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ARTICLE

When Green Percentage Misleads: Population-Adjusted Stress and Leverage of Urban Green Connectivity in Seven European Cities

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Abstract

Green-area comparisons based solely on percentage cover, patch count, and aggregated connectivity may understate the stress on green systems caused by their high population pressure, limited resident-level supply, fine-grained grain, concentration of connectivity, and water shortage in dry climates. For the current comparison, the Population adjusted Connectivity Stress and Leverage (PaCSL) is calculated for the cities of Almada, Antwerp, Lisbon, Paris, Poznan, Tartu, and Zurich. PaCSL includes five normalized stress indices: population pressure, supply of green areas per 1000 residents, UGA fine-grained morphology, dominance of large or highly connected patches, and climate-induced water constraints. A distinct leverage factor is calculated as the product of the connectivity intensity and the percentage of green area cover, thus allowing to separate stressed systems from those with high consolidation potential. As the comparison demonstrates, the green percentage measure is an insufficient criterion for evaluating green-network condition in cities. For instance, Paris and Lisbon both have 16% green areas, yet in Paris there is a much smaller share of green area per 1000 inhabitants (0.80 ha) compared to Lisbon where this figure stands at 2.49 ha per 1000. Paris has the largest PaCS stress index (0.989) with its maximum population pressure, maximum green supply scarcity, near-maximum UGA grain stress, maximum dominance, and moderate water constraint. The second highest score belongs to Lisbon (0.522) primarily due to small amount of green space per 1000 residents and severe water constraint. The third position, with PaCSL scores of 0.377 and 0.350 respectively, is shared by Almada and Tartu; however, the two have vastly differing leverage values of 0.835 and 0.018. Zurich has the largest leverage score (1.000) corresponding to 30% green coverage and 292.90 connectivity units per hectare.

Keywords: urban green areas; green infrastructure; landscape connectivity; PaCSL; population-adjusted green supply; patch dominance; aridity; European cities

1. Introduction

Green infrastructure is an essential element in the provision of biodiversity, temperature regulation, rainwater retention, recreation and other aspects that promote the well-being of urban populations [1, 7, 8, 12, 22]. Green percentage gives no information about the performance of green infrastructure. Parks, forests, cemeteries, riparian buffers, allotments, institutional lands, gardens and green corridors can vary in area, location, connectivity,

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accessibility and management. As a result, a city may have a medium or even high green percentage and still have relatively few hectares of green land available for its residents, especially in the case of high population densities. On the contrary, another city having a lower percentage green area may face relatively low pressures due to fewer residents who rely on hectares of green land per capita.

According to the studies in landscape ecology, the spatial arrangement determines the performance of any habitat due to such factors as patch size, isolation, edge effect, permeability and connectivity [6, 10, 20, 21]. The urban environment amplifies this effect, because buildings, streets, railways, higher temperatures and management systems transform the functioning of green spaces [14, 17]. While a large park or woodland may include a larger part of connectivity, smaller green patches may provide opportunities for local cooling, everyday contact with greenery and acting as stepping stones. Thus, the same number of patches may present very different ecological and social situations depending on UGA grain, resident demand and connectivity.

Several advances have been made recently in connectivity research, including methods such as habitat-availability indices, proximity analyses, graph metrics, circuit-theory simulations and landscape pattern analysis [15, 18, 19]. Such studies give insights about whether the patches can be expected to function as parts of connectivity or not. However, a city also needs to be aware of whether such connectivity is widespread or concentrated at a few major anchors. High total connectivity may co-exist with dominance, and a network of many small UGAs may generate a low level of leverage if those green patches do not generate significant contributions to connectivity. Thus, resident-level green supply, UGA grain, dominance and water constraints should all be taken into account.

Urban greenspace research warns against the use of simple comparison of green area sizes. Assessment of ecosystem services takes into account such criteria as supply, demand, trade-offs and distribution [4, 8, 16]. Environmental justice studies prove that new additions of green areas increase well-being and liveability, but raise questions concerning access and distribution [24]. Studies dedicated to climate change issues show that vegetation reduces heat exposure, but this is possible only if there are enough trees, evapotranspiration, local climate and sufficient water [5, 11, 13, 25]. Thus, a calculation of connectivity in cities should combine physical structure, demographic pressures and climatic constraints.

Stress and leverage are separated in PaCSL. Stress represents the combined influence of population density pressure, green supply scarcity, UGA grain pressure, structural dominance and water scarcity. Leverage represents the combined effect of connectivity intensity and percentage green area. This distinction allows one to differentiate between cases when a city has a high stress and a high leverage and when a city faces the same level of stress, but with low leverage. In the first case, it makes sense to protect major green anchors and reinforce them, while in the latter case, new connective elements are required.

The following study is dedicated to the examination of seven cities in Europe representing different urban and climatic conditions. The selected cities are Almada, Antwerp, Lisbon, Paris, Poznan, Tartu and Zurich. They differ in size, population density, percentage green area, UGA density, mean UGA size, aridity index, sampled patch size, total connectivity, connectivity intensity and dominance ratio. The values provided by Aleixo et al. [2] for cities and patches are used to calculate PaCSL for cities. This analysis aims to determine whether population-adjusted supply, UGA grain, dominance, water constraint and leverage allow differentiation of cities based on equal green percentage and total connectivity.

