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ORIGINAL ARTICLE

European patterns of local adaptation planning—a regional analysis

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Abstract
While European regions face a range of different climate hazards, little is known about how these differences affect local climate adaptation planning. We present an analytical framework for evaluating local climate adaptation plans (LCAPs) and apply it to 327 cities in 28 countries across different European regions. To do this, we use statistical methods to identify regional clusters based on overall plan quality, impacts, vulnerable population groups, and sectors addressed by LCAPs. By comparing both geographic and statistical clusters, we found (1) significant spatial heterogeneity across European cities but (2) higher average plan quality scores and more consistent strategies across cities in Central and Eastern Europe. Notably, we found no regional differences regarding (a) the climate impacts and vulnerable communities identified in plans: (b) the most commonly addressed impacts, which were urban temperature and changing precipitation patterns; and (c) the residents that cities identified as most vulnerable, namely older people, women, infants, and the sick. Our study provides a spatial analysis of European LCAPs to uncover regional policy perspectives on local climate adaptation issues. Such approaches can effectively inform broader EU, national and regional strategies that aim to support local adaptation planning in a context of multi-level governance.

Keywords Climate adaptation · European regions · Local adaptation plan · Quality of plan · Impacts · Vulnerabilities

Introduction

Cities play a crucial role in various aspects of climate change action through decarbonization (Mi et al. 2019), knowledge-sharing (Lin et al. 2021; Pee and Pan 2022), and adaptation-oriented activities (Rodriguez et al. 2018). The adverse effects of climate change require cities to develop effective and well-structured strategies in order to reduce their vulnerabilities in a rapidly changing environment (Dodman et al. 2022), and also require them to develop planning, coordination, and leadership capacities (Elmqvist et al. 2021). Although cities around the world face quite similar challenges, such as an intensifying urban heat island effect (He et al. 2021; Jiang et al. 2019) and increased risks of heavy precipitation and pluvial flooding (Pour et al. 2020; Zhang et al. 2019), their specific impacts will be unique to particular localities, which therefore need to develop their own solutions (Bulkeley 2010).

Urban scholars have examined various aspects of climate adaptation, with a particular focus on the content of plans and policies (Reckien et al. 2014; Woodruff and Stults 2016; Olazabal and Ruiz de Gopegui 2021; Cannon et al. 2023), their implementation (Palermo et al. 2020; Yang et al. 2021), and monitoring (Scott and Moloney 2021; Rivas et al. 2022). Increasingly, studies have analyzed the effectiveness or consistency of local climate strategies and related plans (Mendizabal et al. 2021), based on the understanding that decision-makers and planners need to support the transformation of urban areas (Hölscher and Frantzeskaki 2021). Studies in the mid-2010s focused mainly on elaborating different analytical frameworks, based on the number of selected cities and their geographical position, to examine mitigation-adaptation interdependencies regarding goals and actions (Donner et al. 2015; Heidrich et al. 2016; Reckien et al. 2015; Walsh et al. 2022). These initial attempts to analyze and compare different cities according to their distinct geographical locations, policy backgrounds, and levels of local awareness or governance support helped to define

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methodological practices and identified important challenges that underpin contemporary studies in the field.

Alongside examining overlaps between mitigation and adaptation, scholars have also studied progress in each climate action field independently. Since we can measure and assess decarbonization ambitions fairly easily by using CO_2eq to quantify GHG reduction targets, studies have been able to compare urban areas within (Deetjen et al. 2018; Markolf et al. 2018) and across countries (Eisenack and Roggero 2022; Mia et al. 2018; Salvia et al. 2021). In contrast, research into climate adaptation initiatives requires a more qualitative and fine-grained analysis (Mendizabal et al. 2021); consequently, studies in this field adopt a much broader range of applied methodologies.

As with mitigation, numerous studies have examined adaptation in cities from the same country (Gurney et al. 2022; Heidrich et al. 2013; Hughes 2015; Woodruff and Stults 2016; Kalbarczyk and Kalbarczyk 2020; Kern et al. 2023; Kristianssen and Granberg 2021; Otto et al. 2021; Pietrapertosa et al. 2019; De Gregorio Hurtado et al. 2015). Furthermore, although scholars face methodological challenges regarding the comparability of local-focused urban plans across countries, some international studies do appear in the literature, revealing spatial differences across the studied areas. For example, Paz et al. (2016) analyzed climate-related health impacts in five Mediterranean cities; Reckien et al. (2018) provided an EU-level comparison of 885 cities regarding their mitigation and adaptation planning issues; Grafakos et al. (2020) adopted a regional perspective to study the integration of mitigation and adaptation in 147 Climate Change Action Plans throughout Europe. Beside the well-studied European countries, several studies also address similar topics in other geographical contexts (Aboagye and Sharifi 2023; Hurlimann et al. 2021; Sharifi 2021; Singh et al. 2021; Lioubimtseva 2020; Hunter et al. 2020; Abubakar and Dano 2020). Common threads that run throughout these studies include the importance of undertaking city-level climate impact and risk assessments, the need to take greater account of synergies and potential conflicts in mitigation and adaptation, and the lack of substantial progress on implementation.

In parallel, various studies have sketched out regional patterns behind the planning differences across cities, both on a single continent and worldwide. This literature has produced mixed results, often reflecting the geographical locations and size of the selected cities; for example, Araos et al. (2016) and Heikkinen et al. (2020) found that wealthier and larger cities were more effective in adaptation planning. Alongside intercontinental comparisons of local adaptation plans (LCAPs) (Fitton et al. 2021; Olazabal et al. 2019; Olazabal and Ruiz de Gopegui 2021; Patterson 2021; Fila et al. 2023), studies aimed to analyze and compare climate planning in European cities at various regional levels (inter alia Dubo et al. 2023; Geneletti and Zardo 2016; Heidrich et al. 2016; King 2022; Nohrstedt et al. 2022; Teixeira et al. 2022). Most notably, Aguiar et al. (2018) identified regional clusters illustrating different approaches to local adaptation planning across Europe.

