

A Systematic Review of Climate Action Plans: A Focus on Urban Green Spaces for Adaptation and Energy Saving

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Abstract. Given the rising temperatures and more frequent and intense events typical of the climate crisis, urban areas are increasingly subject to severe effects. In the search for effective adaptation, Climate Action Plans (CAPs) are seen as one of the main strategic approaches, and within these, greening interventions emerge as cross-cutting solutions, achieving goals in both mitigation and adaptation and generating multiple benefits for urban systems.

The research reported in the current contribution is part of a broader project aimed at developing a tool in support of decision-making by policy makers for the development of more resilient cities. The present study systematically analyzes the CAPs of a sample of twenty cities recognized globally for their commitment to climate action. The objective is to identify significant relationships between the adaptation strategies put in place by the different cities and their urban, climatic, physical, social, and environmental characteristics, searching in particular to understand the role of green spaces in mitigating the effects of global warming.

To achieve this objective, a three-step methodology is proposed. In the first step, multivariate statistical analysis is used to identify clusters of cities based on their climatic, physical, social, and environmental characteristics. In the second step, topic modeling techniques are used in the systematic analysis of the classes of adaptation actions contained in the CAPs. Finally, the results of the first two steps are used to conduct a comparative analysis of cities versus classes of actions, revealing the strengths and weaknesses of the measures in the individual CAPs. This knowledge forms the basis for construction the final tool, aimed at supporting decision-makers in selecting effectively contextualized measures for application in urban scenarios.

Keywords: green space · climate action plans · urban characteristics

1 Introduction

More than half of the global population resides in urban areas and cities account for over 80% of global GDP. They serve as strategic nodes for economic activity, governance, and innovation and are central to global systems. With rising temperatures and more frequent

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and intense climatic events, the impacts on cities are thus highly complex and extensive. The risks to urban citizens, infrastructure, and ecosystems are devastatingly profound, however given their role as engines of development and innovation, cities can also lead in implementing actions for climate resilience [1, 2]. Recognizing the climate risks, decision-makers have adopted strategies aiming to mitigate the most dramatic effects, however it is becoming clear that planning must also include actions for adaptation [3–7]. Actions for climate adaptation generate positive effects on other aspects of the urban system, such as in public health, enhancement of biodiversity, reduction of inequalities and promotion of economic development.

Cities are in themselves dynamic engines of change. Worldwide, numerous city administrations have joined networks to fight, adapt to and prepare for climate change [8]. Furthermore, a growing number of cities have developed a Climate Action Plan (CAP), outlining a roadmap addressing the multiple impacts of climate change and contributing to sustainable development. Such plans typically place strong emphasis on emissions reduction, but given the realities of climate change, also on adaptation [9]. In this scenario, urban greening interventions have gained ground on urban agendas as measures that contribute to both adaptation and mitigation, thereby strengthening urban resilience while simultaneously reducing greenhouse gas emissions [10, 11].

Researchers have attempted to define the range of factors, among which climatic conditions, physical morphology and socio-economic variables, which influence the exposure of a city to climate risks, its vulnerability to climate-related impacts, and its capacity to effectively implement context-specific strategies of response and adaptation. Urban climate vulnerability describes the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change. It is typically a function of exposure, sensitivity, and adaptive capacity. Urban areas with high population densities, aging infrastructure, or socio-economic inequalities tend to be more vulnerable [12]. Yılmaz and Işınkaralar [13] emphasize the crucial role of the morphological characteristics of cities in defining climate resilience policies, suggesting that CAPs should directly address such characteristics. Less concerned with actions in regard to physical context, Aboagye and Sharifi [8] instead propose a holistic approach to the socio-economic and political dimensions of urban areas. Reinwald et al. [14] share this approach, recommending climate analyses and planning maps of local characteristics to identify both risks and opportunities for adaptation and mitigation. Wamsler et al. [4] explore how urban form shapes climate resilience, offering insights into the transition from theoretical planning to practical implementation. In general these studies stress the need for CAPs tailored to the specific vulnerabilities and capacities of individual cities. It is noteworthy, however, that few studies focus on understanding the inter-relations of the climatic, physical and environmental characteristics of different cities with their specific adaptation-mitigation plans.

This contribution is part of a broader research project aimed at developing a tool that will assist policymakers and urban planners in considering the characteristics of their specific cities in making decisions on the design of climate resilience. In particular, through a systematic analysis of the CAPs of a global sample of cities that are among the most active in climate action, it investigates the relationships between urban characteristics and implemented adaptation actions, with a specific focus on the role

of green spaces in mitigating the effects of global warming. To achieve this objective, a three-part methodology is developed. The first step defines clusters of cities based on their climatic, physical, social, and environmental characterization, through a series of multivariate statistical analyses. Using topic modeling techniques, the second step identifies and systematically analyzes the classes of adaptation actions proposed in the CAPs. The results from these first two steps then allow the final comparative analyses of the groups of cities versus classes of actions, thereby highlighting the strengths and weaknesses of the measures included in the CAPs.