2. Materials and analytical procedure

2.1. City variables

Seven cities cover the variety of climates from Mediterranean to Continental and Urban environments. Municipal areas range from 38.8 km^2 in Tartu to 256.3 km^2 in Poznan. Population density varies between 2088 inhabitants km^{-2} in Poznan and 20,238 inhabitants km^{-2} in Paris. Percentage green area ranges from 11% in Antwerp to 30% in Zurich. Such discrepancies reveal that green percentages do not reflect urban green stress, since equal percentages might mean quite different levels of population-adjusted green supply.

Population-adjusted green supply was estimated as follows: population was calculated using municipal area and population density, and green areas were divided by population. UGA density was calculated as the number of green patches per square kilometre. Mean UGA size equals green area divided by the number of green patches. These parameters do not substitute neighbourhoods' accessibility, but correct the main city-level distortion: green areas serve different numbers of residents.

The values in Table 1 reveal three contrasts that shape the rest of the analysis. Paris and Lisbon share the same green percentage, yet Paris has the lowest green supply because its density is more than three times that of Lisbon. Poznan has neither the highest green percentage nor the lowest aridity index, but it has the highest resident-level green supply because of its larger area and lower density. Zurich has the highest green percentage and the highest aridity index, which gives it a structurally favourable and less water-constrained starting condition. These differences justify a calculation that treats green percentage, resident-level supply, and aridity as separate evidence rather than as interchangeable measures of urban greenness.

Table 1. City variables used in PaCSL.

City	Area (km^2)	Density (hab. km^{-2})	Green (%)	Green supply (ha/1000 residents)	UGA density (km^{-2})	Mean UGA size (ha)	Aridity index
Almada	70.0	3728	23	6.06	1.86	12.15	0.71
Antwerp	224.2	2438	11	4.46	0.50	21.95	1.09
Lisbon	86.9	6429	16	2.49	1.96	8.19	0.73
Paris	104.9	20238	16	0.80	4.00	4.06	0.77
Poznan	256.3	2088	19	9.10	1.66	11.46	0.70
Tartu	38.8	2240	12	5.51	3.30	3.74	1.03
Zurich	92.0	4867	30	6.20	2.14	14.08	1.48

Figure 1. City pressure profiles.

The composite profile in Figure 1 gives a visual entry point for the seven-city comparison. The strongest contrast is between the dense, low-supply Paris condition and the greener Zurich profile. Almada and Lisbon show

Mediterranean water limitation, while Poznan has high resident-level supply despite a lower green percentage than Zurich. This visual comparison supports the central analytical premise: urban green stress is a multi-variable condition, not a property of green percentage alone.

2.2. Resident supply, green-area grain, and connectivity variables

Population and green supply were calculated as:

$$Pop_i = \frac{A_i}{100}\rho_i, \tag{1}$$

$$GS_i = \frac{1000G_i}{Pop_i}, \tag{2}$$

where Pop_i is estimated population, A_i is city area in hectares, ρ_i is population density, G_i is total green area in hectares, and GS_i is green supply in hectares per 1000 residents. UGA density and mean UGA size were calculated as:

$$UD_i = \frac{100n_i}{A_i}, \tag{3}$$

$$\overline{G}_i = \frac{G_i}{n_i}, \tag{4}$$

where n_i is the number of UGAs. The two variables describe the grain of the green system. High UGA density combined with small mean UGA size indicates a fine-grained structure. Such a structure may support local access but may also increase dependence on small patches and connective streetscapes.

Patch-size inequality was expressed through the coefficient of variation:

$$CVA_i = \frac{\sigma_i^a}{\overline{a}_i}, \tag{5}$$

where σ_i^a is the standard deviation of sampled patch size and $\overline{a}_i$ is the mean sampled patch size. Connectivity concentration was expressed through the dominance ratio:

$$CDR_i = \frac{K_i^{max}}{K_i^{med}}, \tag{6}$$

where K_i^{max} is maximum patch connectivity and K_i^{med} is median patch connectivity. A high value indicates that the most connected patch is far more influential than a typical sampled patch. This is useful because a city can have high total connectivity while being structurally vulnerable if much of that connectivity is concentrated in a few sites.

These patch values show that total connectivity and connectivity intensity can lead to different interpretations. Paris has the highest total connectivity, 51,271.32, but its connectivity intensity is only 73.96 because the sampled patch area is very large. Zurich has lower total connectivity than Paris, 38,282.03, but the highest connectivity intensity, 292.90. Almada and Lisbon also generate high connectivity per sampled hectare. Tartu has many UGAs at the city level but the lowest sampled connectivity intensity, 16.64, indicating that fine grain alone does not create strong leverage.

Table 2. Patch connectivity values.

City	Patches (n)	Sampled area (ha)	Mean patch size (ha)	Size CV	Total conn.	Conn. intensity	Dominance ratio
Almada	16	100.04	6.25	1.71	25,103.36	250.93	2166.29
Antwerp	36	334.39	9.29	2.59	13,026.80	38.96	75.35
Lisbon	36	181.56	5.04	1.36	43,339.28	238.71	537.07
Paris	28	693.24	24.76	4.46	51,271.32	73.96	6598.60
Poznan	36	252.37	7.01	2.56	23,718.58	93.98	782.28
Tartu	31	165.04	5.32	1.42	2,746.40	16.64	41.74
Zurich	36	130.70	3.63	1.43	38,282.03	292.90	632.29