According to the IPCC Sixth Assessment Report, different regions of Europe are facing significantly different challenges regarding the magnitude and frequency of climate impacts, including higher temperatures, fewer cold spells, and decreased lake, river, and sea ice (Bednar-Friedl et al. 2022). Specifically, although temperatures are set to rise across the continent in the coming years and decades, these increases will be more pronounced in Nordic and Eastern European countries during the winter months, whereas the Mediterranean region will experience the most intensive summer warming. The Mediterranean is also expected to be most affected by all types of drought, whereas projections remain uncertain in Northern, Western, Central, and Eastern Europe at a limited warming pace (although a more intensive heating scenario suggests that they will also increase in these regions). These asymmetric climate impacts are likely to result in diverse economic and social impacts across different European regions: the total predicted economic loss related to climate change is higher in Western European countries than in Eastern ones. At the same time, property and infrastructure in Western Europe are more likely to be insured against climate losses, suggesting that Eastern and Mediterranean regions may be more sensitive and, therefore, more vulnerable to climate threats (European Environment Agency 2022).

Furthermore, the recently published EU Regional Competitiveness Index 2.0 (European Commission 2023) highlighted significant differences regarding well-being across European regions and outlined the need for regional-scale analysis in a rapidly changing environment. Finally, the spatial distribution of the most vulnerable social groups to extreme weather events (European Environment Agency 2018) adds an additional layer to strengthen the role of analyzing regional patterns in climate-related studies, especially policy-oriented ones. In 2021, for example, 23.5% of the population in Italy was aged over 65, compared to only 14.8% in Ireland (Eurostat Data Browser n.d.); we might therefore expect Italian cities to focus more on how climate change might affect older and more vulnerable people than their Irish counterparts.

This paper seeks to update our knowledge of regional adaptation and reveal differences and similarities in LCAPs by examining cities' policies in the context of geographical and statistical clusters. Drawing on our analysis of the adaptation strategies of 327 European cities between 2005 and 2020, we make several contributions to the literature. First, we provide a comprehensive, updated overview of LCAPs across different European regions based on the ADAQA-3 index of plan quality developed by Reckien et al. (2023). Second, we identify the impacts and vulnerable population groups that municipal governments in different European regions are seeking to address in terms of climate adaptation, inter alia, because Reckien et al. (2023) noted that European cities adaptation plans focus less and less on vulnerable groups over the last 20 years. Third, we draw out contrasts and similarities between geographical and statistical clusters of LCAPs in terms of the principles they consider and the amount of consistency between (a) potential local climate impacts on the one hand, and the municipality's objectives on the other, (b) the risks to vulnerable people and the measures that the municipal government adopts, and (c) the risks to vulnerable economic sectors and the measures that the municipal government adopts. Consistency of plans has been identified as insufficient in previous studies (Olazabal and Ruiz de Gopegui 2021; Reckien et al. 2023). Finally, by comparing existing geographical clusters of European urban areas with groups of cities that share similar statistical attributes, we suggest new ways of extending our knowledge of local adaptation planning that have relevance for policy and practice.

Methodology

To investigate regional patterns of local climate adaptation in Europe, the first step in this research involved identifying the sample of cities and the key data and indicators to characterize them in regional terms. This mainly relied on statistical and geographical clustering techniques, which led to a refinement of both the initial research questions and the methods, as well as an integration of the collected data. An overview of the main research steps, described in this section, is represented in Fig. 1.

Study area

This study analyzed a sample of 327 core cities from the former EU-28 Member States covered by the Urban Audit (UA) database, now included in the Cities Statistics database of the European Statistics Office (Eurostat City statistics n.d.). This dataset includes various socio-economic, environmental, and institutional data to periodically monitor and evaluate urban-level developments using methodologically rigorous measures. UA is a representative database of urban areas regarding size and regional distribution per country, which fulfills several requirements: (1) the cities cover at least 20% of the country's population; (2) all NUTS-3 regions are represented by at least one city; (3) both small (population under 50,000) and large (population above 50,000) cities are considered. Although the UA database currently lists almost 900 urban areas, in this study we referred to the reduced sample of core cities mentioned in Eurostat's 2011 Regional Yearbook and previously used by Salvia et al. (2021) to compare cities' mitigation targets based on what was stated in their local climate plans. We analyzed adaptation planning in this UA-reduced sample. Figure 2 shows the location of the sample cities and depicts the six geographical regions (Berglee 2016) that we defined to reveal the spatial characteristics of the LCAP features studied. Our regional division follows the traditional European regions, representing geographical diversity, and distinguishing six groups of former EU-28 countries, consisting of the following countries:

- *Baltic countries*: Estonia, Latvia, Lithuania;
- *Central and Eastern Europe (CEE)*: Bulgaria, Croatia, Czechia, Hungary, Poland, Romania, Slovakia, Slovenia;
- *Nordic countries*: Denmark, Finland, Sweden;
- *Southern Europe*: Cyprus, Greece, Italy, Malta, Portugal, Spain;
- *UK and Ireland*: Ireland, United Kingdom;
- *Western Europe*: Austria, Belgium, France, Germany, Luxembourg, The Netherlands.

