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Adaptation and energy saving through urban green spaces in Climate Action Plans: the experiences of 20 global cities

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Abstract

With the increasingly severe impacts of climate change in urban areas, city administrations worldwide are increasingly adopting Climate Action Plans. Among the most popular interventions are those on greening and energy-saving, offering cross-cutting benefits across mitigation and adaptation goals. However, the choice of these interventions is often out of context, as they are not informed by the specific urban characteristics of each city. The present study seeks to fill this gap by investigating the CAP of 20 global cities and identifying the critical relationships between their distinctive urban characteristics and their greening and energy-saving strategies. The final aim of the research is to develop an evidence-based foundation for a decision-support tool that assists decision-makers in selecting greening and energy-efficiency measures tailored to their city's unique context. To achieve this, a three-step methodology is applied to twenty leading cities from the C40 network. The proposed method integrates multivariate statistical analysis to cluster cities by urban features and topic modeling to classify greening and energy-saving actions within their CAPs. A subsequent comparative analysis links city clusters to action classes, revealing the strengths and weaknesses of different approaches across contexts. The results lay the groundwork for a tool to guide the design of more effective, context-specific climate interventions that enhance urban resilience.

Keywords
Climate change; Greening actions; Energy saving

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1. Introduction

Urban areas currently host more than half of the total global population. Besides that, metropolitan areas have made a significant contribution to the world’s total greenhouse gas emissions, with their share exceeding 70% along with consuming almost 75% of power resources (UN-Habitat, 2024). The increase in the frequency and intensity of climate change effects, such as floods, heat waves, and rising sea levels, contributes to cities’ high vulnerability. However, at the same time, urban areas' vast and well-connected infrastructure, capable institutions, and creative thinking enable them to be at the forefront of building climate change resilience (Batty, 2016; Scorza & Santopietro, 2024).

Over the last couple of years, climate change has, on the one hand, been a key part of mitigation efforts and, on the other, an essential part of urban climate strategies. More local governments are implementing Climate Action Plans (CAPs) whose purpose is not only to reduce emissions but also to prepare cities for the inevitable consequences of climate change (Stone et al., 2012; Aboagye & Sharifi, 2024).

Among the several strategies proposed in the CAPs, urban greening and energy efficiency stand out as the most important. The existing studies often treat these issues as if they were completely separate (Wamsler et al., 2013; Reinwald et al., 2024). On the contrary, there is a scarcity of research that examines how urban areas combine the two in a single action. A few comparative analyses have examined the relationship between green infrastructure and energy-saving measures, and the impact of city-specific characteristics on these ties. Because CAPs are customized to local conditions, the research aims to investigate how different city types integrate green space development with energy-saving measures into their plans. It will also analyze the extent to which climate, physical, and demographic characteristics influence these combined strategies. Our innovation in the empirical investigation of certain urban profiles tied to the combination of greening and energy-saving strategies within CAPs is very particular in the context of our research. Previous comparative studies have focused mainly on theoretical relationships, whereas intervention analyses have not systematically connected the different urban typologies. This research aims at empirically investigating the direct relationship between the city’s climatic, physical and socio-demographic characteristics and the way in which the city’s CAP integrates and articulates coherently green space development and energy-saving measures.

Hence, this study seems to be a step forward in urban resilience planning, as it relates urban attributes to the specific actions in CAPs. The idea is to analyze the overall worldwide scenarios through the urban context of different cities, while, at the same time, investigating the linkage between the physical characteristics of the cities and the way they are going about the integration of greening and energy-efficient efforts, thus encouraging different adaptation pathways. The proposed methodology consists of three parts: (1) categorizing the twenty cities selected for this study according to the characteristics they possess; (2) distinguishing the major adaptation themes through topic modeling; and (3) demonstrating how urban profiles are associated with integrated strategies through result comparison. The conclusions drawn from this investigation will provide the foundation for the development of a supportive tool for policymakers to use when they are preparing practical, context-sensitive adaptation measures.

The following section of the paper presents the authors' view and the reflections on how to better present the research questions by analyzing the most critical changes in the literature on urban greening and energy-saving measures taken in the context of climate adaptation. This will soon be accompanied by an in-depth explanation of the methodological framework, the presentation of the findings from the 20 case studies, and, lastly, a discussion of the implications for future urban adaptation policies.

2. Literature review

Cities should consider the adoption of climate resiliency through risk-reducing ways and strengthening the urban systems' ability to cope with extreme events. The scientific community has unanimously stated that the enhancement of urban greenery and transition to clean energy are the major factors among the two that lead to this change. The subsection elaborates the roles of these two measures in detail and also their overall contribution to climate change adaptation in cities (Sanfilippo et al., 2025). The tools of urban resilience are urban greening initiatives that establish green spaces, city forests, parks, and green roofs. The physical and biological effects of applying nature-based solutions in an urban setting are identical to those of nature; the urban area cools, more water is stored, which reduces runoff, and even the existing plants are given a boost, which lowers the energy needed for lighting and cooling. Since it also meets the needs of environmental justice, social inclusion, and public health, the notion that green infrastructure may have multiple uses has led to its recognition as an essential element of urban sustainability. According to studies, a building's need for air cooling can be reduced by roughly 30% when trees are planted, which results in significant energy savings. Additionally, if parks and gardens were planted, urban areas would emit significantly less carbon dioxide, be quieter, and have healthier residents. These areas are therefore crucial to strategies that combine adaptation and mitigation. Energy conservation measures are typically referred to as part of the mitigation strategy for climate change; however, their contribution to the adaptation process is not as well understood.