2.3. Stress and leverage computation

Each component was normalized to the interval $0, 1$. Positive normalization was used when higher values indicate greater stress:

$$Nx_i = \frac{x_i - \min x}{\max x - \min x}. \tag{7}$$

Inverse normalization was used when lower values indicate greater stress:

$$N^{-}x_i = \frac{\max x - x_i}{\max x - \min x}. \tag{8}$$

Population pressure, green-supply scarcity, UGA-grain stress, structural dominance, and water constraint were calculated as:

$$P_i = N\rho_i, \tag{9}$$

$$S_i = N^{-}GS_i, \tag{10}$$

$$F_i = \frac{1}{2}NUD_i \ \frac{1}{2}N^{-}\overline{G}_i, \tag{11}$$

$$D_i = \frac{1}{2}NCVA_i \ \frac{1}{2}N\log_{10}CDR_i, \tag{12}$$

$$W_i = N^{-}AI_i, \tag{13}$$

where AI_i is the aridity index. Lower aridity-index values are treated as stronger water-related constraint. The final stress value was calculated as:

$$PaCS_i = 0.30P_i \ 0.25S_i \ 0.20F_i \ 0.15D_i \ 0.10W_i. \tag{14}$$

The weighting gives the strongest influence to population pressure and green-supply scarcity because the calculation evaluates urban green connectivity as an ecological and public asset. UGA grain, structural dominance, and water constraint remain explicit because they change the kind of action needed. A city with a high F_i value needs different green-network treatment from a city with a high D_i value, even if the final stress score is similar.

Connectivity intensity was calculated as:

$$KI_i = \frac{K_i^{tot}}{A_i^s}, \tag{15}$$

where K_i^{tot} is total sampled connectivity and A_i^s is total sampled patch area. The leverage value was calculated as:

$$L_i = 0.65N \log 1 \;\; KI_i \;\; 0.35NQ_i, \tag{16}$$

with Q_i being percentage green area. Leverage gets higher weight as it demonstrates how many connections the network generates per one sampled hectare. Percentage green area stays in the model because consolidation potential depends also on the volume of green lands. The leverage value does not substitute stress; it helps to evaluate whether an already existing green system is able to become more effective through reinforcement.

3. Results

3.1. Residents' level of green supply

There was a significant difference between percentage green area and residents' level of green supply within the seven cities analyzed. Paris and Lisbon have the same percentage of green areas equal to 16%. However, Paris provides just 0.80 ha of green per 1000 inhabitants, while Lisbon offers 2.49 ha per 1000 inhabitants. Such situation is explained by population density: there are 20,238 inhabitants per km^{-2} in Paris and 6429 inhabitants per km^{-2} in Lisbon. This comparison illustrates why green percentage alone cannot reveal urban green stress.

Poznan provides maximum value of residents' level of green supply with 9.10 ha per 1000 inhabitants despite of low percentage of green area that equals to 19%. Zurich takes the first place by percentage green area with 30%. Nevertheless, it shows high value of residents' level of green supply with 6.20 ha per 1000 inhabitants. Similar value is obtained for Almada, with 6.06 ha per 1000 inhabitants. At the same time, the values for Tartu and Antwerp are lower and equal to 5.51 and 4.46 respectively.

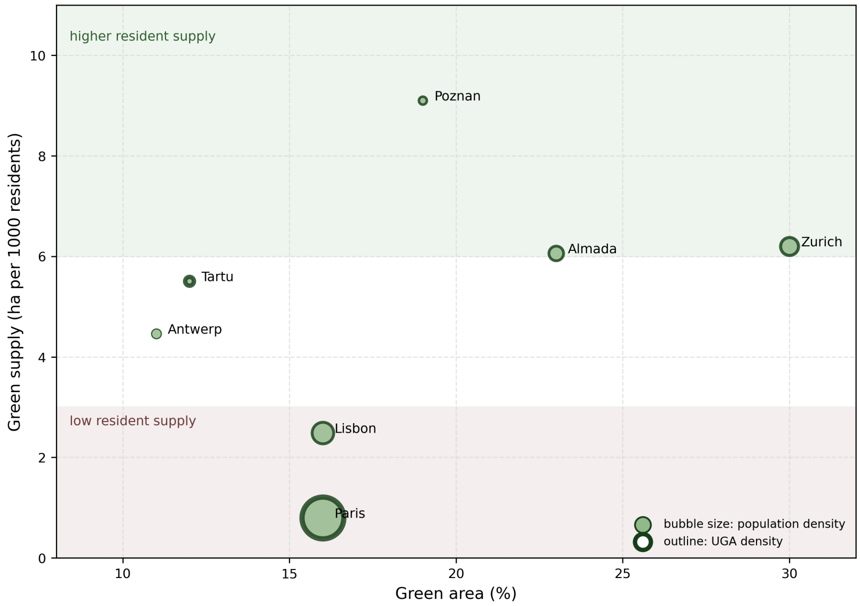


Figure 2. Green percentage and resident supply.

Figure 2 presents the supply plot, in which Paris and Lisbon are juxtaposed on the same x-axis point. This plot clarifies why green supply per resident is relevant in addition to the green percentage area. As shown, the cities have similar percentages of green space yet very different y-coordinates. Moreover, Paris appears to have the smallest bubble, confirming its status as not only having little green area but also being the densest of all seven cities.