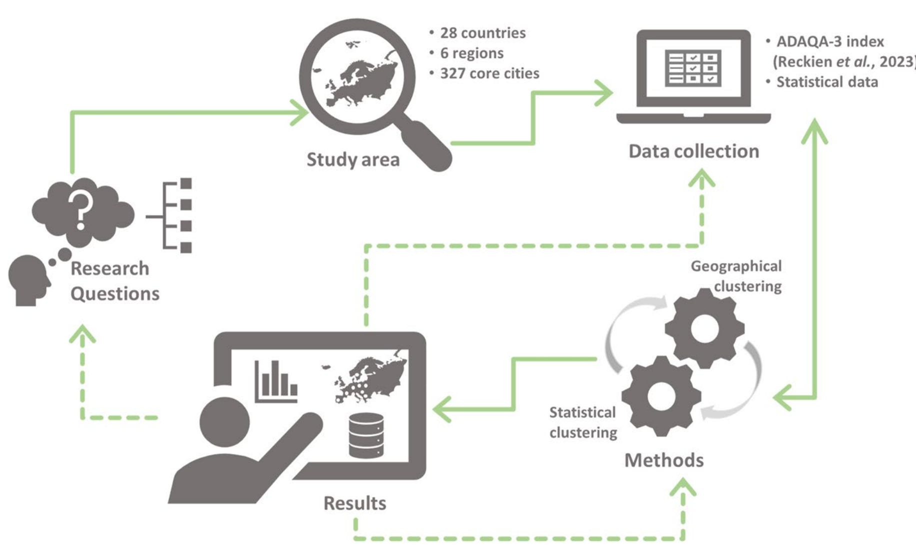

Fig. 1 Overview of the main research steps

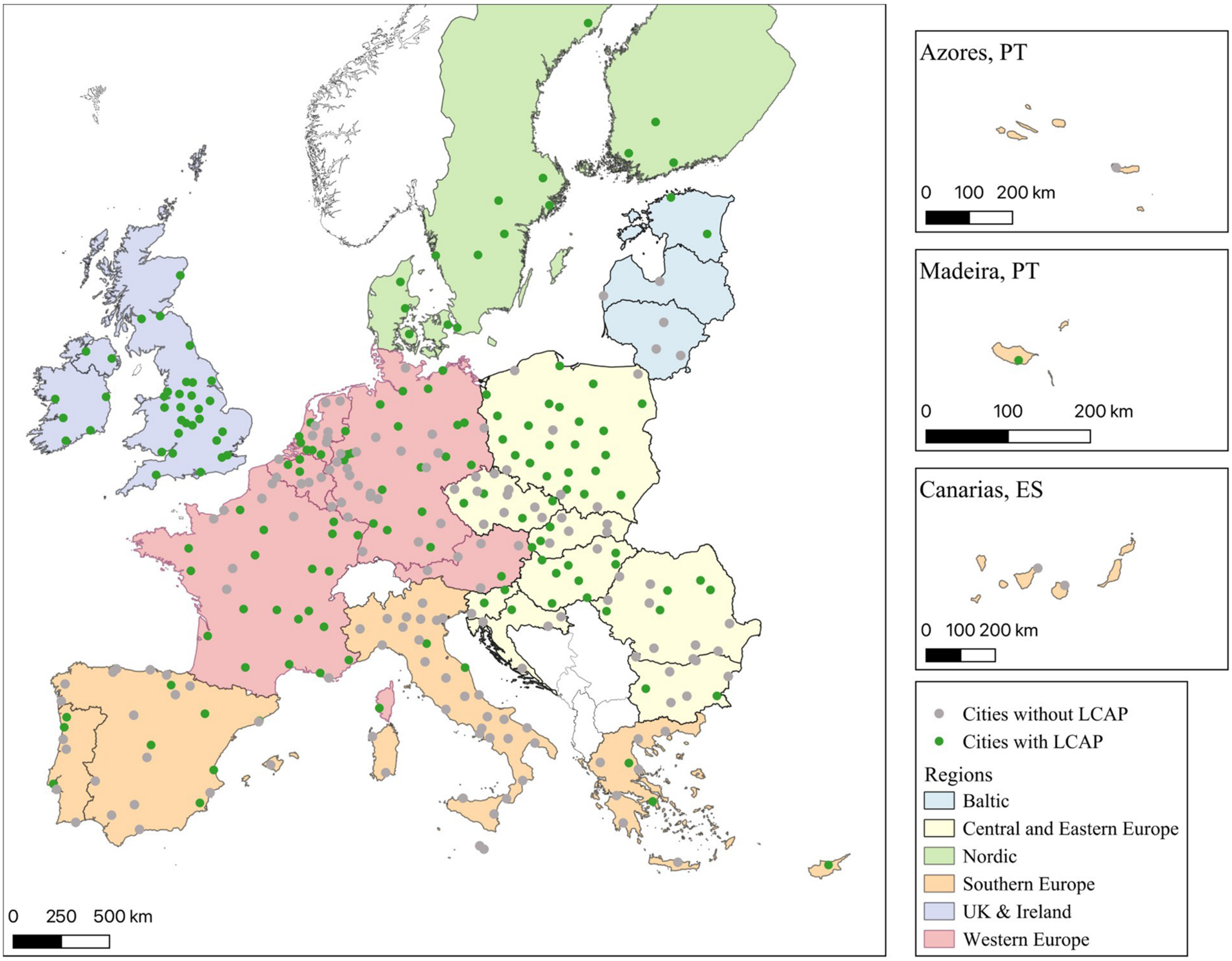

Fig. 2 Study area—cities in the sample (with and without LCAP) and predefined geographical regions

Data collection

We based our analysis on cities' Local Climate Adaptation Plans (LCAPs) approved in the period 2005–2020, which were researched, collected, and then analyzed by a team of native-speaker experts in local climate planning across the sampled countries. The aim was to assess their quality and measuring their adaptation progress through the application of the "ADAptation plan Quality Assessment" indices developed by Reckien et al. (2023) and based on six well-established principles of plan quality:

I. Fact base: impacts, risks, and vulnerabilities;
II. Goals;
III. Measures;
IV. Implementation: tools and processes;
V. Monitoring & Evaluation; and
VI. Participation.

We here use the most elaborate ADAQA-3 index (available in the online database https://easy.dans.knaw.nl/ui/datasets/id/easy-dataset:248371), which reflects the equal importance of the six adaptation quality principles mentioned above while emphasizing the need for consistency between impacts/risk/vulnerability, adaptation measures, monitoring and evaluation, and participation. This dataset was complemented with ad hoc collected statistical and geographical data on the sample cities.

Clustering methods and statistical analyses

To further explore the similarities of pre-determined geographical regions (depicted in Fig. 2) in LCAP development and quality, we applied geographical and statistical clustering to our selection of cities. More specifically, we grouped the integrated ADAQA-3 scores into quintiles and analyzed the LCAPs' relative performance from a spatial perspective, focusing on geographical patterns and trends.

We also applied statistical clustering to the underpinning elements (i.e., principles and consistency scores) of the ADAQA-3 index. Firstly, we applied k-means clustering (Carvalho et al. 2016) to each of the six aforementioned principles (P) and to three (out of five) underpinning types of consistency (C) scores of the ADAQA-3 index. We focus on the first three consistency types as we consider the aspects reflected by those to be of the highest priority in terms of plan quality. We determined the number of clusters across the six principles and three consistency checks, ensuring significant differences between clusters and minimizing the range of case numbers within clusters: 60, 56, and 51 cities were grouped into principle-based clusters; and 62, 54, and 52 cities participating in consistent clusters, respectively.

To ensure the credibility of our analyses, we paid attention to several thresholds; for details, see the Supplementary Material tabs "principle" and "consistency." The first criterion we considered was achieving convergence by reducing the changes in cluster centers to zero within ten iteration steps. We were able to achieve this by the 6th step for principles and the 5th step for consistency scores by distinguishing three clusters for each case. Second, we used analysis of variance (ANOVA) tables (Ståhle and Wold 1989) to determine the statistical differences between clusters for each principle and consistency score. As a final step, we used the one-way ANOVA with Tukey HSD tests (Abdi and Williams 2010) to define statistically different or similar regions based on the cities' ADAQA-3 scores, identifying interregional connections. The statistical tests were performed by IBM SPSS Statistics (version 24); furthermore, we used QGIS 3.28 Firenze to create maps to interpret our results visually.