Following this introduction, the next section of the paper provides a detailed description of the methodology developed. The third presents the results derived from the application of the method to twenty selected cities. Finally, the last section summarizes the main results and proposes directions of future research.

2 Materials and Method

The core hypothesis of the current research is that the decision-makers responsible for the development and implementation of CAPs require instruments for comprehensive understanding and analysis of urban systems, enabling them to identify climate risks and tailor approaches to address the unique vulnerabilities and capacities of each city. The methodology developed here allows systematic analysis of the interventions defined in CAPs relative to the physical, socio-economic and environmental characteristics of the cities adopting them. The specific objective of the current paper is to assess the alignment of greening actions with city profiles. The general benefits of greening approaches in urban contexts are well recognized, however for optimal effectiveness, the specific actions must be meticulously customized to suit the distinct characteristics of each city, including in terms of integration with other sectors of potential intervention, among which energy efficiency, mobility, water management and social equity, so as to foster synergies of climate resilience. Supported by tools for examination of the inter-connections, decision-makers can gain valuable insights into the way nature-based solutions contribute to broader climate adaptation and mitigation goals. Subsequently, the implementation of greening actions as part of a cohesive strategy sensitive to the specific urban characteristics, rather than in isolation, can achieve the desired synergies for the specific urban environment.

The methodology workflow (Fig. 1) is structured in three steps, as described in Fig. 1 below.

The methodology is applied to a sample of global cities selected according multiple criteria, ensuring a diverse and representative dataset. Geographic diversity is prioritized, with at least two cities from each continent, and the sample is also heterogeneous in terms of the population size, density, morphology and socio-economic conditions of the cities, all of which influence the planning and implementation of climate strategies. The cities are also selected based on their exposure to different climate hazards, among which excessive heat, rising sea levels rise and precipitation events. Finally, the cities were selected from those belonging to the C40 Climate Leadership network, formally committed to mitigation and adaptation for climate change through adoption of policies and allocation of resources, and in general for their strategic importance at the national and international levels.

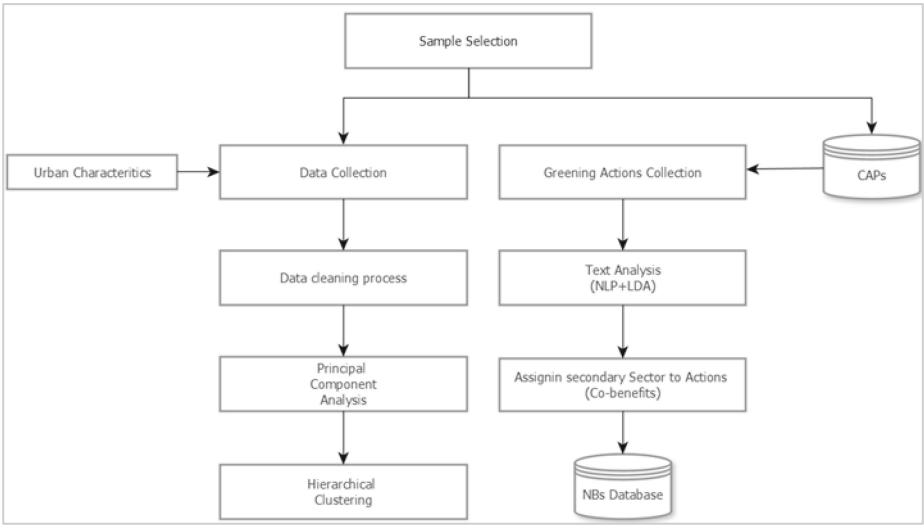


Fig. 1. Methodology workflow

Once the sample of cities is defined, two parallel analyses are conducted. The first focuses on classifying cities into groups based on urban features that influence their climate response. The second identifies the climate actions promoted in CAPs and categorizes them according to their primary and secondary sectors of focus.

The step of classifying the cities consists of four main tasks. The first two consist of collecting and cleaning data so as to accurately represent the urban characteristics that influence climate response. Based on a significant body of scientific literature, these factors can be categorized into four main domains: climate, physical environment, social dynamics, and environmental systems. For example, variables associated with the climatic domain include the maximum annual temperature recorded in each city, the Cooling Degree Days (CDD) which represents the amount of energy required to maintain indoor thermal comfort as outdoor temperatures increase. Rising cooling demand is often associated with higher electricity consumption and increased greenhouse gas emissions in cities [15]. For what concerns the physical domain, examples of relevant variables are the extension of green areas within the city and the range of elevation, defined as the difference between the highest and lowest points in the urban area. The socio-anthropic domain includes variables such as the percentage of the elderly population, considered among the most vulnerable groups, and the average monthly salary. Finally, the environmental domain encompasses variables such as the reduction in CO_2 emissions that refers to the release of carbon dioxide into the atmosphere, primarily due to the combustion of fossil fuels for electricity, transportation, heating, and industrial activities. CO_2 is the most prevalent anthropogenic greenhouse gas and a major driver of global warming [16]. All the characteristics within these domains are summarized in the table below (Table 1).