3.2. Green-area grain

In terms of UGA grain, Paris is the most finely grained city, with the largest UGA density, 4.00 UGAs km^{-2}, and the smallest mean UGA size, 4.06 ha. At the other extreme, Tartu displays fine grain in terms of density, 3.30 UGAs km^{-2}, but has the smallest mean UGA size, 3.74 ha. Both of these cities represent a certain planning challenge, because Paris has a very dense fine-grain green area but is subject to high population pressure, whereas Tartu has the weakest leverage.

Antwerp displays coarse grain by combining the fewest number of green areas per area, 0.50 UGAs km^{-2}, and the largest mean UGA size, 21.95 ha. Zurich and Almada have relatively coarse grains, as well as higher UGA densities, namely, 0.83 UGAs km^{-2} and 1.36 UGAs km^{-2}, respectively. Zurich and Almada are also characterized by relatively large mean UGA size, 14.08 ha and 12.15 ha, respectively. Lisbon and Poznan are positioned mid-way in terms of the studied parameters; they display 1.96 and 1.66 UGAs km^{-2} in the first case and 8.19 and 11.46 ha, in the second case.

In the plot in Figure 3, one can see that many green units do not necessarily imply good conditions. Thus, Paris and Tartu are positioned in the dense part of the chart, but they differ significantly in social conditions, because Paris suffers from high social and structural pressure, whereas Tartu is poorly connected within its sample frame. On the contrary, Antwerp is characterized by large UGAs, but has relatively low numbers of those UGAs per square kilometre. Zurich has an intermediate position on the graph, which contributes to a relatively high leverage.

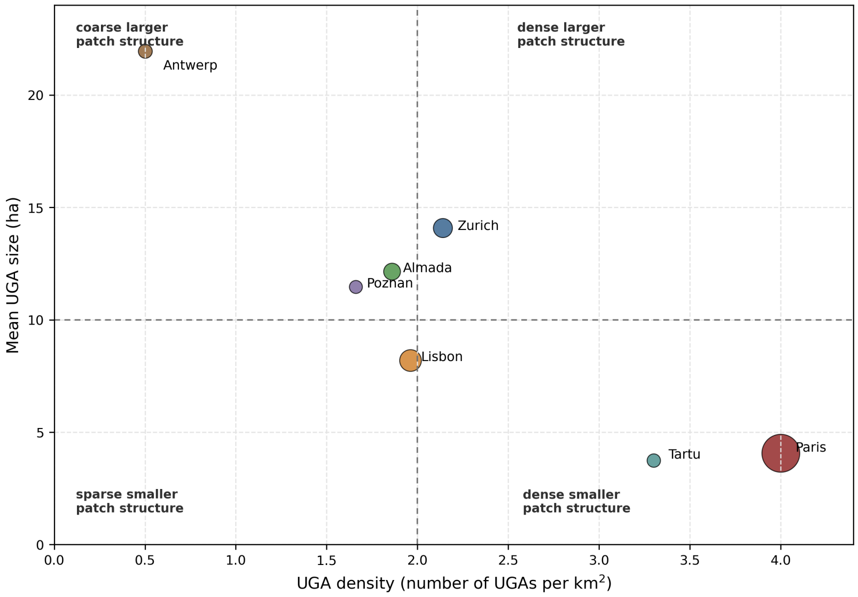


Figure 3. UGA density and mean size.

3.3. Connectivity concentration

It can be seen from the patch-level analysis that high aggregate connectivity does not mean that connectivity is spread throughout the city. Paris has the largest average sampled patch size, 693.24 ha, and the largest total connectivity, 51,271.32. Besides, Paris has the largest patch-size coefficient of variation, 4.46, and the highest dominance ratio, 6598.60. As such, the maximum-connectivity patch is thousands of times more connected than the average one, which is indicative of significant anchor dependence. Paris cannot be considered a well-connected city from the planning standpoint; it is characterized by a highly concentrated connectivity.

Almada is characterized by a relatively high dominance ratio, 2166.29, in spite of having only 16 sampled patches, which also makes it structurally vulnerable to connectivity loss. However, a relatively high connectivity intensity, 250.93, suggests that this city has strong connective assets, taking into account the water constraint. Lisbon has high connectivity intensity, 238.71, but the lowest dominance ratio, 537.07, indicating that connectivity is less concentrated. Zurich has a high connectivity intensity, 292.90, with a moderate dominance ratio of 632.29, which indicates a conservation-friendly interpretation of this city. Tartu has the lowest values of total connectivity and connectivity intensity, whereas Antwerp shows low connectivity intensity with large mean city-level UGA size.

On the plot in Figure 4, one can distinguish between median-to-maximum connectivity span and the variance in patch size. As seen, Paris displays the most extreme values in both categories, which makes this city particularly sensitive to the loss of connective assets. In turn, Almada displays high concentration but relatively high connectivity intensity, which gives this feature a special meaning because the dominant patches can be seen as climate-sensitive anchors. Finally, Tartu and Antwerp display relatively low dominance spans but have poor leverage, which cannot contribute to the interpretation of these cities as robust green networks.