The above-mentioned policies increase the energy systems' resistance to climate change-related challenges and disasters. Global warming can impact the electrical networks negatively, for instance, by causing heat waves and heavy storms. Thus, outages due to overloaded grids can occur leaving people without power and at risk from life's thread, i.e., heat. Among the energy-saving measures are better building insulation, energy-efficient appliances, and advanced grid technologies, which all together contribute to the reduction of energy demand and consequently the prevention of disruptions. Turning to a small-scale solar PVs and battery storage solutions helps one to be less dependent on the grid and thus continue to have access to the essential services such as refrigeration and medical equipment during outages These days, most frameworks for adapting cities are putting energy efficiency and green infrastructure in the same category as strategies that work together. According to research, green infrastructure has many interconnections and increases a city's resilience in addition to saving energy. Green roofs, for instance, reduce the amount of energy required for heating and cooling by acting as a natural barrier to heat transfer. Planting trees along streets with care can also provide shade, which will further cool buildings and save energy (Canessa et al , 2025; Martinelli, 2025).

Increasing the biodiversity footprint within urban environment can help reduce the heat island effect and save a significant amount of energy. In actuality, the advantages of the previously created synergy are still far from being realised. The scholarly community is in favour of more comprehensive and mutually beneficial approaches to urban climate change mitigation. However, little research has been done to demonstrate how these ideas are actually implemented in city climate action plans. Whether the connection between energy efficiency and urban greening is a purposeful goal or just a consequence is still unknown.

There is still a significant disconnect between theory and practice, even with the compelling evidence for these synergies. However, proponents of integrated and co-beneficial approaches request more research on how municipalities integrate these into formal plans. Moreover, it is still unknown how economic, climatic, and physical factors affect the uptake of these tactics in various cities. The methodological framework developed to address these research concerns is described in the section that follows.

3. Materials and methods

In order to empirically determine the relationship between the urban characteristics of global cities and the energy-saving and greening initiatives that constitute significant interventions in their Climate Action Plans (CAPs), this study employs a multi-phase methodological framework. This framework's central assumption is that the success of such interventions primarily rests on how well they mesh with the particular context of a city and how they relate to other urban sectors.

n the first phase, the procedure for choosing a representative sample of twenty international cities was discussed. To include a range of cities and allow for thorough analysis at the same time, three main criteria were applied during the selection process. At least two cities were chosen from each continent to represent a range of population sizes, densities, and morphologies, as well as the socioeconomic profiles that go along with them. This was done in order to prioritise geographic diversity, which could have an effect on the creation and implementation of climate strategies. Second, the cities were chosen based on the different climate hazards they are likely to encounter, including extreme heat, sea level rise, and heavy precipitation. Third, all of the chosen cities have formally committed to climate adaptation and mitigation through resource allocation, policymaking, and active participation in global climate initiatives by joining the C40 Climate Leadership Network. The methodology described here was used to create a sample with a range of urban and environmental contexts. From the more dispersed Auckland to the heavily populated Mumbai and Istanbul, the chosen cities displayed a broad range of population densities. Additionally, their climate risks varied: Rotterdam and New Orleans face serious threats from sea level rise, while Milan and Ahmedabad face extreme heat. Severe storms frequently hit Mumbai and New York. Every city has a big impact on the economy and culture of the country and the world.

After sample selection, the methodology proceeded via two main analytical streams running in parallel. The first analytical stream was directed at cities classification according to urban characteristics impacting climate response (Reckien et al., 2025). Subsequently, the collection and cleaning of data for a range of variables denoting four domains that are frequently mentioned in literature: climatic, physical, socio-anthropogenic, and environmental was done. The climatic domain encompassed, for example, annual maximum temperature and cooling degree days as indicators which are closely related to cooling energy demand (Santamouris et al., 2015). In the physical domain, factors like total green area, and altitude range, were considered for assessment, and the socio-anthropological domain represented the demographic variables one of which was the proportion of old age people living in that area. The environmental domain encompassed data regarding CO_2 emissions which is a major contributor to global warming (Environmental Protection Agency, 2023; Özkan et al., 2025). A full list of the variables is presented in Tab.1.

The available data were collected from open-source databases and subjected to a strict cleansing guaranteeing its trustworthiness. For the purpose of data set stability, correlation coefficients were computed and those variables highly correlated were rejected (Asuero et al., 2006). After the Bartlett test of sphericity confirmed the dataset's suitability, latent structures within dataset were discovered using Principal Component Analysis (PCA). Based on the PCA results, cities with comparable features were grouped using hierarchical clustering. This identified trends that may influence their CAPs' selection and integration of greening and energy-saving measures. A hierarchical clustering method based on PCA results was used to group cities with similar characteristics in order to identify underlying factors that may influence the selection and blending of greening and energy-saving measures in the cities' climate action plans (CAPs).

The second line of analysis consisted of a comprehensive review of the climate initiatives covered by the CAPs (Fu, 2024). A database created to facilitate analysis contained all of the interventions in the selected cities' plans that were collected and put together as a whole. The actions were analysed using topic modelling and Natural Language Processing (NLP) techniques in compliance with the methodology proposed by Breton-Carbonneau et al. (2025). The well-known standard NLP preprocessing methods used to guarantee the accuracy and consistency of the classification included tokenisation, stop-word removal, and lemmatisation. A unique dictionary was created by combining terms from related academic literature with intervention descriptions from CAPs in order to further increase the interpretive reliability (Jin et al., 2023). Each action marked by the algorithm was then attributed not only to one main thematic area but also to one more sector demonstrating possible co-benefits or cross-sectoral linkages.