Results

Figure 2 shows that, overall, half of the cities in our sample (i.e., 167 cities) had developed a LCAP by our cut-off date of 2020. These cities are spread across various regions in Europe: the presence/absence of a plan is highlighted by the green/grey dots in Fig. 2, which shows that the regional patterns of cities with and without a LCAP across the study area are highly heterogeneous. The most covered area is the UK and Ireland, where all of the Urban Audit core cities have developed a LCAP. In contrast, cities in the Southern Europe group are much less covered by adaptation-focused strategic and planning documents.

To better comprehend the interregional patterns of the ADAQA-3 values, we rely on Table 1, which provides basic descriptive statistics. Our findings reveal that Central and Eastern European cities performed better than those in other regions, with an average score of 41.94, in parallel with a substantially reduced standard deviation. The Baltic cities take second place, albeit with some reservations, as the limited number of sampling points from this region calls into question the accuracy of their ranking. We must acknowledge that only Tallinn and Tartu developed adaptation strategies, making them the sole participants in our analysis (the other five Baltic cities in our sample had not produced adaptation plans by the cut-off date of 2020). Southern Europe, with quite a low number of cities, lies in third place, followed by cities from the UK and Ireland, and Western Europe, whose scores exhibit relatively high standard deviation, resulting in substantial gaps between the minimum and maximum values. Finally, the scores of Nordic cities are below average, surprisingly putting the region at the bottom of our ranking regardless of the inherently sustainable and often climate-friendly cities from those countries, considering their reliance on renewable energy sources and high adaptive capacity.

Despite these general results, it must be acknowledged that half of our sample had not developed strategies by 2020. Table 1 also shows the regional average values for all cities with and without a plan, calculated on the basis that cities without a plan receive a score of zero (3rd column), considerably modifying the initial ranking of regions that can be seen in the 2nd column. Regions where adaptation planning is well-spread, such as Nordic countries and the UK and Ireland, maintain their original scores, putting them in first and third place on the podium, respectively. In all other cases, our initial results were significantly modified by adding a vast number of zeros to Southern Europe and Western Europe, with the sharpest decrease in modified values observed in Southern Europe. CEE and the Baltics are also in very different positions: because most cities in these regions had not published a plan, the revised method almost halved and quartered their scores, respectively.

Table 1 Descriptive statistics for the ADAQA-3 index across regions

	No. of analyzed cities with a plan	Average score for plans that exist	Average score for all cities in our sample	Min	Max	St. dev
Central and Eastern Europe	47	41.94	22.39	18.19	63.17	9.13
Nordic	16	21.92	21.92	6.37	49.60	12.17
Southern Europe	15	38.28	7.36	13.60	59.68	12.38
UK and Ireland	35	30.61	30.61	5.15	65.57	14.04
Western Europe	52	31.36	15.63	5.55	56.20	13.10
Baltic	2	40.93	11.69	24.89	56.97	22.69

In addition, the cities' ADAQA-3 scores reveal significant heterogeneity in intra-regional patterns, even within countries. Figure 3 displays the relative performance of cities, highlighting differences through quintiles to detect spatial characteristics. The 1st quintile represents cities with the lowest values, while the 5th quintile includes cities with the highest ADAQA-3 scores. In general, the above-average performance (4th and 5th quintiles) in Central and Eastern European cities is due to the high positions of several Polish municipalities, along with cities from the Czech Republic (Prague), Slovakia (Trenčín), Hungary (Budapest and Debrecen), Romania (Sibiu and Piatra Neamt), and Bulgaria (Sofia). Significant regional differences are observed in the UK and Ireland, where Irish cities rank in the 4th and 5th quintiles, while UK cities are often placed in the bottom two groups, except for Coventry and Aberdeen. In Western Europe, French cities are mainly in the first quintiles, except for Dijon, Besançon, Metz, and Limoge. Cities in Benelux and Central Germany perform below average, while Northern and Eastern German towns can improve the regional average with their high values. Nordic cities are mostly found in the lowest quintile, with only Copenhagen and Aarhus classified in the 4th quintile, as mentioned below.

To compare regional patterns, the following paragraphs highlight the findings from our content analysis of LCAPs, while country-level analysis can be found in the Supplementary Material. Most of the analyzed LCAPs identified impacts or risks on at least one timescale (past, present, and future); however, this was not the case for several cities in Slovenia, Slovakia, the Netherlands, Hungary, Estonia, and Belgium. Although climate adaptation planning must be future-oriented to improve the adaptive capacity of human and natural systems, none of our regions placed great emphasis on future impacts and risks under different scenarios or projections. At the country-specific level, however, Romania, Bulgaria, and Austria stood out, with