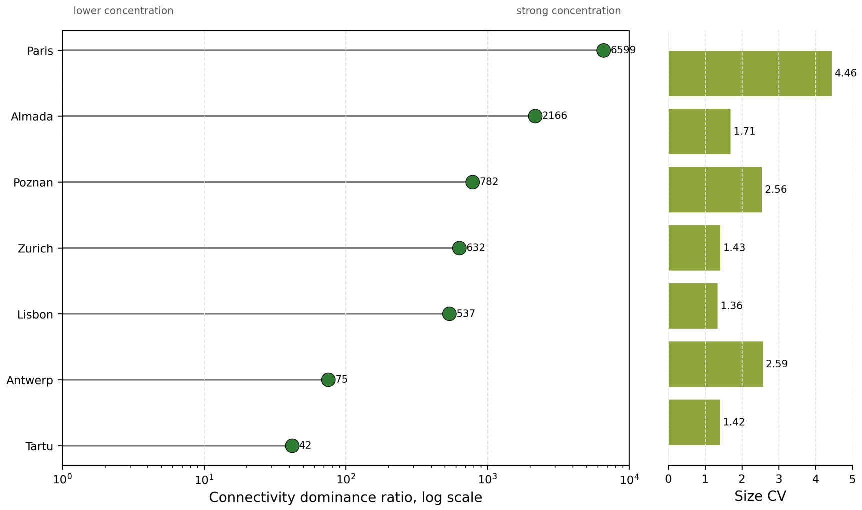


Figure 4. Connectivity dominance and size variation.

3.4. Stress component profiles

Component values reveal reasons for each city's final stress scores. Paris demonstrates high population pressure (maximum value), scarcity (maximum value), near-maximal grain (0.840), high dominance (0.814), and water-constraint components (0.382). Thus, the final score is 0.989 and is not attributable to one component value. Lisbon demonstrates the highest scarcity (0.796) and water constraint (0.962) among other cities but lower dominance (0.252). Consequently, its stress score is 0.522. Third in this regard is Almada with 0.377, which results from water constraint (0.987), moderate grain (0.463), and dominance (0.447). Next is Tartu with 0.350 stress score; however, its components indicate a completely different situation: population pressure is close to zero (0.008), the dominance component is extremely low (0.009), whereas the grain component dominates (0.899). Finally, Zurich, Poznan, and Antwerp have relatively low scores, but they have distinct weaknesses. For instance, Zurich demonstrates moderate grain and dominance but lacks water constraints in the normalized comparison. In turn, Poznan displays the maximum water-constraint component. Finally, Antwerp is characterized by scarcity of 0.560 and low leverage.

From the component fingerprints in Figure 5, one can see that the cities may have similar stress scores owing to different components' contribution. This is demonstrated by Almada and Tartu, which have similar scores but extremely different fingerprints: Almada demonstrates high water constraints and leverage, while Tartu has fine-grained and poorly leveraged green network. Therefore, the same final scores cannot inform planning decisions about cities.

The stress and leverage numbers in Table 3 demonstrate that ranking alone is not enough to make decisions. Although Paris is the most stressed city, its leverage of 0.426 demonstrates that it also retains some connective capacity. The fact that Lisbon does not experience the same level of stress as Paris but has greater leverage implies that climate change-related repair will benefit from what is already there. In turn, Almada and Tartu are used to demonstrate that leverage needs to be evaluated separately – both cities have similar stress values, but while Almada possesses high consolidation capacity, Tartu lacks it. The leverage of Zurich is equal to 1.000, indicating that it requires conservation efforts rather than urgent repair.

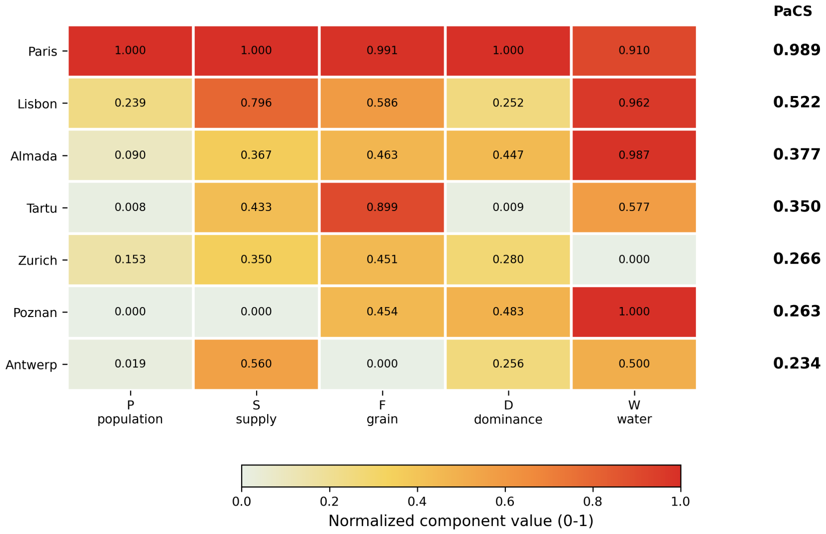


Figure 5. PaCSL component fingerprints.

Table 3. Stress and leverage values.

City	P	S	F	D	W	Stress	Leverage	Principal interpretation
Paris	1.000	1.000	0.991	1.000	0.910	0.989	0.426	Extreme demand and concentrated connectivity.
Lisbon	0.239	0.796	0.586	0.252	0.962	0.522	0.695	Supply scarcity under water constraint.
Almada	0.090	0.367	0.463	0.447	0.987	0.377	0.835	Strong leverage under climatic pressure.
Tartu	0.008	0.433	0.899	0.009	0.577	0.350	0.018	Fine grain with weak leverage.
Zurich	0.153	0.350	0.451	0.280	0.000	0.266	1.000	High leverage and strong green percentage.
Poznan	0.000	0.000	0.454	0.483	1.000	0.263	0.536	High supply with water constraint.
Antwerp	0.019	0.560	0.000	0.256	0.500	0.234	0.189	Low stress but limited leverage.