Once data collection is completed, a cleaning process is performed, followed by calculation of a correlation matrix. To ensure the stability of the dataset, variables exhibiting

strong correlations are removed [17]. Then the Bartlett test of sphericity is performed to confirm whether PCA (Principal Component Analysis) would be justified on the database. Using PCA to reduce its dimensionality, hierarchical clustering is then performed to cluster cities according to their similarities in urban characteristics. This clustering helps identify patterns in the characteristics of cities that may influence the selection and implementation of greening actions.

Alongside the PCA (Principal Component Analysis) and hierarchical clustering analysis, the second step is to analyze the actions proposed in the CAPs of the selected cities, using information collected in a detailed database.

The Climate Action Plans (CAPs) of the sample cities are systematically assessed to identify the full range of promoted climate actions, and on this basis construct a structured database of actions. Once identified, the actions are classified into primary sectors using topic modeling and Natural Language Processing (NLP) [18]. Each action is assigned to a thematic category, with an additional sector representing any possible generation of co-benefits. A specialized dictionary, developed by integrating climate plan descriptions and academic literature, refines the classification process [19]. NLP techniques, such as tokenization, stop-word removal and lemmatization, ensure accurate and consistent classification of actions.

The final step of the methodology is a comparative analysis of the trends in how cities with different characteristics implement greening actions, by comparing the characteristics of the city clusters derived in the first step with the climate actions outlined in their CAPs. The development of diagrams and charts serves to accentuate patterns, similarities, and differences among cities and to identify congruencies between greening initiatives and urban characteristics. This analysis assists in understanding which urban profiles are more prone to implement specific greening actions and how these interventions contribute to the cities' climate adaptation strategies. Finally, the methodology aims to uncover insights into how urban characteristics influence the selection and effectiveness of greening actions as nature-based solutions for climate adaptation.

Based on the criteria describe above, a sample of twenty cities is selected for application of the three-step methodology, with at least two from each inhabited continent: from North America, New York, New Orleans, Los Angeles, and San Francisco; from South America, Buenos Aires and Rio de Janeiro; from Africa, Accra and Cape Town; from Europe, Milan, Paris, Barcelona, Copenhagen, Rotterdam, Istanbul; from Asia, Mumbai, Ahmedabad, Wuhan, Seoul; from Australia, Sydney and Auckland.

The selected cities are heterogeneous in population density, ranging from the very high densities of cities such as Istanbul, Mumbai and Rio de Janeiro to the lesser densities of Auckland and San Francisco. These differences can be crucial in terms of the policies and strategies needed for climate adaptation.

Moreover, the sample represents exposure to a range of climate hazards. Cities such as Rotterdam, Cape Town and New Orleans face rising sea levels, while Milan, Ahmedabad and Paris are increasingly subject to longer periods of very high temperatures. Accra and Los Angeles face problems of drought and desertification, while Mumbai, New York and Rio de Janeiro experience periodic storms of heavy rain.

Although not all of the selected cities are national capitals, all serve as important economic, social and cultural hubs at regional or global levels.

Table 1. Urban system characteristics affecting cities response to extreme events, according to literature review

System	Variable	Description	References
Climatic	Average annual temperature	Annual average of temperatures recorded in a year	[12, 20]
	Maximum annual temperature	Maximum temperature recorded from October 2023 to September 2024	
	Cooling degrees days	Summation over a year of the days with average temperature in excess of thermal comfort temperature (25 °C)	[12]
	Difference between the average temperature of urban and rural area	Annual average of the difference in average temperature between urban and surrounding rural areas	[12, 21]
	Maximum wind speed	Annual maximum wind speed	
	Average wind speed	Annual average wind speed	
	Maximum monthly average of mm of precipitation	Maximum value of average monthly rainfall over one year	[22]
	Average number of days per month when a rain event occurred	Annual average of 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	[23]
	Linear extension of coast	Linear measure of any coastal frontage	[24]
	Altitude	Weighted average altitude with respect to the territorial extension of the city, compared to the average sea level	[23]
	Green space extension	Percentage of extension of total green spaces relative to extension of the entire city	[20, 25]
	Percentage of water coverage	Percentage of extension of water bodies relative to extension of the entire city	[25]

(*continued*)

Table 1. (*continued*)