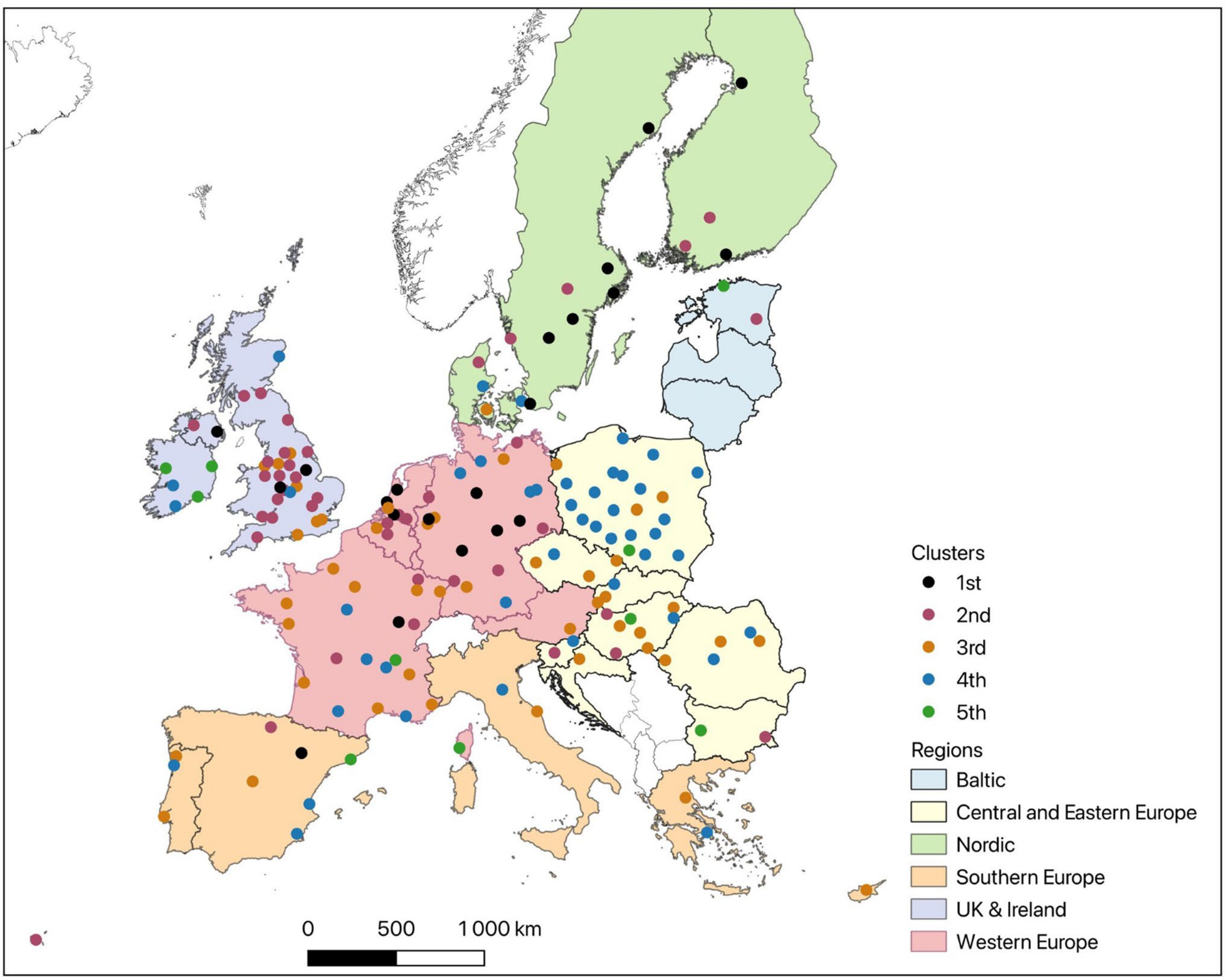

Fig. 3 Quintiles of ADAQA-3 values across cities and regions. Cluster 1 represents cities with the lowest scores, while Cluster 5 shows those cities that have the highest ADAQA-3 scores. Between them, increasing cluster numbers mean better performance

around 50% of their plans considering and distinguishing future impacts. In contrast, no cities in Sweden, Poland, or Italy focused on this aspect in their plans. There was a much more uniform picture in terms of identifying past and present climate impacts, both within and across our geographic regions. The LCAPs reveal a complex picture regarding identified climate change impacts, ranging from temperature and precipitation-related extremes to inland flooding, landslides, heavy storms, and coastal flooding (although, predictably, the latter affects a smaller number of cities in our sample). Encouragingly, the plans generally identify a broad range of potential impacts, but surprisingly, a handful of LCAPs do not address any specific climate change-related impacts, despite the fact that it is very difficult to imagine that any city will not be affected in some way (Bednar-Friedl et al. 2022). Urban temperature variation, precipitation variation, and inland flooding are the most commonly mentioned impacts throughout the continent, especially in CEE cities, followed by storms and wind variation as an often-mentioned challenge. However, it is worth noting that UK and Irish, Western, and Southern European cities were more likely to list a broad range of different impacts than their CEE counterparts. Finally, in keeping with the reduced magnitude of heatwaves in that region, Nordic cities paid much less attention to extreme temperatures; instead, they emphasized water-related impacts more in their LCAPs. Finally, we analyzed the various vulnerable population groups identified in the analyzed LCAPs, grouped into nine specific clusters. It reveals broad uniformity across different European regions in terms of whether each of these groups is mentioned in adaptation plans. Generally, older people, infants, and children are equally prominent in the plans throughout Europe, with only slight differences across regions. However, in the case of sick people, we identified a potential well-being indicator proxy regarding the regional pattern of mentioning this vulnerable group. CEE cities are more likely to mention immobile and ill people in their LCAPs as specific social groups that are particularly vulnerable to climate change, especially compared to Nordic, Southern European, and UK and Irish municipalities.

According to the results of the cluster analysis, all groups were significantly different from each other; however, in the case of Principle 6 (participation), the p-value was calculated as more than 0 (0.001), meaning that there are slightly fewer differences between clusters considering this aspect. After meeting all the statistical requirements, we used the outputs of the cluster analyses to define specific characteristics of each cluster based on the final cluster centers (see Fig. 4). For principle-based clusters, we identified three groups, called them P1, P2, P3, respectively. It is worth mentioning that Galway (Ireland) had to be excluded from this analysis since it was specified as an outlier based on its above-average performance, mainly regarding Principle 6. P1 included LCAPs with substantially above-average performances in all principles, making them highly comprehensive. Cities in P2 had plans with scores around the average for Principles 1-2-3, making them quite detailed in the early planning steps. However, they performed less well against the last three principles, focusing on the implementation, monitoring, and participation phases. P3 scored well below average for Principles 1-2-3, but performed better in terms of the implementation-related aspects, monitoring phase, and participation.

Regarding consistency-related clusters, we also identified three statistically different groups—called them C1, C2, C3—based on the same methodological requirements. C1 included plans that set out goals related to significant impacts and addressed related actions that covered vulnerable population groups effectively. City plans in C2 did not include many objectives and measures that addressed climate risks for vulnerable people, but did do well to define measures targeted at vulnerable economic sectors. Finally, C3 had below-average performances for all consistency scores, making them the least consistent of the three groups.

In addition to using statistical methods, we sought to understand the regional patterns of the identified clusters by visualizing them on our initial map; Fig. 4 displays the cities belonging to each cluster. C1 and P1 comprise the best-performing cities in both principle-based and consistency-based clusters; these cities are located in the same geographic areas, including Poland, Ireland, and southern France, and occasionally Western Europe and the CEE region. P2 includes cities with higher-quality LCAPs that were published relatively early; these are found in the UK, Germany, Belgium, central and southern Germany, and Nordic countries. Cities in P3 were stronger in implementation, monitoring, and participation processes, and are located more sporadically than in the previous cases. Although these cities can be found in many European countries, some intra-regional cluster centers can be identified in the UK, Belgium, the Netherlands, Western France, and Hungary.

