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Urban climate action in the Nationally Determined Contributions: exploring the multilevel climate governance gap

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This study assesses the integration of urban climate action within Nationally Determined Contributions (NDCs) under the Paris Agreement. Analysing 194 updated NDCs, we investigated the level and type of urban-related content, including mitigation and adaptation challenges and responses, and means of implementation. Despite varied levels of urban content across NDCs, overall representation remains insufficient, with one-third of the NDCs having no urban-related content. At the urban level, sectors like energy, transport, and waste receive more attention for mitigation, while infrastructures and water are given more focus for adaptation. Urban climate responses are more frequently mentioned than challenges, with few NDCs identifying dedicated means of implementation. Clear identification of urban challenges, responses, and means of implementation is crucial for assessing the effectiveness and monitoring the progress of climate interventions. This study provides insights useful for integrating multilevel governance and subnational engagement in supporting national climate plans and commitment.

Cities are thought to be responsible for 70% of global greenhouse gas (GHG) emissions and 75% of total energy consumption[1,2]. According to the United Nations' (UN) forecasts, cities will host more than 68% of the global population by 2050[3]. At the same time, cities are exposed to the negative effects of climate change in the form of extreme events such as floods, drought, heat waves and storms, to name a few[4–6]. These not only compromise fundamental urban infrastructures and ecosystems but affect directly human health[7]. Therefore, cities must develop and implement action for mitigating and adapting to climate change by reducing GHG emissions and adapting to the increasing frequency and magnitude of extreme weather events[8–12].

Climate change, which is both caused and experienced by cities, also has an amplifier effect on other key urban issues, from sustainability to urban development. In fact, the challenge ultimately lies in rapidly adapting and transforming urban areas. This transformation must occur within the increasingly limited timeframe available to avoid irreversible overshoot of planetary boundaries and to keep the increase in global average temperature well below 2 °C above pre-industrial levels, while pursuing efforts to limit warming to 1.5 °C[13,14].

As the defining global issue of our time, climate change needs to be tackled through collective action, from national to local level, through multilevel governance. Fostering effective collaboration is essential, involving mechanisms to unite relevant stakeholders from national to local level, cultivate a sense of trust, and promote shared efforts[15]. Multilevel governance conceptualises climate governance as dispersed across multiple territorial levels and multiple actors, rather than as a hierarchical, state-centric system[16,17]. Local climate action can contribute to, and should be aligned with, achieving national climate targets, and overall, to raise the ambition of national climate policies. Moreover, local climate action needs support from national government in terms of technology, finance, legislation and institutional frameworks. National climate policies and local climate action require effective multilevel governance through vertical and horizontal integration. The vertical integration should harmonize and strengthen national, regional and local governments' climate action through clearly identified and complementary mandates, divisions of labour, and appropriately matching resource allocation[18,19]. The horizontal integration is considered a critical factor for the effectiveness of climate action, at both national and local levels, focusing on the harmonization and articulation of

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the level of collaboration across ministries and/or departments[20,21]. This is necessary to avoid silos and sectoral action, which increases the risk of generating negative rebound effects and of reducing synergies and co-benefits, which are fundamental for timely and efficient climate action. However, many factors militate against achieving the vertical and horizontal integration of multilevel governance, including control by opposing political parties of national-local authorities, overlapping or unclear mandates, outdated legislation and regulations, and human and financial capacity[22–26].

The Member States of the UN Framework Convention on Climate Change (UNFCCC) approved the adoption of the Paris Agreement in 2015, which recognized the importance of local authorities in addressing climate change. The Nationally Determined Contributions (NDCs) are the cornerstone of the Paris Agreement, through which countries define their objectives for climate mitigation and adaptation. According to the Agreement, Members should also increase their ambition with a new NDC submission every five years. NDCs should include targets for the GHG reduction, define how such targets will be reached, outline how the country will adapt to the effects of climate change, and identify the financial, technical and capacity building needs of the country. The Agreement is legally binding, but each country determines how to contribute to it. Thereby, the NDCs should be viewed as strategic guidance for all national climate policies and actions, allowing to stocktake and monitor the progress globally[27].