System	Variable	Description	References
	Extension of urban area	Extension of the surface of the urbanized area	
	Building Coverage Ratio	Percentage of land occupied by buildings relative to extension of the entire city	
Socio-anthropic	Population	Total number of residents	[22, 25]
	Population density	Ratio between population and urban area extension	[25]
	Percentage of elderly population	Percentage of elderly inhabitants (over age 65) out of total population	[22]
	Percentage of population below the poverty line	Percentage of population living below the poverty threshold, defined at national or local level	[22, 26]
	Unemployment rate	Percentage of the population that is unemployed	[25, 26]
	Average monthly salary	Average monthly salary (net after tax) in euros	
Environmental	Percentage of renewable energy used	Percentage of energy consumed from renewable sources relative to total energy consumed per year	[12, 27]
	Percentage of energy consumed in the transport sector	Percentage of total energy consumed for transport relative to total energy consumed per year	[28]
	Percentage reduction in CO2 emissions over the past ten years	Percentage reduction in CO_2 emissions over the past 10 years	[12, 29]
	Percentage of use of sustainable modes of transport	Percentage of journeys made using sustainable modes of transport, i.e. walking, cycling, public transport	[12, 30]

The collection of data on the variables outlined in Table 1 relied on open sources. Some data, in particular on reductions in CO_2 emissions, were not always available from open sources. In these cases, the existing data on current emissions were used as a substitute.

3 Results

This section presents the findings from the application of the three methodological steps, as outlined above.

The first step was the set of statistical multivariate analyses to assess the robustness of the sample and then cluster the selected cities based on features affecting their response to climate hazards, as identified through review of the scientific literature.

First, to address multi-collinearity, two highly correlated variables identified in the analysis, Max TY (annual maximum temperature) and MaxPrecipIntensity (annual maximum precipitation intensity) for selected locations, were removed from the dataset. The Bartlett test was then conducted, yielding a p-value lower than 0.0005, confirming the statistical significance necessary to proceed with Principal Component Analysis (PCA).

The PCA results show that the first five principal components explain over 70% of the total variance, indicating a strong explanatory power of the selected variables. PC1 combines both climatic factors (patterns of temperature and precipitation) and socio-economic factors (e.g. CO_2 emissions), revealing relationships between cooling demand, climate vulnerability, and emissions.

The higher emissions of this component are linked with increased climate vulnerability, suggesting that areas with greater emissions are more susceptible to climate-related risks. PC2 primarily captures socio-economic dynamics, involving factors such as income distribution and urban infrastructure with physical variables such as range of elevation. The inclusion of this latter factor would reflect its role in shaping local climate impacts. PC3 integrates physical characteristics, such as land use and density, with sustainable mobility patterns. PC4 is influenced by both physical features and socio-economic elements (such as population density), capturing the complexity of urbanization and its effects on environmental sustainability. PC5 is primarily shaped by CO_2 emissions and urban sprawl, with lower-density cities showing greater reliance on private transport and less sustainable mobility, which reflects the challenges posed by urban expansion. The contribution of all urban, climatic, and socio-economic variables in these principal components reveals their relevance for further analysis and provides a solid foundation for understanding the multifaceted nature of urban climate adaptation.

The combination of correlated variables into composite components was used to provide a clearer understanding of the key factors driving urban resilience and, consequently, how cities have been clustered. The hierarchical clustering (Fig. 2) categorizes cities based on the selected variables, with these groupings further clarified through PCA.

Cities in Cluster 1 (Cape Town, Auckland, Istanbul, Seoul, Rio de Janeiro, and Los Angeles) are characterized by their coastal positioning, variable elevations, extensive green space, and moderate cooling demand. However, these cities exhibit a lower level of reliance on sustainable mobility measures.

The second cluster is comprised exclusively of Wuhan, a city that merits particular attention due to its minimal seasonal climate variability, its substantial reliance on sustainable transportation, and its low population density dispersed across an extensive urban area.

Cluster 3, which includes Accra, Ahmedabad, and Mumbai, is characterized by high cooling demand, significant climate variability, low CO_2 emissions, extreme population

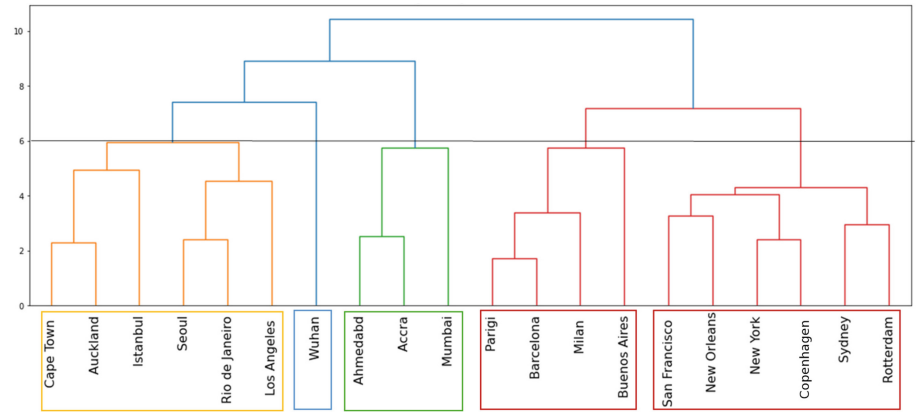


Fig. 2. Hierarchical cluster analysis dendrogram

density in small urban areas, and predominantly young populations. Cluster 4, which includes the cities of Barcelona, Buenos Aires, Milan, and Paris, is characterized by stable annual precipitation patterns, moderate population density, and a high proportion of sustainable mobility. These factors suggest that cities may have prioritized climate action through mitigation policies, such as more sustainable mobility.