3.5. Stress and leverage classes

The strongest decision-making tool in our case study is stress and leverage together. High stress means that there is an element of danger; high leverage means that there is some kind of capacity. Paris becomes a key point for action since it has high stress levels with leverage being not too high to cope with pressure. Lisbon is an example of high stress and better repair capacity. Intermediate stress and high leverage define Almada as a targeted reinforcement case. On the other hand, intermediate stress with very low leverage points out to the need for adding new connective elements before consolidating the network.

Almada and Tartu stand out for having the largest differences. In Almada, there is sufficient room for reinforcement within the existing green system, whereas in Tartu, the task involves strengthening small UGA clusters. Zurich stands out with the strongest potential for consolidation, while Antwerp proves that a very low stress level does not preclude low leverage.

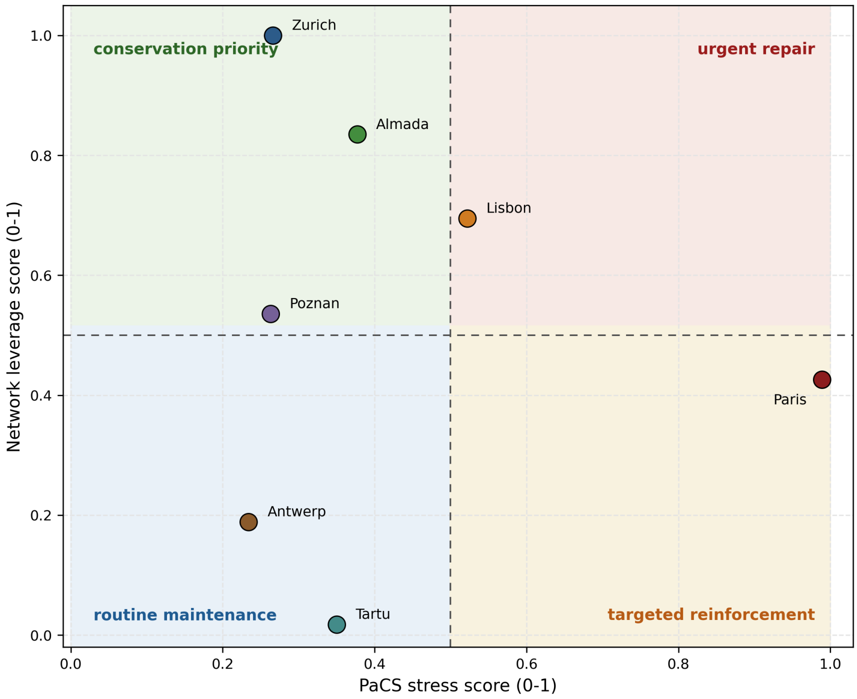


Figure 6. Stress-leverage plane.

4. Discussion

4.1. Density makes green percentage insufficient

The examples of seven cities show that the percentage of green area is necessary but insufficient for assessing green space needs. Although the green percentages are equal for Paris and Lisbon, their resident-level supply differs by more than a factor of three. This finding is consistent with other studies on urban green space showing that benefits of the vegetation depend on factors such as spatial pattern, accessibility, demand, and context in addition to surface area [12, 16, 24]. Therefore, percentage green area should be understood as supply, not as sufficiency.

The Paris example highlights the significance of density for green network assessment. Despite 16% of green coverage, Paris is densely populated and must ensure sufficient green supply per resident. Thus, even though the percentage is relatively high, Paris has less than 0.80 ha of green per 1000 residents. Such low green supply per capita requires that green planning include measures like infill, neighbourhood greening, street tree continuity, provision of small public spaces, schoolyard greening, courtyard greening, protection of all green fragments.

Poznan and Zurich provide another example of the difference in meaning between green percentage and per-capita green space supply. While Zurich has the highest percentage green area, Poznan has the highest supply per capita. However, these numbers mean different things. High percentage in Zurich indicates good ecological connectivity and good leverage because connectivity intensity is also high. High per-capita supply in Poznan suggests a small demographic burden on green area, although the maximum water-constraint value implies that green abundance must be managed in response to drought. Therefore, percentage green area and per-capita supply should be interpreted with regard to climatic stress.

4.2. Dominance reveals structural vulnerability

One of the key features of the modified PaCSL method is connectivity dominance. Indeed, without including this element, it might be difficult to interpret a high value of total connectivity as anything else than resilience. However, Paris has the highest total connectivity but the highest ratio of patch to median connectivity as well. With a dominance ratio of 6598.60, Paris appears to have a strong dependency on few connective anchors. Destruction, deterioration, and restriction of access to those anchors could have an adverse effect on the whole urban green network.

It is common for an urban environment to contain some legacy green areas (parks, riparian corridors, cemeteries, wooded hillsides, etc.). While these are valuable green elements of the city, dependence on them is associated with risks that are discussed in the landscape ecology literature [15, 18, 20]. PaCSL makes these dependencies visible through the connectivity dominance indicator. Therefore, a city characterized by high dominance and high connectivity must focus on protecting its green anchors and decreasing dependency.

While dominance might seem to be a purely negative attribute, sometimes it might actually be advantageous for urban planning. Almada has a high dominance ratio, but its leverage is also high. This means that in Almada, dominant patches play the role of climate-critical anchor sites that can be reinforced and planted to be drought-adapted. Meanwhile, Zurich's dominance and leverage are both moderate, implying that its dominant elements form a favourable green network structure. In turn, although Tartu and Antwerp have low dominance, their leverage value is also low, indicating poor network structure.