Given the role of cities in climate mitigation and adaptation, it appears fitting for national climate strategies, like the NDCs, to encompass provisions for urban areas. Ideally, these should involve subnational governments (states, regions, and cities) in formulating, executing, and reporting on mitigation and adaptation policies[28]. The inclusion of cities in national climate policies, specifically the NDCs, is fundamental to raise ambition of national climate action and its appropriate and timely delivery[18,28,29]. The exclusion of cities from the NDCs, on the other hand, may hinder the provision of needed technology, finance and capacities, as well as limiting and/or impeding the access to bilateral and multi-lateral funds[30].

Despite the growing body of literature analysing NDCs, existing studies have largely focused on mitigation ambition, emissions targets, transparency, finance, or sectoral coverage at the national level[29,31,32]. In parallel, a substantial body of research has examined urban climate action, governance, and planning at the city level, often independently of national climate commitments[18,29,33]. Literature that links NDCs to subnational action is fragmented and mostly case-based. Many studies treat NDCs primarily as national targets or sectoral policy signals (e.g., energy transitions, land use and forestry, agriculture), and then examine implementation challenges or pathways in specific contexts—such as a single municipality (e.g., Nakhon Ratchasima)[34], selected provinces (e.g., Korea)[35], or a single city/region linked to a national policy instrument (e.g., Shanghai ETS, Shenzhen co-benefits, Riyadh mobility)[36,37]. Even when subnational and non-state actors are considered at scale, the focus is typically on quantifying emissions impacts of commitments and overlaps rather than systematically examining how cities are reflected within NDC texts[38]. Overall, there remains a clear gap in systematic, cross-country evidence on whether and how NDCs explicitly acknowledge cities/urban areas across key urban mitigation and adaptation sectors, and what this implies for multilevel governance, coherence, and resourcing of urban climate action. Explicit recognition of urban sectors in NDCs constitutes a necessary precondition for coordinated multilevel governance, targeted policy support, and effective implementation of climate action at the city level[18,29,39]. Assessing whether and how NDCs reference urban mitigation and adaptation sectors, therefore, provides essential insights into the alignment between national climate commitments and urban climate action.

In this study, we have investigated the content of all NDCs to answer the following research question (RQ):

RQ: *To what extent and in which way is urban-related content included in the NDCs?*

The main RQ has been expanded with the following sub-questions:

RQ1: *What are the key urban adaptation and mitigation challenges in the NDCs?*

RQ2: *What are the key urban adaptation and mitigation responses in the NDCs?*

RQ3: *To what extent are urban means of implementation (MoI) explicitly mentioned in the NDCs?*

MoI refers to international support in the form of finance, technology, and capacity building. Inadequate MoI appear to be the main barrier to the implementation of NDCs and are a recurrent hot topic at climate negotiations, such as the UNFCCC Conference of the Parties (COP)[40–42].

To answer the RQs, we conducted a qualitative content analysis, manually extracting data from 194 NDCs.

In the following sections of this article, we present the results, we discuss the implications of our findings and the limitations of the study, and we detail the applied methodology.

Results

The findings reveal a substantial absence of urban content in one-third of NDCs. NDCs with urban-related content tend to list more mitigation and adaptation responses than challenges. Furthermore, the analysis reveals a stark discrepancy in the identification of MoI, with strong national-level MoI provisions but very limited references at the urban scale.

Level of inclusion of urban content in the NDCs

About two-thirds of the submitted NDCs (129 of 194) have urban content, as climate mitigation and/or adaptation challenges and/or responses at the urban level. The remaining 65 NDCs have no urban content.