The spatial distribution of the consistency-based clusters is similar to the principle-oriented groups, but there are some notable differences. C1 shares the same regional patterns as P1, with one significant difference: Danish cities were included in the highly consistent category, even though the identified impacts and goals were around the European average (P2). The top-performing cities previously identified are also part of this cluster, indicating that their plans have a more extensive range of impacts, goals, and measures, and they addressed these issues in a highly consistent way. The cities in C2 are located similarly to P2, indicating that these LCAPs focused less on implementation and monitoring aspects but effectively linked vulnerable sectors and measures. Finally, the spatial distribution of cities in C3 is comparable to that of the same cluster regarding principle values (P3). These

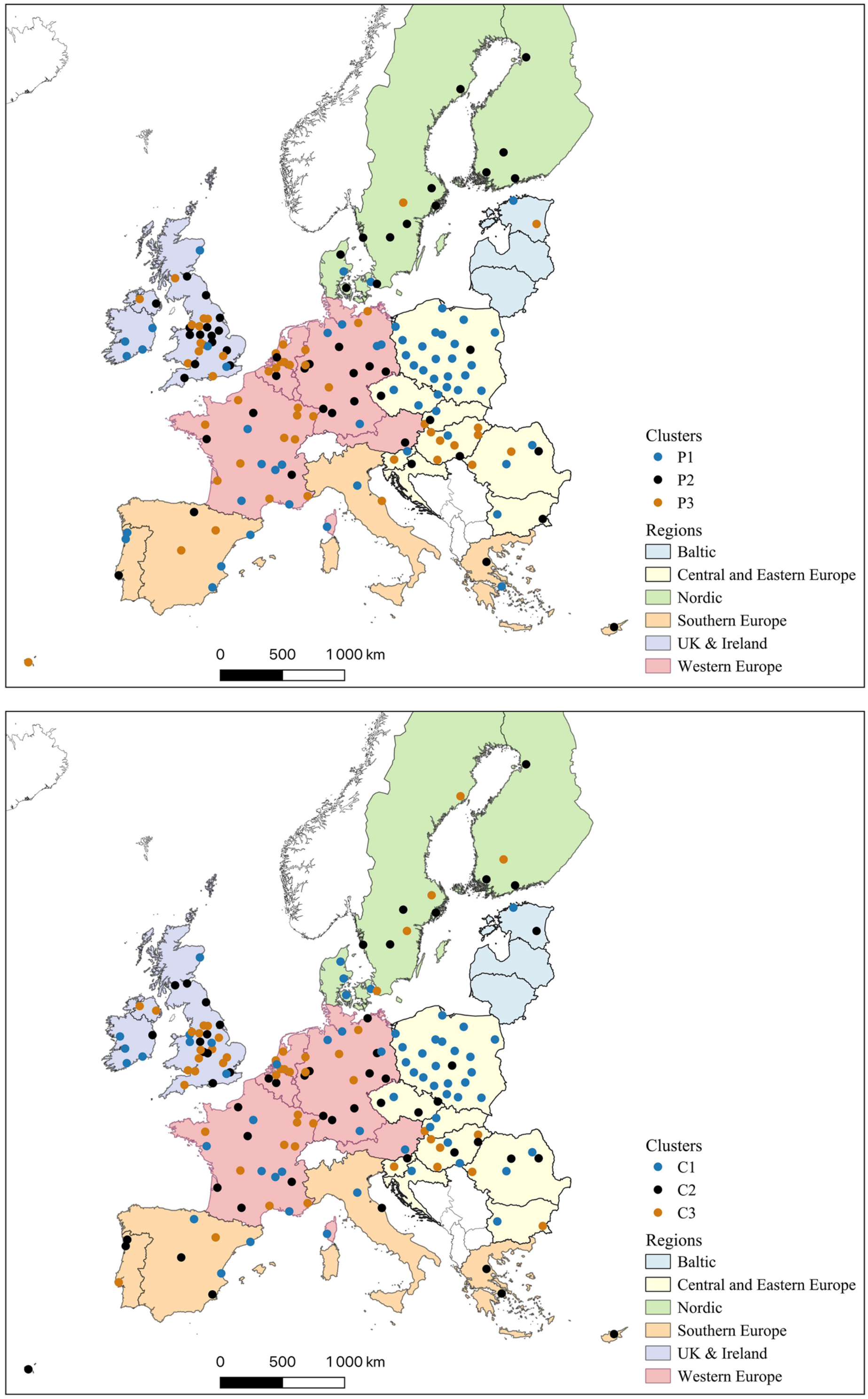

Fig. 4 Statistical clusters regarding **a** principle and **b** selected consistency scores. P1 listed plans with above-average scores on each principle; P2 represents those LCAPs that have significantly higher scores for early planning steps, while P3 shows strategies that performed better in terms of implementation, monitoring, and participation. The plans in C1 took well into account vulnerable social groups and related measures; C2 includes LCAPs that effectively identify vulnerable economic sectors and highlight related actions; while C3 are those plans that were least consistent in all aspects

LCAPs paid less attention to the fact base, adaptation goals, and measures and were less consistent regarding impacts, vulnerable people, sectors, and related measures. Perhaps surprisingly, these cities are located in the UK, Western Europe, Sweden, and Finland; however, these countries have stronger institutional capacities to develop detailed, consistent, and effective climate adaptation plans (Heidrich et al. 2016). Additionally, these plans tend to be older than those of, e.g., Polish cities, and therefore future revisions may incorporate such improvements.

In our final analysis, we aimed to identify whether our regions were significantly different or whether we could reveal interregional common features based on the ADAQA-3 values of cities. To accomplish this, we performed one-way ANOVA with Tukey HSD tests. The statistical data regarding multiple comparisons of different regions are summarized in Table 2, with the following group numbers: group 1 represents the CEE region, group 2 refers to Nordic countries, group 3 represents Southern Europe, group 4 indicates the UK and Ireland, and finally, group 5 refers to Western Europe. Since the Baltic countries are represented by only two cities with LCAP in our analysis, we decided to exclude this region from our final assessment.