Cluster 5, which includes the cities of San Francisco, New Orleans, New York, Copenhagen, Sydney, and Rotterdam, is characterized by a low demand for cooling, temperate climates with high carbon dioxide emissions, and high average incomes. However, some of these cities are low-lying and therefore particularly vulnerable to climate risks such as rising sea levels.

This clustering approach offers a structured understanding of how different urban characteristics and climate risks shape city-level adaptation strategies, providing a foundation for further analysis of climate action plans.

The second methodological step involved a systematic review of CAPs and the actions they promote. To categorise climate interventions by sector, a refined dictionary was developed. This dictionary serves to augment the NLP and Topic Modeling process by referencing two sources: the actions delineated in Climate Action Plans (CAPs) and the findings of Jin et al. [19]. The latter applied a similar topic modeling approach to climate action documents.

The dictionary classifies actions into ten sectors. The Urban Planning and Policies sector encompasses measures pertaining to territorial planning. The Energy and Buildings sector focuses on the adoption of renewable energy sources and enhancement of building energy efficiency. Mobility and Transport encompasses strategies for sustainable mobility. The Waste Management and Resource Management sector focuses on optimization of resources and waste recycling. The Climate Emergency sector encompasses emergency response actions, particularly related to extreme weather events, public health and urban safety. Community Engagement and Communications encompasses initiatives to raise public awareness and engage residents in climate planning. The Sustainable Economy and Finance sector encompasses initiatives promoting a circular economy, while actions under Responsible Consumption and Sustainable Lifestyles promote more

sustainable everyday behaviors. The Monitoring and Evaluation sector encompasses actions for assessing the effectiveness of adaptation and mitigation strategies.

Finally, the sector of Green Space and Biodiversity, of particular interest to the current study, encompasses urban greening initiatives and actions for conservation of biodiversity. This sector includes interventions for enhancing, preserving, and managing urban natural assets, at both neighborhood and city-wide levels. Examples seen among the twenty selected cities would include tree planting campaigns in Milan and Los Angeles, creation and connection of blue-green corridors in Rotterdam and San Francisco, and promotion of green roofs in Barcelona and Mumbai. In the Ahmedabad CAP we see the critical role of green spaces in the action of opening parks and gardens for extended hours during heat alerts. Among many of the twenty cities there are programs of assistance, advice and training to build the capacities and capabilities of local communities in developing and protecting green areas. Given the multifaceted nature of these actions and interventions, which often extend across multiple sectors, a secondary sector classification was assigned to each action. However, for the purpose of this contribution, only actions classified under Green Space and Biodiversity as either their primary or secondary sector were considered.

The final methodological step was the comparative analysis integrating the results from cluster analysis with the database of actions for green spaces. The initial result of this analysis is a pie chart, seen in Fig. 3, displaying the ten sectors of all of actions planned under the CAPs, in which Green Space and Biodiversity is seen to account for 9% of aggregate actions. A second pie chart relating to the first one focuses on Green Space and Biodiversity, assigning the actions to the five clusters of cities identified in the first methodological step. This approach facilitates the identification of the clusters that implement the most actions.

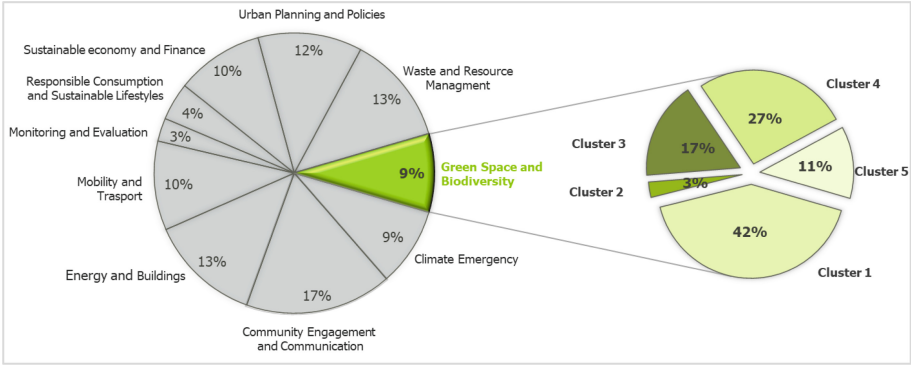


Fig. 3. The first pie illustrates the distribution of actions across ten sectors. The second pie provides a detailed analysis of Green Space and Biodiversity actions, by cluster.