NDCs have been clustered according to the level of urban content as follows:

- Fifty-three (27%) NDCs of 194 have strong urban content (cluster A), identifying the urban sector as a priority.
- Seventy-six (39%) have moderate urban content (cluster B), mentioning the urban sector, but not identifying it explicitly as a national priority.
- Sixty-five (34%) have low or no urban content (cluster C) Fig. 1, not mentioning explicitly the urban sector.

Of the 129 NDCs with urban content (cluster A + cluster B), ninety-two NDCs (71%) include both mitigation and adaptation-related urban content. Therefore, these NDCs include mitigation and/or adaptation challenges and/or responses.

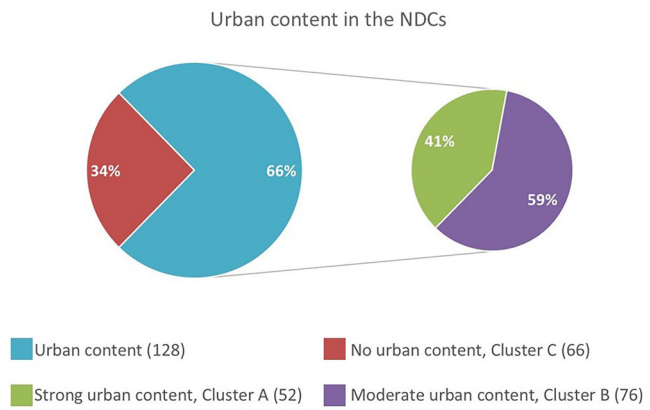

Fig. 1 | Urban content in the NDCs. Thirty-four percent of the 194 examined NDCs do not include urban-related content (Cluster C, red). Of the remaining 66% that include various degrees of urban-related content, 41% have a strong degree of urban-related content (Cluster A, green). These NDCs have one or more sections dedicated to urban areas, and/or identify urban as a priority sector. Fifty-nine percent have a moderate degree of urban content (Cluster B, purple). These NDCs include urban mitigation and/or adaptation challenges and/or responses, but don't explicitly identify urban areas as a priority sector nor have a dedicated section to urban areas.

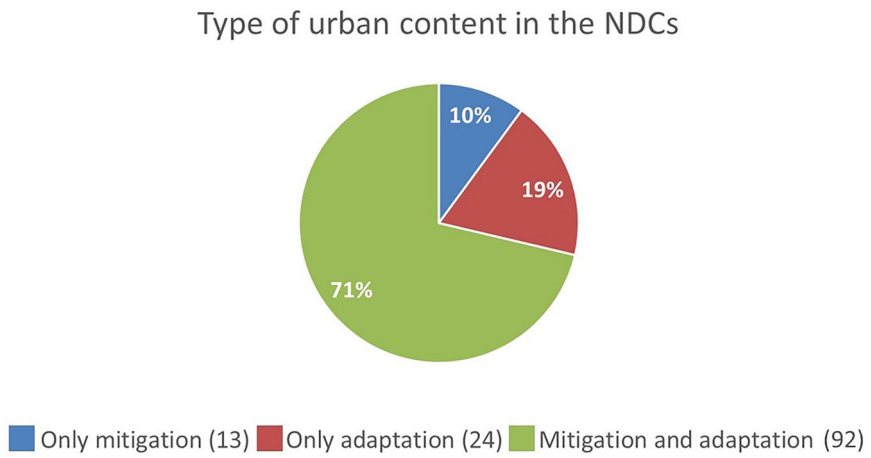

Fig. 2 | Type of urban content in the NDCs. Of the NDCs that include urban-related content, 71% include both mitigation and adaptation related to urban areas (green), nineteen % only adaptation and 10% only mitigation.