A key part of the methodology was a comparative analysis that aimed to link the city characteristics identified earlier to the corresponding greening and energy-saving actions. To achieve this, the city clusters obtained in the first analytical phase were compared with the climate actions taken from each city's CAP. In order to detect relationships between urban characteristics and the actions taken with regard to greening and energy efficiency measures, this process used a number of charts and diagrams that were intended to visually depict the development of patterns and the similarities and differences between cities.

System	Variable	Description	References
Climatic	Average annual temperature	Annual average of temperatures recorded in a year	IPCC, 2022; Ferranti et al., 2023
	Maximum annual temperature	Maximum temperature recorded from October 2023 to September 2024	
	Cooling degree days	Summation over a year of the days with average temperature in excess of thermal comfort temperature (25°C).	IPCC, 2022;
	The difference between the average temperature of urban and rural areas	Annual average of the difference in average temperature between urban and surrounding rural areas	IPCC, Isinkaralar et al., 2024,
	Maximum wind speed	Annual maximum wind speed	
	Average wind speed	Annual average wind speed	
	Maximum monthly average of mm of precipitation	Maximum value of the average monthly rainfall over one year	Ramli et al., 2023
	Average number of days per month when a rain event occurred	Annual average of the number of days per month with a rainfall event	
	Standard deviation of the number of days per month in which a rainfall event occurred	Annual standard deviation of the number of days per month with a rainfall event	
Physical	Range of elevation	Difference between maximum and minimum elevation	Ahmadi et al., 2022
	Linear extension of the coast	Linear measure of any coastal frontage	Wu, 2021
	Altitude	Weighted average altitude with respect to the territorial extension of the city, compared to the average sea level	Ahmadi et al., 2022
	Green space extension	Percentage of extension of total green spaces relative to the extension of the entire city	Ferranti et al., 2023; Sun et al., 2022
	Percentage of water coverage	Percentage of extension of water bodies relative to the extension of the entire city	Sun et al., 2022
	Extension of the urban area	Extension of the surface of the urbanized area	
	Building Coverage Ratio	Percentage of land occupied by buildings relative to the extension of the entire city	
Socio-anthropic	Population	Total number of residents	Ramli et al., 2023; Sun et al., 2022
	Population density	Ratio between population and urban area extension	Sun et al., 2022
	Percentage of the elderly population	Percentage of elderly inhabitants (over age 65) out of the total population	Ramli et al., 2023
	Percentage of population below the poverty line	Percentage of population living below the poverty threshold, defined at the national or local level	Leichenko et al., 2014; Ramli et al., 2023
	Unemployment rate	The percentage of the population that is unemployed	Leichenko et al., 2014; Sun et al. 2022
	Average monthly salary	Average monthly salary (net after tax) in euros	

System	Variable	Description	References
Environmental	Percentage of renewable energy used	Percentage of energy consumed from renewable sources relative to total energy consumed per year	IPCC, 2022; Olabi and Abdelkareem, 2022
	Percentage of energy consumed in the transport sector	Percentage of total energy consumed for transport relative to total energy consumed per year	Champman 2007
	Percentage reduction in CO2 emissions over the past ten years	Percentage reduction in CO_2 emissions over the past 10 years	IPCC, 2022; Hansen et al.,2013
	Percentage of use of sustainable modes of transport	Percentage of journeys made using sustainable modes of transport, i.e., walking, cycling, public transport	IPCC, 2022; Mashayekh et al., 2012

Tab.1 Urban system characteristics affecting cities' response to extreme events, according to the literature review

The comparative analysis identified the different types of cities that were more or less supportive of the adoption of specific interventions, while also emphasising that certain urban characteristics, such as density, climate exposure, or socioeconomic structure, had an impact on the type and intensity of the measures implemented. It also made it possible to see how these cities' combined efforts strengthened their overall climate adaptation plans. In summary, this stage illustrated the interaction between urban characteristics and natural solutions, as well as the possible effectiveness of energy-saving techniques.

The selection of energy-saving measures and nature-based solutions, as well as their integration and possible efficacy within urban resilience planning frameworks, are all determined by urban characteristics, it was also made clear.

4. Results

The results of the aforementioned methodology are presented in this section. To achieve the intended results, a number of analytical techniques were used, such as autocorrelation analysis to further refine the dataset. Maximum annual temperature (MaxTY) and maximum annual precipitation intensity (MaxPrecipIntensity), two highly correlated variables, were eliminated as a result of the process; as a result, the resulting analyses were more reliable and understandable.

Following data refinement, a p-value of less than 0.0005 was obtained from Bartlett's test of sphericity, indicating that the dataset was appropriate for Principal Component Analysis (PCA). With the first five principal components collectively accounting for over 70% of the variance, the PCA results were statistically significant. Each principal component highlighted a specific underlying dimension of the urban dataset, thus providing an understanding of the interaction between climatic, physical, and socioeconomic factors.

Principal Component 1 (PC1) combined the socioeconomic variables of average monthly salary and the percentage of the elderly population with several climatic indicators, including temperature and precipitation patterns. This element demonstrated the complex relationship between emissions, climate vulnerability, and cooling demand. However, the study did reveal an unexpected finding: there was a positive correlation between high emissions and high vulnerability to climate threats. This implies that cities with higher greenhouse gas emissions were also more vulnerable to climate-related risks.