Within these percentages, it is notable that clusters 1 and 4 have the highest number of planned green space actions, while cluster 2 shows the lowest absolute number. However, relating the total number of actions within each cluster to the numerosity of cities, it can

be observed that green space actions never exceed 20% of total actions in a cluster, while in clusters 3, 4 and 5, green space actions are always less than 10% of the total actions.

Figure 4b instead illustrates planned actions in other sectors that have the potential to positively impact green space and biodiversity. The analysis indicates that the Waste and Resource Management sector is the most significant contributor, with a percentage of 31%. This finding suggests a robust correlation between circular economy initiatives and the enhancement of urban ecological systems. Community Engagement and Communication also plays a role, with 21% of association. This finding underscores the



Fig. 4. (a) Sectors benefiting from greening and biodiversity actions. (b) Sectors generating benefits for greening and biodiversity

significance of participatory and awareness-raising initiatives in fostering stewardship of greenspace and enhancing biodiversity protection.

Other sectors, among which Climate Emergency, Monitoring and Evaluation, and Mobility and Transport, exhibit a mere 5% of actions yielding co-benefits in the green space sector. These percentages suggest that greater attention could be directed toward identifying and enhancing green co-benefits in the relative sectors, and may reflect underexplored potentials. The diagrams also demonstrate that green space actions are multifunctional and can provide co-benefits in a broad spectrum of urban governance domains.

4 Conclusions

This contribution represents the first result in research aimed at building a tool to support the decisions of policymakers and urban planners in designing more resilient cities in relation to their specific characteristics.

In particular, the current study provides an updated framework for the analysis and understanding of how very large cities equip themselves to respond to the challenges posed by climate change, through the identification of strategies and actions for mitigation and adaptation within their Climate Action Plans (CAPs). The particular interest of the current study is to understand the results achieved through actions of greening and promotion of biodiversity. The proposed methodology proceeds in three steps, aimed at identifying the relationships between the characteristics of cities and the adaptative actions and interventions for minimization of effects from climate change [31]. The first research step applies multivariate statistical analysis to classify the sample of cities based on their urban characteristics (climatic, physical, socio-economic, environmental, etc.). The second step applies topic modeling to classify the actions of the CAPs into different categories, following a preliminary review of scientific literature aimed at identifying all the possible actions and interventions considered effective in respect of the various urban characteristics (physical, functional, environmental, climatic, etc.). The last methodological step consists of a comparative analysis between city clusters to identify specific actions adopted in the plans relative to the actual urban characteristics.

While it presents the overall results of sectors of CAP actions relative to urban characteristics for the twenty cities under study, this contribution focuses on the actions taken for green spaces. The study identified how the different clusters of cities implement greening interventions in respect of their specificities and strategies for climate-related management. As shown in Fig. 3, Clusters 1 and 4 have the highest absolute number of actions for green spaces. Cluster 1 includes cities such as Cape Town and Rio de Janeiro, known for their coastal location and important range of altitude. Cluster 4, includes cities such as Barcelona and Paris, characterized by stable precipitation patterns and high levels of sustainable mobility. In contrast, Cluster 3, which includes cities like Ahmedabad and Mumbai, characterized by a high cooling demand and high population density, and Cluster 5, which includes cities like New York and Rotterdam, known for their temperate climates and high CO2 emissions, show relatively low percentages of actions for green spaces. It is noteworthy that actions for green spaces never exceed 20% in any cluster and are less than 10% in clusters 3, 4, and 5, indicating that while greening is considered,

it is often not the primary objective of the CAP. As illustrated in Fig. 4(a), which outlines the sectors in which greening initiatives also generate benefits in other sectors, such positive impacts are predominantly concentrated in the sectors of climate emergency (35%) and urban planning and policies (34%). This underscores that green spaces are not only beneficiaries of other urban strategies but are deemed essential for mitigating climate-related emergencies and defining strategic urban development. The significant role of green spaces in urban planning and policies indicates that cities recognize the need for holistic approaches, integrating green space planning into broader urban development frameworks. In contrast, Fig. 4(b), which illustrates the sectors that generate benefits for green spaces, highlights Waste and Resource Management (31%) and Community Engagement and Communication (21%). This suggests that cities recognize the multiple impacts of greening beyond environmental benefits, acknowledging its potential to promote broader sustainability goals, such as waste reduction and increased community engagement.