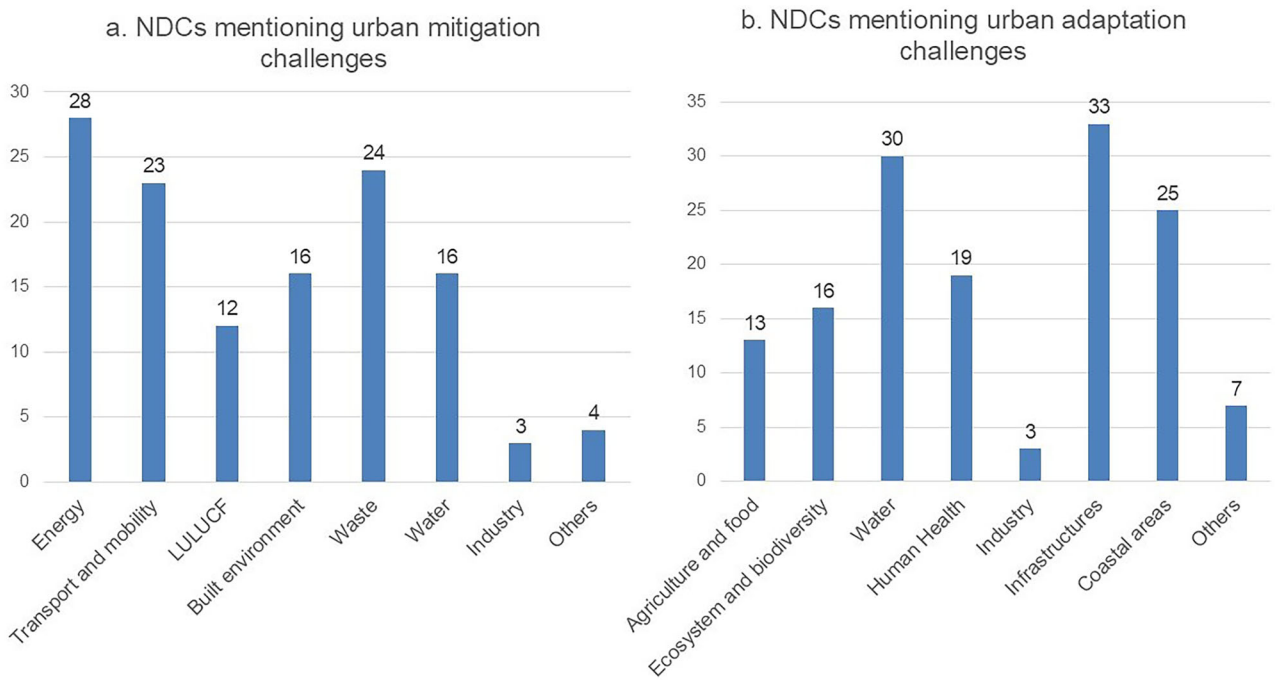

Fig. 3 | Urban mitigation and adaptation challenges in the NDCs. a Number of NDCs mentioning urban mitigation challenges, by sector. The top 3 mentioned mitigation challenges in urban areas are related to the energy sector in 28 NDC, followed by challenges related to waste in 24 NDCs, and challenges related to transport and mobility in 23 NDCs. **b** Number of NDCs mentioning urban adaptation challenges, by sector. The top 3 mentioned adaptation challenges in urban areas are related to the infrastructure sector in 33 NDCs, the water sector in 30 NDCs, and coastal areas in 25 NDCs.

Of the 129 NDCs with urban content, 24 (19%) include only adaptation-related. urban content, whereas 13 NDCs (10%) include only mitigation-related urban content. Sixty-six NDCs (34% of 194 NDCs) did not include any urban content (Fig. 2).

Urban mitigation and adaptation challenges

Urban mitigation challenges are related to energy (in 28 NDCs), waste (24), transport and mobility (23), built environment (16), water (16), LULUCF (12), industry (3) and other miscellaneous challenges not included in the categories selected by the researchers (4).

Urban adaptation challenges are related to agriculture and food (in 13 NDCs), ecosystem and biodiversity (16), water (30), human health (19), industry (3), infrastructure (33), coastal areas (25) and other miscellaneous once that were not included in the set of analytical categories (7) (Fig. 3).

