provide city-size-specific guidance and thresholds, and governments at all levels to collect open data, address data gaps, and allocate resources to improve data quality. These steps will promote inclusive, data-driven urban policies that enhance health and sustainability for all city residents.

Contributors

FM and MN conceptualised the study idea. FM worked on the study design. MC worked on data collection. FM did the data analysis. FM, NM, SK, EPB, TI, AB, CD, and MN contributed to data interpretation and selection of indicators. AB and RS provided the green spaces accessibility data. KdH contributed to developing the ELAPSE models and provided input on air pollution exposure estimations. TCC calculated the canopy urban heat island intensity. FM wrote the manuscript. FM, TI, SK, EPB, and MC accessed and verified the data. All authors reviewed the manuscript and provided feedback on the study design, data analysis, and interpretation of results. FM, NM, and CD revised the manuscript after extensive reviewer comments. NM finalised the revisions and did final editing. All authors were responsible for the decision to submit the manuscript for publication.

Declaration of interests

We declare no competing interests.

Data sharing

All collected data are routinely gathered and contain no personal information. The data, code, and documentation are fully accessible and easily adaptable for use with local datasets through our GitHub[21] and Zenodo[22] repositories. Map data copyrighted by OpenStreetMap contributors are available.

For more on **map data** see https://www.openstreetmap.org

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Editorial note

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