These results, taken together, emphasize the recognition of green spaces as strategic elements for implementing urban resilience and sustainability, highlighting their dual role as contributors and beneficiaries of various urban sectors [32–35]. The research and methodology proposed in the current work represent a fundamental step towards the broader research aim of defining a comprehensive decision-support tool for climate adaptation actions tailored in respect of the main characteristics of urban areas, thereby avoiding maladaptation. By analyzing the relationships between CAPs and the specific characteristics of the cities that adopted them, this study has developed a valuable collection of actions and insights. This collection can serve as a basis for future research and development activities, with the goal of providing urban planners and policymakers with concrete and specific recommendations integrate green space initiatives into their climate adaptation strategies in manners suitable for their specific context.

Despite the fact that the study yielded significant results, it is important to note that it is not without certain limitations. It is acknowledged that reliance on open data sources, while promoting replicability of the methodology, can result in inconsistencies and missing values due to variations in update frequency, spatial and temporal resolutions, and data collection protocols. In order to limit such inconsistencies, when specific selected indicators were unavailable, proxy variables were employed to approximate the intended dimensions of analysis. Although proxies can be useful, they may also introduce additional uncertainty, particularly when their relevance or correlation with the variables is context dependent. In the context of ongoing research, the analysis of cities from the same region is proposed as a solution to mitigate potential biases arising from collecting data exclusively from open sources.

The topic modeling approach, while effective, may overly simplify the complex language of the CAP, overlooking important details. Furthermore, the categorization of complex climate actions into primary and secondary sectors may overly abstract the interconnected nature of these interventions, reducing the understanding of other benefits and synergies. Given these limitations, and considering that the current study has been limited to twenty cities, future research will expand the sample of cities to include a broader range of urban contexts, refine data collection methodologies to minimize inconsistencies and gaps and also incorporate qualitative data, such as interviews

with stakeholders and case studies, to provide a more articulated understanding of the decision-making processes underlying the development of the CAP.

References

1. Batty, M.: Complexity in city systems: understanding, evolution, and design. In: Healey, P. (ed.) A Planner's Encounter with Complexity, pp. 99–122. Routledge, London (2016)
2. Portugali, J.: Handbook on Cities and Complexity. Edward Elgar Publishing, Cheltenham (2021) https://doi.org/10.4337/9781789900125
3. Laukkonen, J., Blanco, P.K., Lenhart, J., Keiner, M., Cavric, B., Kinuthia-Njenga, C.: Combining climate change adaptation and mitigation measures at the local level. Habitat Int. **33**(3), 287–292 (2009). https://doi.org/10.1016/j.habitatint.2008.10.003
4. Wamsler, C., Brink, E., Rivera, C.: Planning for climate change in urban areas: from theory to practice. J. Clean. Prod. **50**(2), 68–81 (2013). https://doi.org/10.1016/j.jclepro.2012.12.008
5. Papa, R., Galderisi, A., Vigo Majello, M.C., Saretta, E.: European cities dealing with climate issues: ideas and tools for a better framing of current practices. TeMA – J. Land Use Mobility Environ. 63–80 (2015). https://doi.org/10.6092/1970-9870/3658
6. Zucaro, F., Morosini, R.: Sustainable land use and climate adaptation: a review of European local plans. TeMA – J. Land Use Mobility Environ. **11**(1), 7–26 (2018). https://doi.org/10.6092/1970-9870/5343
7. Scorza, F., Santopietro, L.: A systemic perspective for the sustainable energy and climate action plan (SECAP). Eur. Plan. Stud. **32**(2), 281–301 (2024). https://doi.org/10.1080/09654313.2021.1954603
8. Aboagye, P.D., Sharifi, A.: Urban climate adaptation and mitigation action plans: a critical review. Renew. Sustain. Energy Rev. **189**, 113886 (2024). https://doi.org/10.1016/j.rser.2023.113886
9. Stone, B., Vargo, J., Habeeb, D.: Managing climate change in cities: will climate action plans work? Landsc. Urban Plan. **107**(3), 263–271 (2012). https://doi.org/10.1016/j.landurbplan.2012.05.014
10. Kabisch, N., et al.: Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. Ecol. Soc. **21**(2) (2016). http://www.jstor.org/stable/26270403
11. Mazzeo, G., Polverino, S.: Nature-based solution for climate change adaptation and mitigation in urban areas with high natural risk. TeMA – J. Land Use Mobility Environ. **16**(1), 47–65 (2023). https://doi.org/10.6093/1970-9870/9736
12. Intergovernmental Panel on Climate Change (IPCC): Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. In: Pörtner, H.-O., et al. (eds.) Cambridge University Press, Cambridge (2022). https://doi.org/10.1017/9781009325844
13. Yılmaz, D., Işınkaralar, Ö.: Climate action plans under climate-resilient urban policies. Kastamonu Univ. J. Eng. Sci. **7**(2), 140–147 (2021)
14. Reinwald, F., Thiel, S., Kainz, A., Hahn, C.: Components of urban climate analyses for the development of planning recommendation maps. Urban Clim. **57** (2024). https://doi.org/10.1016/j.uclim.2024.102090
15. Santamouris, M., et al.: On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings—a review. Energy Build. **98**, 119–124 (2015)
16. Environmental Protection Agency (EPA): Carbon Dioxide Emissions. https://www.epa.gov/ghgemissions/carbon-dioxide-emissions (2023)