Urban mitigation and adaptation responses

The urban mitigation responses concern the energy sector (in 59 NDCs), transport and mobility (53), LULUCF (31), built environment (39), waste (56), water (28), industry (6), and others not included in the analytical categories (7).

The urban adaptation responses are related to the agriculture and food sector (in 19 NDCs), ecosystem and biodiversity (29), water (48), human health (17), industry (4), infrastructure (55), coastal areas (26), and other responses not covered by the analytical categories (9). (Fig. 4)

Mention of MoI at the urban level

Overall, the majority of the NDCs (48%) include mitigation and adaptation responses whose implementation is partially conditional to international support in the form of finance, technology and/or capacity building at the national level. Of 194 NDCs, 23% are entirely conditional to international

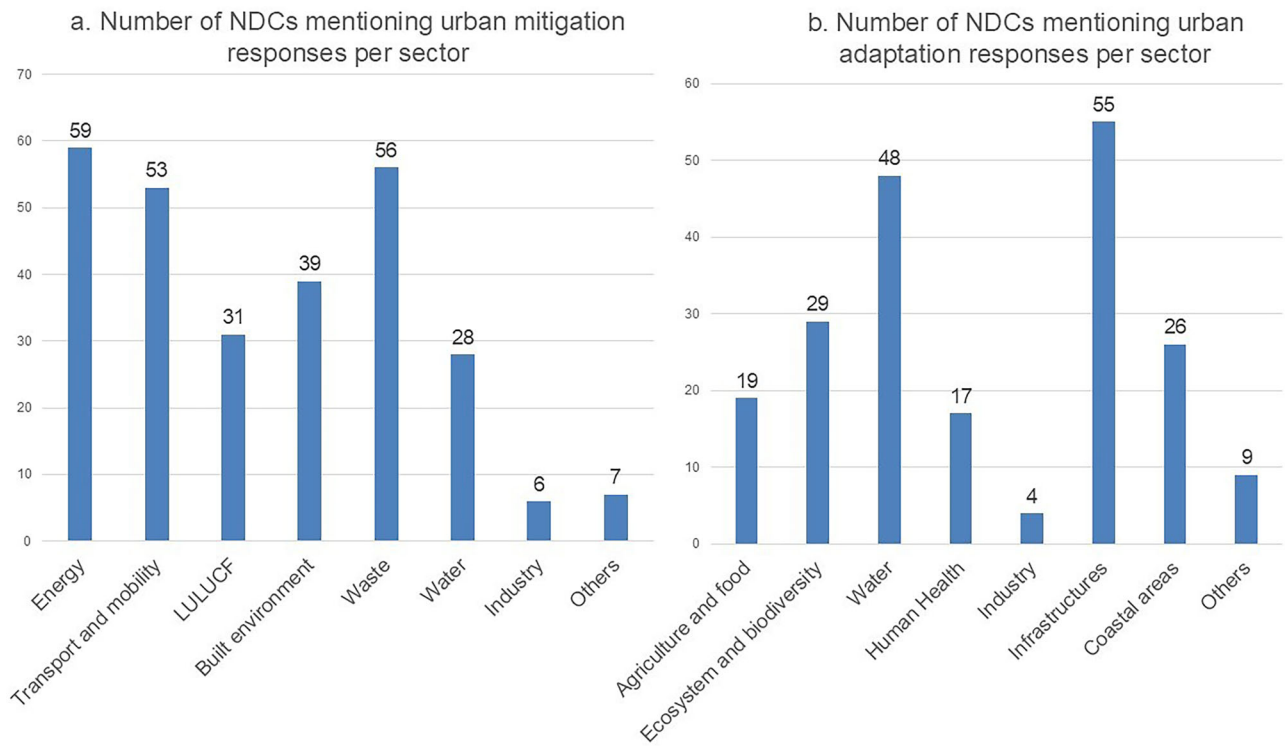

Fig. 4 | Urban mitigation and adaptation responses in the NDCs. a Number of NDCs mentioning urban mitigation responses, by sector. The top 3 mentioned mitigation responses are related to the sectors of energy in 59 NDCs, waste in 56 NDCs, and transport and mobility in 53 NDCs. **b** Number of NDCs mentioning urban adaptation responses, by sector. The top 3 mentioned adaptation responses are related to the sectors of infrastructure in 55 NDCs, water in 48 NDCs and ecosystem and biodiversity in 29 NDCs.