Because it integrated variables related to age and income distribution with physical characteristics like elevation above sea level, Principal Component 2 (PC2) was essentially a representation of the socioeconomic dynamics. Elevation was included because it has a direct bearing on assessing the effects of climate change and communities' capacity to put solutions into place. Principal Component 3 (PC3) linked indicators of sustainable mobility with physical factors such as land use and population density. The component's green space denoting variables (GreenSup) had a moderately positive weight (0.239), suggesting that the existence of green space, specific physical urban features, and sustainable mobility patterns are positively correlated.

The complex relationship between the intensification of urbanisation and environmental sustainability is captured by Principal Component 4 (PC4), which was formed under the influence of both physical and social features, especially population density. The GreenSup component's more significant positive weight (0.336) indicates that green space is crucial for reducing the negative environmental effects of densely populated urban development areas.

Principal Component 5 (PC5) emphasised the environmental issues caused by urban sprawl and was based solely on CO_2 emissions and the total area of the city. Again, GreenSup's weight was moderate at the positive level (0.273), indicating that green spaces were generally linked to patterns of less intense urbanisation.PCA thus put forth a strong statistical basis for not only the identification of the hidden structure of the data but also for the determining of the variables that had the greatest influence in the first five principal components. The next steps were guided by these results which led to a clustering analysis that classified the 20 sampled cities into distinctive groups based on their urban characteristics similarities. The mean values of the standardized variables were then calculated for each cluster to show the deviations from the overall sample mean. This, in turn, enabled the traits and patterns across the clusters to be identified.

The distinctive characteristics of the five resulting city clusters are summarized below, supported by the standardized deviations presented in Tab.2. In the table, color coding denotes the magnitude and direction of deviation from the mean: red cells indicate positive deviations, whereas blue cells indicate negative deviations.

Cluster	**1**	**2**	**3**	**4**	**5**
Av Ty [%]	0,50	-20,45	13,50	6,21	0,24
Max TY [%]	5,12	-45,05	45,76	1,35	-7,18
CDD [%]	-5,57	-99,36	182,73	-2,03	-75,77
MaxWindSpeed [%]	-25,24	-57,47	46,00	49,22	-12,51
AvWindSpeed [%]	13,19	-12,65	-6,48	-7,41	13,35
MaxPrecipIntensity [%]	-23,06	28,08	89,75	-47,91	-46,87
AvPrecipFreq [%]	0,88	5,47	-5,77	-7,14	6,56
DevStdPrecFreq [%]	-9,17	-18,12	119,71	-57,40	-35,02
HeightRange [%]	191,49	-69,80	-38,77	-49,46	-33,45
CoastlineLength [%]	175,66	-100,00	-52,88	-76,36	53,59
Altitude [%]	21,30	-12,45	-11,54	66,21	-63,52
GreenSup [%]	30,41	14,67	14,67	-36,76	-22,99
UrbanSup [%]	-53,26	314,87	-82,73	-92,79	-86,08
Population [%]	20,20	75,37	39,22	-65,59	-69,20
Pdensity [%]	-24,69	-88,18	112,82	41,83	-41,78
POver65 [%]	-10,84	-11,20	-60,98	65,36	17,67
AvMonSalary [%]	9,35	-58,28	-74,60	-5,39	128,92
CO_2Em/pp [%]	-14,47	2,86	-70,14	-42,32	124,06
PercetSustMob [%]	-37,59	58,36	-46,29	28,77	-3,24

Tab.2 Percentage deviations from sample mean, by cluster

Cluster 1, made up of Cape Town, Auckland, Istanbul, Seoul, Rio de Janeiro, and Los Angeles, was marked by coastal areas (CoastlineLength: +176%), significant altitude differences (HeightRange: +191%), and huge parks and gardens (GreenSup: +30%). On the contrary, as the data showed, these cities also preferred to use the less Polluting transportation modes only to a certain extent (PercetSustMob: -38%).

The Cluster 2 was represented by nothing other than Wuhan, which was a regular outlier, in the whole arrangement. The city displayed the highest percentage of sustainable transport users (PercetSustMob: +58%) and the lowest population density of a city this size (Pdensity: -88%) as indicated in Tab.2.

Cluster 3, which included Accra, Ahmedabad, and Mumbai, was singled out for factors like these, but the cities were still very far apart. Thus, urban climates produced very cool regions with high cooling demand (CDD: +183%), huge climate variability (DevStdPrecFreq: +120%), and very little CO_2 emissions per inhabitant (CO2Em/pp: -70%). The cluster was characterized as well by population density which was double that of most urban areas in growing countries (Pdensity: +113%) and as well by a very young population where 65 years was the cut-off (POver65: -61%).

Cluster 4, which included Barcelona, Buenos Aires, Milan and Paris, was characterized by its consistent annual precipitation patterns (DevStdPrecFreq: -57%), medium-high population density (Pdensity: +42%) and a good percentage of sustainable mobility (PercetSustMob: +29%).Countries belonging to this cluster seemed to have taken the right way to cope with climate change through the application of measures favoring the development of urban areas sustainably, therefore, they were less prone to suffer from it.

Cluster 5, consisting of cities like San Francisco, New Orleans, New York, Copenhagen, Sydney, and Rotterdam, was characterized by temperate climates with minor cooling demand (CDD: -76%), but at the same time it had high carbon dioxide emissions (CO2Em/pp: +124%) and high average incomes (AvMonSalary: +129%). Additionally, some of these cities had low geographical height (Altitude: -64%) which made them more susceptible to climate risks like flooding from rising sea levels due to their location.