17. Asuero, A.G., Sayago, A., González, A.G.: The correlation coefficient: an overview. Crit. Rev. Anal. Chem. **36**(1), 41–59 (2006). https://doi.org/10.1080/10408340500526766
18. Jelodar, H., et al.: Latent dirichlet allocation (LDA) and topic modeling: models, applications, a survey. Multimedia Tools Appl. **78**, 15169–15211 (2019). https://doi.org/10.1007/s11042-018-6894-4
19. Jin, S., Stokes, G., Hamilton, C.: Empirical evidence of urban climate adaptation alignment with sustainable development: Application of LDA. Cities **136**, 104254 (2023). https://doi.org/10.1016/j.cities.2023.104254
20. Ferranti, E., Cook, S., Greenham, S., Grayson, N., Futcher, J., Salter, K.: Incorporating heat vulnerability into local authority decision making: an open access approach. Sustainability **15**(18), 13501 (2023). https://doi.org/10.3390/su151813501
21. Isinkaralar, O., Sharifi, A., Isinkaralar, K.: Assessing spatial thermal comfort and adaptation measures for the antalya basin under climate change scenarios. Clim. Change **177**, 118 (2024). https://doi.org/10.1007/s10584-024-03781-8
22. Ramli, M.W.A., et al: Spatial multidimensional vulnerability assessment index in urban area – a case study Selangor, Malaysia. Prog. Disaster Sci. **20**, 100296 (2023). https://doi.org/10.1016/j.pdisas.2023.100296
23. Ahmadi, S., Amjadi, H., Chapi, K., Soodmand Afshar, R., Ebrahimi, B.: Fuzzy flash flood risk and vulnerability assessment for the city of Sanandaj, Kurdistan Province. Iran. Nat. Hazards **115**, 237–259 (2023). https://doi.org/10.1007/s11069-022-05552-z
24. Wu, T.: Quantifying coastal flood vulnerability for climate adaptation policy using principal component analysis. Ecol. Ind. **129**, 108006 (2021). https://doi.org/10.1016/j.ecolind.2021.108006
25. Sun, Y., Li, Y., Ma, R., Gao, C., Wu, Y.: Mapping urban socio-economic vulnerability related to heat risk: a grid-based assessment framework by combining the geospatial big data. Urban Climate **43**, 101169 (2022). https://doi.org/10.1016/j.uclim.2022.101169
26. Leichenko, R., Silva, J.A.: Climate change and poverty: vulnerability, impacts, and alleviation strategies. Wiley Interdisc. Rev. Clim. Change **5**(4), 539–556 (2014). https://doi.org/10.1002/wcc.287
27. Olabi, A.G., Abdelkareem, M.A.: Renewable energy and climate change. Renew. Sustain. Energy Rev. **158**, 112111 (2022). https://doi.org/10.1016/j.rser.2022.112111
28. Chapman, L.: Transport and climate change: review. J. Transp. Geogr. **15**(5), 354–367 (2007). https://doi.org/10.1016/j.jtrangeo.2006.11.008
29. Hansen, J., et al.: Assessing "dangerous climate change": Required reduction of carbon emissions to protect young people, future generations and nature. PLOS ONE **8**(12), e81648 (2013). https://doi.org/10.1371/journal.pone.0081648
30. Mashayekh, Y., et al.: Potentials for sustainable transportation in cities to alleviate climate change impacts. Environ. Sci. Technol. **46**(5), 2529–2537 (2012). https://doi.org/10.1021/es203353q
31. Codemo, A., Favargiotti, S., Albatici, R.: Fostering the climate-energy transition with an integrated approach. TeMA – J. Land Use Mobility Environ. **14**(1), 5–20 (2021). https://doi.org/10.6092/1970-9870/7157
32. Gargiulo, C., Tulisi, A., Zucaro, F.: Climate change-oriented urban green network design: a decision support tool. In: Network Design and Optimization for Smart Cities, pp. 255–278 (2017). https://doi.org/10.1142/9789813200012_0011
33. Gargiulo, C., Lombardi, C.: Urban retrofit and resilience: the challenge of energy efficiency and vulnerability. TeMA – J. Land Use Mobility Environ. **9**(2), 137–162 (2016). https://doi.org/10.6092/1970-9870/3922
34. Gargiulo, C., Zucaro, F.: A method proposal to adapt urban open-built and green spaces to climate change. Sustainability **15**, 8111 (2023). https://doi.org/10.3390/su15108111

35. Zucaro, F., Gargiulo, C.: Greening networks for smart and resilient cities: from methodology to application in densely built urban contexts. Archivio di studi urbani e regionali 127(Suppl. 1), Franco Angeli, Milano (2020)