4.3. Water constraint defines dry-city strategy

A high normalized water-constraint score suggests a specific approach to green network planning. All three cities – Lisbon, Almada, and Poznan – have the highest values. However, their specific combinations of green components suggest different strategies. Since Lisbon has low resident-level green supply, priority must be given to shaded infill and creation of new corridors in addition to increased local green supply. In Almada, there is no shortage in supply and high leverage. Therefore, priority should be given to reinforcement of already-existing connectivity. Lastly, Poznan has high water-constraint score and the highest supply per capita, suggesting that priority must be given to maintenance and making drought resilient existing green spaces.

The findings of this paper support these conclusions regarding prioritizing urban green networks. Although urban greenery helps reduce heat-related hazards, this effect is mediated by the type of climate, green cover structure, evapotranspiration, planting design, and water availability [5, 11, 13, 25]. Hence, in the Mediterranean region, additional vegetation must take into account water availability, selection of drought-tolerant species, water retention in the soil, and canopy persistence during the drought. In this sense, the water-constraint component is crucial as it avoids underestimating a dry city.

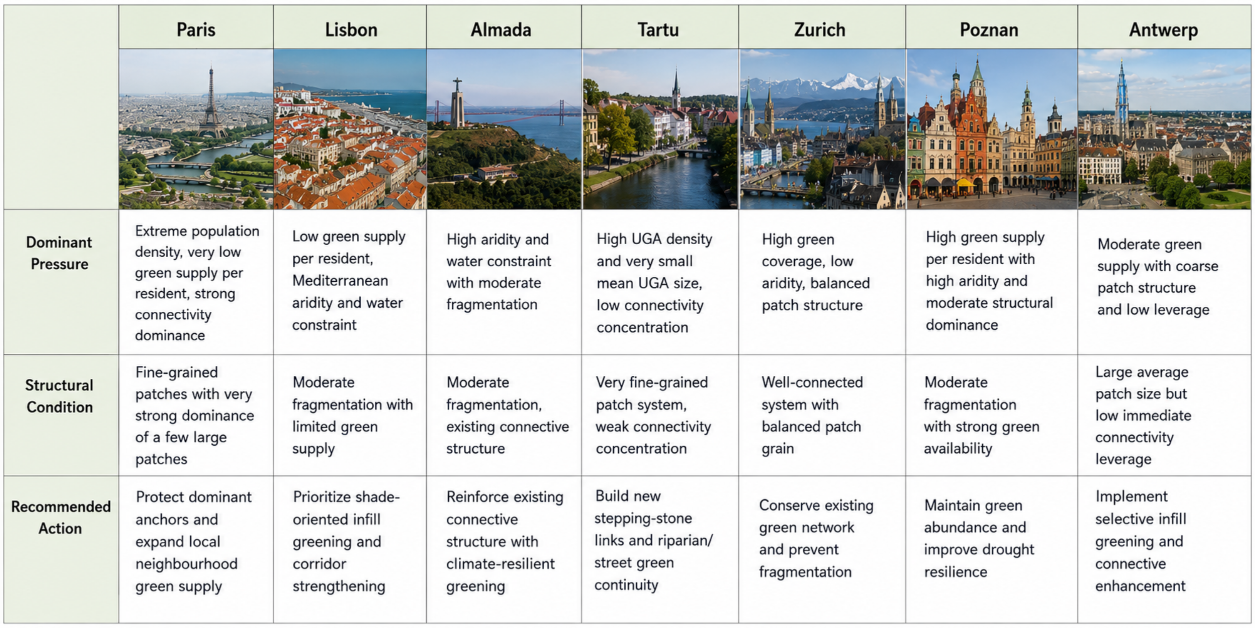
Zurich serves as another illustrative example of the need for normalizing water constraint. According to the method, Zurich has a water-constraint score of 0.000. The reason for this lies in the fact that this city has the highest aridity index in the seven-city data set, rather than high water availability. Therefore, water constraint becomes less significant for its overall stress than grain and dominance components.

4.4. Planning priority by city

It is worth noting that what matters in this method is the combined component profile along with leverage. Ranking each city from high to low stress yields little information about their green planning. For instance, Paris must focus on anchoring, expansion of supply, and diversification of connectivity. Similarly, Lisbon must increase local green supply and develop climate-conscious green corridors. The same applies to Almada with regard to reinforcement of connectivity, while in Tartu, the task involves creating a new connective network. In contrast, in Zurich, priority should be given to conservation of the strong green system, while in Poznan, it is drought-resilient maintenance of abundant green spaces. Finally, in Antwerp, green planning should focus on selective infill.

A diagram in Figure 7 shows green network plans based on the interpretation of green components without any modifications. Instead of ranking cities in stress, the method identifies what kind of measures are required in each case to improve the green network.

In addition to preventing incorrect comparison of cities in terms of stress, the differentiation between stress and leverage makes it possible to avoid wrong generalizations about priority action. A high-stress system with high leverage may benefit from smaller-scale interventions compared to a system with a low level of leverage. On the other hand, high stress and low leverage indicate that large-scale land acquisition and urban greening may be needed. Finally, high stress and high leverage indicate that fragmentation of green connectivity may decrease future resilience, while in cities with low stress and low leverage, this may not be a problem now but can arise later.