The table below (Tab.3) presents a summary of each city cluster's principal urban characteristics.

Cluster	Cities	Feature (% difference from mean)
1	Cape Town, Auckland, Istanbul, Seoul, Rio de Janeiro, Los Angeles	– Coastal cities (+176% length of coastline) – High elevation range (+192%)
2	Wuhan	– Outlier for urban surface (+300%)
3	Ahmedabad, Accra, Mumbai	– High cooling demand (+183% CDD) – High population density (+113%)
4	Parigi, Barcellona, Milano, Buenos Aires	– High percentage of elderly population (+176%) – Stable climate (-2% CDD) – High use of sustainable mobility (+29%)
5	San Francisco, New Orleans, New York, Copenhagen, Sydney, Rotterdam	– High average annual income (+129% average monthly salary) – High CO_2 emissions (124 %)

Tab.3 Summary of characteristics defining each cluster, showing how selected variables deviate from the sample mean (in percentage terms)

The city clustering was followed by an analysis of the energy-saving and climate adaptation measures described in the municipality's climate action plans (CAPs). Similar to the methodological approach that Jin et al. (2023) validated, a categorization system for actions was developed using topic modeling and computational language processing. Urban Planning and Policy, Mobility and Transportation, Waste and Resource Management, Climate Emergencies, Community Engagement and Communication, Sustainable Economy and Finance, Responsible Consumption, and Monitoring and Evaluation were the ten primary areas of focus that were separated out by this classification framework.

According to the study, the two framework sectors that are most important for adaptation and energy conservation are "Energy and Buildings" and "Green Spaces and Biodiversity". The Energy and Buildings sector encompasses strategic initiatives aimed at increasing the energy efficiency of the current building stock and transitioning to renewable energy sources. Energy retrofitting (Auckland), the development of renewable energy infrastructure (Los Angeles' 100% renewable plan), and advanced building standards (Paris's zero-net-energy buildings, Los Angeles' required cool roofs) were some of the specific measures that directly addressed the energy supply and demand. At the same time, the Green Spaces and Biodiversity sector reduced energy consumption indirectly and gave the city services of urban thermal regulation as the main ones. Examples of these green infrastructure implementations include vegetated roofs (Barcelona, Mumbai), urban forestry initiatives (Milan, Los Angeles), blue-green ecological corridors (Rotterdam), and the ingenious use of parks for heat mitigation (Ahmedabad). Since many interventions fell into more than one category, each action was given both a primary sector and a secondary "co-benefit" sector.

Determining whether these urban features and the implementation of climate action strategies were related was the final step in the analysis. Combining an action classification (mainly the Green Spaces and Energy and Buildings categories) with a city clustering outcome led to a thorough understanding of cities' strategic responses to climate change. A range of graphic techniques were used to map out these intricate relationships. A pie chart was used to show the proportion of all actions in each sector. A Sankey diagram, on the other hand, demonstrated the links and synergies between the Energy and Buildings sector and the Green Space and Biodiversity sector. The following section goes into further detail about the visualisations.

5. Discussion

The comparison of city clusters and their climate strategies shows different patterns between city features and CAPs' strategic priorities. Among the climate interventions identified, Fig.3 illustrates the 10 areas in which all of the planned climate interventions are contained within the CAPs. The area of Green Space and Biodiversity represents 9% of all planned climate interventions; Energy and Buildings represent 13%. The figure also includes 2 additional bar graphs illustrating the planned climate intervention distribution by cluster in each of these 2 areas. Through the combination of the city characteristics (Tab.3) and the planned climate action distributions (Fig.3 & Tab.4), we can identify how city characteristics influence planned climate action. A key finding of the study was the prevalence of greening actions in certain city type. Together, Clusters 1 and 4 account for approximately 70% of all planned climate actions in the area of Green Space and Biodiversity. These findings were not coincidental. Cities in Cluster 1 (e.g., Cape Town, Los Angeles), characterized by an abundance of coastline (+176%) and established green infrastructure, are using their unique natural resources as a central component of their adaptation strategy. Similarly, cities in Cluster 4 (Paris, Barcelona, etc.) have shown a robust and efficient governance structure that permits significant investments in energy and greening projects. These cities are distinguished by stable climates and higher rates of adoption of sustainable modes of transportation (+29%). On the other hand, because of the tremendous strains imposed by their high population density (+113%) and high demand for cooling (+183%), Cluster 3 cities (such as Mumbai and Accra) have less money available to invest in the areas of green space and biodiversity. Even though Cluster 3 cities have focused less of their efforts on these areas, it seems that they are using the little money they do have to deal with these problems while attending to other, more pressing infrastructure requirements.

The outlier status and distinct planning context of Cluster 2 (Wuhan) are reflected in its actions. The distribution of actions for the Energy and Buildings sector shows a similar but different pattern. Clusters 1 (37%) and 4 (31%) are the main players in this case as well, accounting for more than two-thirds of all energy-saving projects. Here, Clusters 1 and 4 are in charge, making up roughly 37% and 31% of all energy-related projects, respectively.

Cluster 1's dominance is likely due to its economic and technological strength. These are the cities that can afford to test out large-scale efficiency projects, such as retrofitting government buildings or investing in smart grid systems. Cluster 4, on the other hand, seems to be more impacted by governance than by financial resources. Its intentional policies have been impacted by its long-term energy strategy and regulations, which call for significant retrofits and stringent performance standards.