Based on the p-values, we found that Central and Eastern Europe was the only region (group 1) that was significantly different from others. Central and Eastern Europe show similarity only with Southern Europe ($p = 0.847$) (group 3), while ADAQA-3 values of Central and Eastern Europe and cities are significantly different from other regions. It is worth noting that we used region-level aggregate values during this analysis; therefore, similar characteristics across and within regions can be defined based on the cities' individual performance. However, by analyzing regional-level numbers, we found how urban adaptation planning across the different regions was often quite similar: not only are ADAQA-3 values from Southern Europe similar to the CEE region, but also to Western Europe (group 5) and the UK and Ireland (group 4). Moreover, the Nordic region (group 2) cannot be distinguished from the UK and Ireland and Western Europe from a statistical perspective, and finally, the UK and Ireland shows similarity with Western Europe.

In summary, the regional-level analysis of the LCAP quality index did not reveal significant differences across European regions, except for CEE. However, in our previous analyses, we were able to depict numerous spatial clusters, both within and across countries.

Discussion

Notwithstanding the regional and statistical variations highlighted in the previous section, a number of cities stand out as having exceptionally high or low scores that do not

Table 2 Summary of statistical tests regarding ADAQA-3 values across regions (green cells represent the significantly similar pairs, where $p > 0.005$)

Group	Group	Std. Error	Sig.	95% Confidence Interval	
				Lower Bound	Upper Bound
1	2	3.509248381	0	10.3353738	29.6989748
	3	3.595456511	0.847	-6.2592862	13.5800007
	4	2.685292635	0	3.872006	18.6891205
	5	2.440168128	0	3.84765747	17.3122051
2	1	3.509248381	0	-29.698975	-10.335374
	3	4.357405526	0.002	-28.378631	-4.3350031
	4	3.642865896	0.121	-18.787054	1.31383199
	5	3.466135585	0.055	-19.000098	0.12561196
3	1	3.595456511	0.847	-13.580001	6.25928621
	2	4.357405526	0.002	4.33500314	28.378631
	4	3.725983797	0.249	-2.6595542	17.8999662
	5	3.55338982	0.297	-2.88401	16.7231581
4	1	2.685292635	0	-18.689121	-3.872006
	2	3.642865896	0.121	-1.313832	18.7870541
	3	3.725983797	0.249	-17.899966	2.65955417
	5	2.628700863	0.999	-7.953056	6.55179208
5	1	2.440168128	0	-17.312205	-3.8476575
	2	3.466135585	0.055	-0.125612	19.000098
	3	3.55338982	0.297	-16.723158	2.88400997
	4	2.628700863	0.999	-6.5517921	7.95305602

necessarily reflect the region within which they are located. Most notably, as Reckien et al. (2023) highlighted, Irish cities performed particularly well, largely due to the specific guidance they received from the Irish government on what to include in adaptation plans. These high scores skew the overall average for the UK and Ireland region and mask the fact that many UK cities did not produce very comprehensive plans. Although most cities in the UK and Ireland region have published strategies, a significant proportion of them came out early in our analysis period, which probably contributed towards them attaining lower scores than those places elsewhere in Europe that developed their plans at a later date. A similar factor may have been in play in the Nordic countries, where most cities produced plans earlier and they were generally of lower quality than those in other regions.

In contrast, most municipalities in CEE, including in Poland and the highest-scoring city of Sofia, Bulgaria, developed their strategies more recently and performed better. As awareness of climate risks has increased and the potential ways in which cities can reduce their vulnerability have evolved over time, we should probably expect that later plans will be more comprehensive in terms of setting out how municipalities will respond. At the same time, the existence of a large number of plans earlier in the UK, Ireland, and the Nordic countries shows that these cities have been aware of the need to combat climate threats for a longer period, and might therefore have made more progress in actually implementing appropriate measures. This is particularly the case if we compare them to those parts of Europe in which only a small share of our sample had developed a plan by 2020 (e.g., the Baltic countries). As such, although the average scores in some regions were quite low, this is partly because our initial analysis excluded cities without adaptation plans; cities that recognized climate threats and developed strategies to address them early on are perhaps more climate resilient than their counterparts elsewhere, irrespective of the quality of their plans.

Multi-level governance arrangements within countries could also contribute towards the differences we identified between regions, because national adaptation policy is likely to influence the number and quality of urban plans. Municipalities in some countries (such as France, the UK, Ireland, and Denmark) are required to have an adaptation plan. We found that this contributes to their respective regions having a greater number of plans, although it does not guarantee their quality.

On the other hand, the history of climate planning in each country and region also leads to significant differences between regions in terms of contextual factors that induce adaptation planning and plan quality. In fact, although we might expect regions that traditionally face extreme weather events or negative effects of global warming, such as heat waves and droughts, to produce better quality plans, this is not a given and is something that could be explored in future studies.

Concerning the extent to which LCAPs addressed the needs of vulnerable population groups—which should be a key priority of adaptation planning—city plans in several countries, including Slovenia, Finland, Cyprus, and Croatia, did not identify any specific vulnerable group, and they received only a cursory mention in many other countries. This represents one of the most critical weaknesses of European LCAPs. In particular, Western European, UK and Irish, Nordic, and CEE cities should pay greater attention to this issue while revising their plans to identify and address those social groups in their cities that are highly vulnerable to the adverse effects of climate change. Considering more specifically the vulnerable groups that have been addressed, we can conclude that immobile persons, lone parents, and migrants are in general underrepresented, indicating another important area for future improvement in the content of European LCAPs. Although we might consider taking account of vulnerable people's needs to be a cornerstone of an effective and well-structured LCAP, it should be emphasized that different cultural characteristics can contribute significantly to this heterogeneous pattern across countries and regions. For example, properties in the Nordic cities are generally well insured, which may contribute towards the limited emphasis on vulnerable social groups in their LCAPs. We suggest that future studies examine country-level differences in the structure of LCAPs with such national or local institutional and legal characteristics in mind, to paint a fuller picture of how populations in different jurisdictions are vulnerable to climate risks.

By taking a regional approach, our study adds to the growing body of literature on local climate planning, addressing a key territorial scale and policy level for climate change adaptation, particularly in Europe. For example, Geneletti and Zardo (2016) analyzed a specific aspect of local climate adaptation by focusing on ecosystem-based adaptation (EbA) planning through 19 European cities and finding that cities in different locations often adopt common EbA approaches. Notably, we also identified several similarities across different regions in our study of a broader range of planning aspects across a larger spatial area.