	Paris	Lisbon	Almada	Tartu	Zurich	Poznan	Antwerp
Dominant Pressure	Extreme population density, very low green supply per resident, strong connectivity dominance	Low green supply per resident, Mediterranean aridity and water constraint	High aridity and water constraint with moderate fragmentation	High UGA density and very small mean UGA size, low connectivity concentration	High green coverage, low aridity, balanced patch structure	High green supply per resident with high aridity and moderate structural dominance	Moderate green supply with coarse patch structure and low leverage
Structural Condition	Fine-grained patches with very strong dominance of a few large patches	Moderate fragmentation with limited green supply	Moderate fragmentation, existing connective structure	Very fine-grained patch system, weak connectivity concentration	Well-connected system with balanced patch grain	Moderate fragmentation with strong green availability	Large average patch size but low immediate connectivity leverage
Recommended Action	Protect dominant anchors and expand local neighbourhood green supply	Prioritize shade-oriented infill greening and corridor strengthening	Reinforce existing connective structure with climate-resilient greening	Build new stepping-stone links and riparian/ street green continuity	Conserve existing green network and prevent fragmentation	Maintain green abundance and improve drought resilience	Implement selective infill greening and connective enhancement

Figure 7. City-specific green planning.

4.5. Interpretation summary

Each of the seven cities can be described based on a combination of dominant components. Paris is dominated by population pressure, scarcity, fine grain, and dominance. Lisbon is dominated by scarcity and water constraint, while Almada has the greatest water constraint and the highest leverage. Tartu has fine-grained and poorly leveraged green network. Zurich is the city with maximum leverage. Poznan has high resident-level green supply and a high degree of water constraint. And finally, Antwerp stands out because of low stress but weak leverage.

Figure 8. Green network priorities in seven cities.

As shown in the synthesis chart, similar values of one component do not imply similar prioritization when all other variables differ. Rather than yielding a universal list of cities based on their stress level, the analysis yields reasons for green planning action, levels of consolidation potential, and prioritized measures in each of the cities.

4.6. Calculation limitations

This study relies on the modified version of PaCSL that allows calculating green network stress level using city and patch values. However, it does not specify exact locations for connectivity enhancement, assesses population needs and green spaces separately, does not consider obstacles, habitat quality, specific connectivity needs of animal species, or barriers (highways and railway lines). These questions require further investigation in a particular city, using more local methods and datasets.

Stress value obtained with this modified method depends on weights, which are selected differently depending on application. This study emphasizes population pressure and green-supply scarcity. Therefore, population pressure gets a relatively high weight of 0.25, while the rest of variables have equal weights. Biodiversity-focused analysis could place greater emphasis on dominance and patch continuity by giving greater weight to the last two variables. Likewise, a heat-health-focused analysis should place greater emphasis on canopy cover, surface temperature, and water constraint.

Despite this method's reliance on component value calculation, it allows checking the cause-and-effect relationship for obtaining a certain stress score. Water constraint, for instance, is a simplified indicator that is subject to various influencing factors. Vegetation performance depends on soil depth, imperviousness of surface, groundwater access, irrigation regime, species traits, canopy cover, drought frequency, and maintenance. Nevertheless, it still serves as an indicative metric for urban green network planning.

5. Conclusion

The results clearly show that percentage green area, patch count, and total connectivity do not suffice for assessing green network priorities of cities. The modified PaCSL calculation combines population pressure, resident-level supply, UGA grain, structural dominance, water constraint, and leverage, distinguishing cities that would be undistinguishable otherwise. Moreover, this combination explains differences between green network priorities in cities with equal green percentage, why high total connectivity does not imply resilience, and how similar stress values should be interpreted.

Paris emerges as a case that deserves special attention because of its low resident-level green supply and relatively low green percentage despite relatively high stress value of 0.989. That is, Paris faces high population pressure, supply scarcity, fine-grained UGA structure, dominance, and water constraint. Priority in this case includes protection of connective anchors and expansion of local green supply. Similarly, high stress value of 0.522 in Lisbon is due to high water constraint and resident-level green supply. Priority here should involve shaded infill and corridor reinforcement under water constraint.

Almada and Tartu illustrate the importance of reporting leverage separately from stress because these two cities have similar stress values of 0.377 and 0.350, respectively. However, high leverage of Almada (0.835) indicates that there is sufficient opportunity to reinforce green network, while low leverage of Tartu (0.018) indicates that connectivity improvement is necessary due to its fine grain. Meanwhile, low-stress Zurich, with maximum leverage and stress value of 0.174, must preserve its strong green network. Poznan, despite high water constraint, requires drought-resilient management of abundant green supply. Finally, Antwerp must undertake selective infill.

To sum up, the analysis clearly shows that green connectivity priority depends on the combination of stress and leverage, rather than on percentage green area. Paris has relatively high percentage, but low supply per capita and high stress (0.989), indicating urgent redistributive greening. Similar percentage and supply per capita but higher supply suggest supply expansion under water constraint in Lisbon with a stress value of 0.522. Low stress in Almada (0.377) indicates targeted reinforcement under water constraint. Fine-grained UGA structure with low connectivity suggests new connectivity in Tartu (stress: 0.350). Low stress, high leverage, and stress value of 0.174 indicate conservation priority. High supply and water constraint indicate drought-sensitive management in Poznan (stress: 0.281).

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