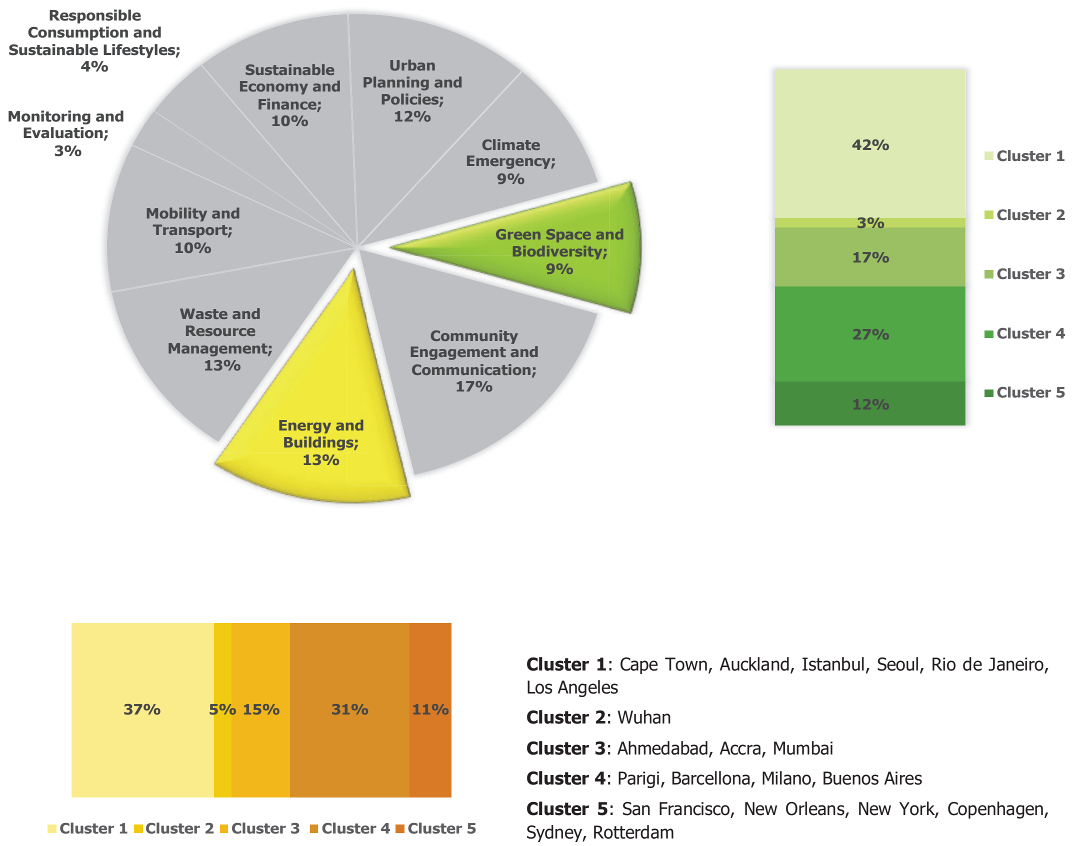
Using a more systematic approach, Cluster 3 makes up around 15% of the total. Their projects appear to be driven more by necessity than by ambition: cities caught between the urgent need for cooling and the competing demands of development.

Cities in Cluster 5 are rich, high-emission, but surprisingly energy-efficient (using only 11%). Although it may seem counterintuitive, it appears to be a logical decision because these cities are usually coastal and prioritise flood prevention, storm protection, and sea level rise, threats that reduce the amount of space available for energy efficiency investments.

All things considered, the pattern implies that a city's urban and economic environment influences not just the kinds of climate actions it takes, but also their relative importance. However, this is only a portion of the story. Finding out where cities behave the most does not show how various behaviours support or contradict one another. In order to investigate that, the analysis mapped sectoral relationships, which are depicted in the Sankey diagram (Fig.4) and indicate how one intervention sector might have a cascading effect on other sectors, such as trash or transportation. The true complexity of urban climate governance starts to emerge in such interdependencies.

Cluster	Cities	Actions in Green Space and Biodiversity	Actions in Energy and Buildings
1	Cape Town, Auckland, Istanbul, Seoul, Rio de Janeiro, Los Angeles	42%	37%
2	Wuhan	3%	5%
3	Ahmedabad, Accra, Mumbai	17%	15%
4	Parigi, Barcellona, Milano, Buenos Aires	27%	31%
5	San Francisco, New Orleans, New York, Copenhagen, Sydney, Rotterdam	12%	11%

Tab.4 Green Space and Biodiversity, Energy, and Buildings actions by cluster



Cluster 1: Cape Town, Auckland, Istanbul, Seoul, Rio de Janeiro, Los Angeles

Cluster 2: Wuhan

Cluster 3: Ahmedabad, Accra, Mumbai

Cluster 4: Parigi, Barcellona, Milano, Buenos Aires

Cluster 5: San Francisco, New Orleans, New York, Copenhagen, Sydney, Rotterdam

Fig.1 The pie chart illustrates the distribution of actions across ten sectors. The two bar charts summarize the distributions of Green Space and Biodiversity, and of Energy and Buildings actions, by cluster

The Sankey diagram (Fig.4) visually maps the flow of influence among different climate action sectors. On the left side, you can see the originating sectors —those planned actions that have the potential to impact Green Space and Biodiversity or Energy and Buildings positively. The diagram's central flow then traces how these originating actions connect to, and influence, the Green Space and Biodiversity sector and the Energy and Buildings sector. Conversely, the right side of the figure shows how actions within Green Space and Biodiversity and Energy and Buildings, in turn, contribute positively to other sectors, indicating resulting co-benefits.