Similarly, Yang et al. (2021) analyzed the activities of 902 European cities concerning climate change strategy-making and found that 218 of the selected municipalities had such a document, providing a comprehensive assessment of local climate change planning in Europe. Notably, they identified a link between the percentage of elderly people in a city and the existence of a climate strategy. Although our analysis considered vulnerable people as well, from a policy-analysis perspective, the main findings of the present study can add an additional layer to Yang et al. (2021), evaluating the same social groups from different angles. Aguiar et al. (2018) analyzed 147 European cities and their activities regarding adaptation planning, providing thought-provoking results about triggers for and barriers to adaptation, and addressed impacts and sectors. We build on their study in three ways: by focusing on the specific impacts of LCAPs from a temporal perspective, by providing quality-related indicators and findings from a regional perspective, and by examining plans published since 2016. Finally, Reckien et al. (2023) dealt with the same pool of European cities to analyze their quality over time. We build on their findings by highlighting how the most recent plans from Poland, Ireland, and the South of France mean that the more comprehensive and consistent LCAPs are concentrated in specific European regions. Given that we used the same dataset, it is unsurprising that we reached similar conclusions; however, we revealed regional patterns in local adaptation planning and stress that Nordic cities, which have some of the oldest LCAPs in Europe, have higher scores for consistency than other plans from the same period.

Adaptation and mitigation planning have several similarities, and as they often cover overlapping and complementary issues, it would be worthwhile comparing our regional results to mitigation-oriented papers, identifying a future research area by applying statistical methods to prove the connecting points, since the following comparisons cannot be complete in the absence of quantitative analyses of our results. Grafakos et al. (2020) developed the so-called Urban Climate Change Integration Index (UCCII) to measure the mutual embeddedness of mitigation and adaptation aspects in urban strategies. However, they studied fewer cities (less than 150), and they were geographically concentrated in Western Europe, particularly the UK and France. Nonetheless, interesting comparisons can be made with our findings; UK cities show similarities regarding their UCCII and ADAQA-3 categories since their "moderate" level of integration appears in their cluster memberships with below-average ADAQA-3 scores in our analysis. Although French cities have lower UCCII scores, we calculated higher ADAQA-3 and consistency scores in their cases, pointing out an interesting difference between different quality measures of local strategies. In addition, Salvia et al. (2021) analyzed GHG targets of 327 European cities and found that those with the most ambitious targets were more likely to be located in Northern and Western Europe, and also have higher per capita GDP. Although the high performance of Irish cities appears to suggest that similar geographic and economic factors may also affect the quality of adaptation planning, the presence of CEE cities amongst our high performers suggests that other factors might also be in play. Specifically, the fact that many cities in Central and Eastern Europe published their strategies more recently than their counterparts elsewhere in the continent could mean that this region is overrepresented amongst our high performers, because newer plans tend to be of better quality. Furthermore, a recommended future research direction would be to analyze the co-benefits and trade-offs between mitigation and adaptation to uncover potential connecting points to ensure broader sustainability alongside climate-focused goals. As recent studies have highlighted, there is a need for more research into co-benefits at the urban level (Sharifi 2021, 2022; Boyd et al. 2022).

Concerning the limitations of our study, an obvious one is represented by the number of LCAPs that we analyzed, which was constrained by the availability and existence of strategies. We examined those plans that were published before the end of 2020; some of the cities in our sample have almost certainly produced new or revised strategies since that date. Second, both intra- and interregional distribution of LCAPs are uneven; we excluded Baltic cities from our detailed statistical analysis because an insufficient number of them had developed plans by 2020, and the aggregated results and findings from other European regions are highly dependent on the number of cities that had published LCAPs. Third, we used aggregated values to define regional features and distinguish regional patterns; however, adaptation planning must pay close attention to local conditions to customize challenges and opportunities. Consequently, we need to be aware of the context, assumptions, and conditions of the analysis when presenting European-wide conclusions or policy recommendations due to existing intra-national differences and the importance of local contexts. Finally, although Reckien et al. (2023) point out important policy implications relating to the lack of attention to M&E and participation, and lack of consideration to vulnerable populations generally across their sample of LCAPs, the limited nature of the dataset could easily reduce the robustness and explanatory power of our analysis.

Conclusions

Previous large-scale local climate adaptation assessments indicated a strong North–South divide regarding urban climate change action globally, with progress in adaptation planning concentrated in Northern European and larger coastal cities. We build on these studies by applying statistical and geographic clustering methods to LCAPs from 327 cities across Europe, finding significant interregional heterogeneity in overall plan quality and consistency values. Nonetheless, we also identified several notable regional clusters and similarities. First, Central and Eastern Europe and Irish cities showed significantly higher scores on the ADAQA-3 plan quality index, with greater consistency between the impacts, addressed sectors, vulnerable social groups, and proposed actions. Second, despite their higher regional competitiveness and overall prosperity, Western European and Nordic cities tend to have lower scores and less structured LCAPs. Based on the results of principle- and consistency-based statistical clusters, numerous policy recommendations can be formulated:

- P2 cities (focused on Germany, the UK, and Scandinavian countries) paid less attention to the implementation, monitoring, and participation principles; therefore, these aspects should be given greater emphasis in their future climate strategies or action plans;
- P3 cities (mainly from the UK, Hungary, France, and Benelux) perform significantly higher on the principles on which P2 cities have lower scores; these groups of municipalities could therefore seek to adopt planning-related best practices from each other to improve their overall results.
- Cities in clusters C1 and C2 have overlapping issues regarding consistent planning for vulnerable sectors or populations. Therefore, their strategies should be more detailed and focus on the missing measures related to vulnerable sectors and populations previously addressed by the local policy-makers.
- We recommend analyzing practices from higher-performing Polish and Irish cities in more detail to identify those planning processes that make these strategies above average.

Our results can be used to formulate further hypotheses and analyze regional factors that may act as enablers or barriers to adequate policy progress. They can also serve as a basis for benchmarking and improving the progress of European transnational policies, providing valuable criteria for better multi-level implementation and monitoring of the 2021 EU Adaptation Strategy (COM (2021) 82 final) and the European Mission Adaptation to Climate Change (European Commission 2021) also from 2021, where both regional and local levels are a priority.

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Data availability The questionnaire was used for data extraction by way of document analysis of urban climate adaptation plans, and the data are available at https://easy.dans.knaw.nl/ui/datasets/id/easy-dataset:248371. The download of data is restricted until 30th April 2024 to allow authors to publish further analyses and findings. Until that date all data are available from the corresponding author upon reasonable request.

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