Notable connections are found when the Energy and Buildings domain is examined. Mobility and transportation make up the largest portion, highlighting the intimate relationship between energy use and eco-friendly transportation. This demonstrates a strategic understanding that electrifying public transport requires coordinated efforts with building-centric charging infrastructure and power grid upgrades. Many projects have been proposed within this framework, including the replacement of specialised vehicles and machinery with less polluting alternatives (Barcelona and Los Angeles) and the extension of low-emission transit infrastructure (Wuhan). The second-largest input comes from the Sustainable Economy and Finance sector, underscoring the critical role that financial instruments play in advancing the switch to cleaner energy. For example, Cape Town's local government is investigating the possibility of creating a program that would encourage the use of inexpensive, safe energy sources. Furthermore, as demonstrated in Barcelona, tax-related incentives are employed to encourage the adoption of energy-saving measures. Surprisingly, the direct impacts of green space and biodiversity on the building and energy sectors were negligible and primarily restricted to natural cooling techniques like rooftop vegetation (Barcelona, Milan, and Mumbai). This might point to a large amount of unrealised potential for systematically incorporating green infrastructure into energy strategies at the city level. The primary spillover effects from Energy and Buildings initiatives recurred in terms of outflows to Urban Planning and Policies, indicating that effective energy upgrades have the ability to influence and shape new regulations, resulting in a vicious cycle.

As a result, energy-efficient city planning projects are being carried out, like creating technical guidelines for updated thermal performance standards. These criteria recommend improving the existing structural layers by installing double-glazed windows with low-emission qualities or adding cutting-edge insulation for the walls and roofs, as seen in recent projects developed in Auckland, in order to lessen the cooling load in Mumbai.

A unique network of connections is revealed by an examination of the field of green spaces and biodiversity. The largest inflows were observed in Waste and Resource Management, suggesting a direct correlation between organic waste management and preserving urban green space. To successfully carry out these initiatives, local leaders are directing restoration projects, turning disposal sites into parks, and requiring the expansion of water distribution to populated areas within supply-constrained protected woodland zones. Civic engagement and outreach were also significant factors, emphasising the critical role that collaborative projects play in promoting shared responsibility for urban ecosystems. San Francisco, for example, has tried to incorporate a variety of community viewpoints into ecological climate plans. In a similar vein, Auckland has improved resident involvement in habitat surveillance and bolstered connections to natural environments.

The outflows from this sector demonstrate how adaptable urban vegetation is. Green zones directly promote climate resilience through temperature regulation and carbon sequestration, as evidenced by the main outflow to Climate Response initiatives. New York concentrates on maintaining and restoring urban habitats to increase ecological diversity and human-nature relationships, while Buenos Aires expands accessible parks in key locations to reduce heat stress and enhance physical wellbeing. According to a significant return flow to Community Engagement and Communication, green spaces themselves may serve as catalysts for environmental education and social cohesion, increasing public awareness and support for broader climate goals. For instance, by providing support, direction, and guidance, a program sponsored by Auckland CAP encourages landowners to restore their private properties and plant trees. On the other hand, a network of urban green corridors is being developed with substantial public involvement as part of the Barcelona initiative. The more modest inflows from other sectors, however, demonstrate that the full range of co-benefits from green infrastructure, such as its role in mobility corridors or health and well-being, are still not being fully utilised in current planning. Finally, it is evident that policymakers need to have a firm grasp of urban context in order to effectively address urban climate change. To find the best ways to integrate energy efficiency and green infrastructure—and, most importantly, how to plan for the mutually reinforcing co-benefits that increase resilience, cities must empirically evaluate their unique urban features rather than relying on one-size-fits-all approaches. This strategy guarantees that adaptation efforts are as successful and resource-efficient as possible while enabling customised, successful interventions.

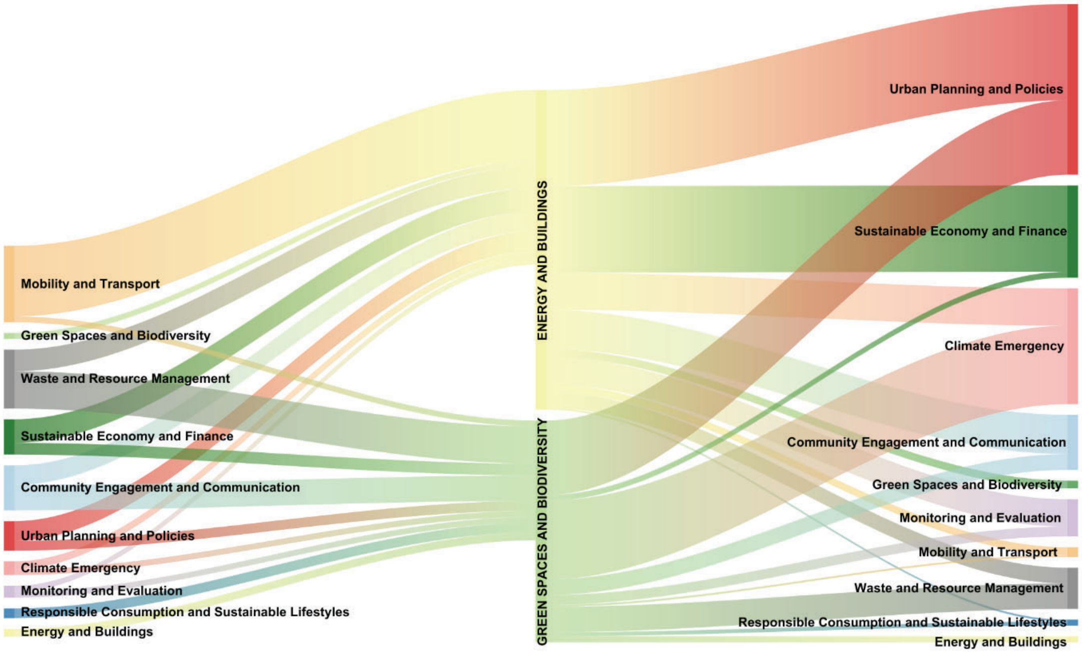


Fig.4 The chart shows, on the left, sectors generating benefits for greening and biodiversity, as well as for energy and building actions. On the right sectors benefiting from greening, biodiversity, energy, and building actions

6. Conclusions

Our study, in our opinion, is a crucial foundation for a research program that aims to develop a digital tool that will help decision-makers create plans of action and strategies to help cities become more resilient to the effects of climate change. This research sought to understand how particular urban characteristics influence the selection of greening and energy interventions, going beyond generally suggested actions, by conducting a systematic analysis of the Climate Action Plans (CAPs) of twenty cities worldwide. Our results are intended to provide empirical data on the current state of urban climate planning and to show not only the positive trends but also the areas where significant improvement is needed.

The major outcome of this study is that the climate action of a city must not be arbitrary but rather would be extremely influenced by its urban characteristics. Our study indicates that the cities under review have opted for a combination of climate actions and interventions that take into account their geographical and socio-economic circumstances, climatic conditions, and environmental characteristics. As an example, cities in Cluster 1 (like Cape Town and Los Angeles) make the most of their long coastlines and natural resources, whereas cities in Cluster 4 (like Paris and Barcelona) take advantage of the existing urban climate governance and the already established sustainable mobility systems to carry out integrated, ambitious actions. On the other hand, cities in Cluster 3 (e.g., Mumbai, Accra) that are vulnerable to climate change face a very different set of measures because of their heavy development pressures and acute vulnerability. This outcome provides empirical evidence for the need of context-sensitive climate planning.

Apart from the influence of context, our second discovery concerns a significant lack of synergy in modern climate planning, particularly between the Energy and Buildings and Green Spaces and Biodiversity sectors. Although they are not yet a significant component of core energy strategies, green spaces are regarded as crucial components of urban resilience. According to the cross-sectoral flow analysis, the relationship between energy efficiency and green infrastructure is primarily restricted to particular applications, such as green roofs. The enormous potential of natural solutions for passive cooling and general energy conservation is overlooked by this. This disparity represents a significant lost chance to create more robust, cohesive, and efficient urban systems, as the literature has also noted (Gargiulo et al., 2021; Gargiulo & Zucaro, 2023).

The goal of the project is to create a new framework for evaluating different cities' climate action plans. The approach provides a better understanding of how local conditions impact climate responses by examining trends across several cities. It concerns how cities respond to adaptation and mitigation challenges associated with their physical characteristics, socioeconomic vulnerabilities, and climate stressors. The goal is to provide policymakers with a useful tool while simultaneously advancing the theory of urban climate governance.

A top-down hanging approach is a hallmark of effective climate planning. Only after a thorough examination of the city's own structure, including its advantages, disadvantages, and limitations, can such mechanisms, like the clusters found in this study, be established.

By acting as global standards, they allow cities to learn from one another and comprehend their place in the larger urban ecology without having to argue over the policies of other cities. The decision-support tool created in this context builds on that exact concept. This tool's main goal is to help cities avoid resource-wasting tactics, take appropriate, context-specific actions, and progressively implement adaptation in meaningful, site-specific ways. In order to help cities incorporate their own efforts into larger climate frameworks, the study also produced an extensive compilation of climate actions by city type. The results will still be favourable despite the limitations, which should be noted. There are still some glaring drawbacks to open data, despite its many benefits, which include greater transparency and easier analysis replication.

Data collection and reporting practices vary by region, and occasionally there is no data at all. It eventually became necessary to eliminate some variables for the purposes of the analysis and to use a proxy to gauge the decrease in CO_2 emissions. In the end, this was a fair compromise, but it brought attention to a problem that often occurs in comparative studies: the uneven quality and availability of urban data. The limitations do not negate the results, even though they draw attention to the areas that require further development. There are limitations to the analytical process itself as well. Although the technique may oversimplify the complex and sometimes contradictory realities of local policymaking, topic modelling assisted in identifying recurrent themes in Climate Action Plans.

The requirement to separate activities into primary and secondary groups creates a division that does not exist in reality because many measures are interdependent. When every action has its own label, people lose sight of the fact that a program that reduces energy use also reduces the number of car trips and changes the way land is used. Analysts need those neat boxes, but the boxes hide how urban climate strategies are interwoven. Nevertheless, there are already several obvious next steps.

The list of cities will grow so that the map covers more places plus the numbers come from the same yardstick. Policy papers detailed stories from single cities and talks with city staff will add words to the numbers. Once the stories sit beside the figures, the picture will show not only what sits in each Climate Action Plan, but also why city leaders choose one path and drop another once politics, rules but also people push back.

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