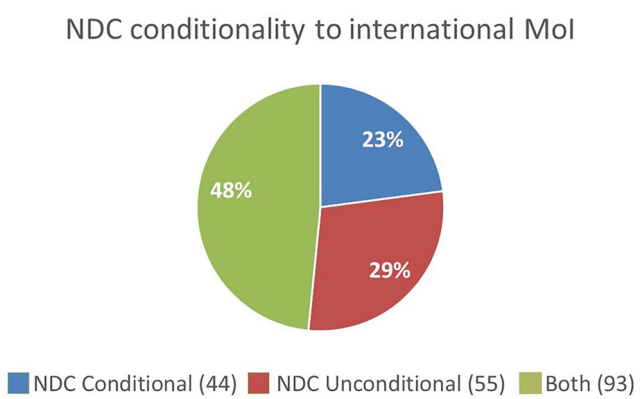

Fig. 5 | NDCs that are conditional or unconditional to international support in the form of MoI (Means of Implementation: finance, technology and capacity building) at the national level. "Both" refers to NDCs that include a mix of conditional and unconditional climate action. 93 NDCs (48%, green) include conditional and unconditional climate action. 44 NDCs (23%, blue) are completely conditional on international support, while 55 NDCs (29%, red) are unconditional.

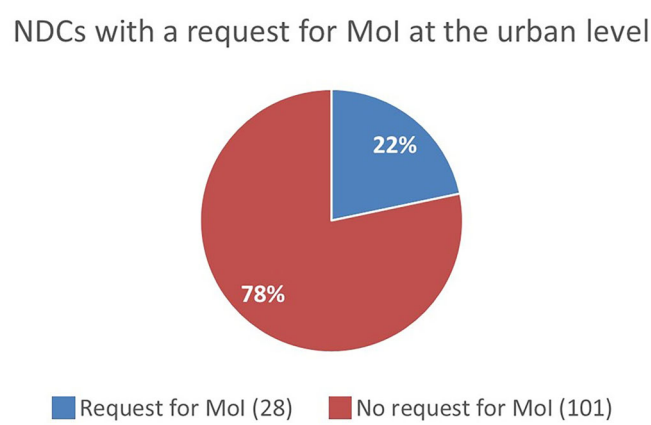

Fig. 6 | NDCs that request MoI (means of Implementation: finance, technology and capacity building) for urban-related climate action. The majority of NDCs that include urban related content do not include a request for MoI at the urban level (78%, red). 28 NDCs include urban content with a request for MoI (22%, blue).

support, and 29% are unconditional, which means that they include responses that will be implemented without any support from the international community (Fig. 5).

Only 22% of the NDCs with urban content include MoI dedicated to their urban climate mitigation and/or adaptation responses, whilst the vast majority of the NDCs, 78%, do not include requests for MoI at the urban level (Fig. 6).

Discussion

We have identified and qualified the urban content in 194 NDCs. Results show that one-third of them do not include any urban content, while the remaining have varied levels of urban content. While it is true that NDCs are mainly focused on the national level, to tackle climate change effectively, cities need to be involved and considered[43,44]. Although the rate of urban content in the NDCs has increased in recent years, according to this research, about one-third of the NDCs do not include cities at all[45,46]. A systematic identification of the status quo is necessary for the effective implementation and monitoring of climate mitigation and adaptation projects, actions, policies, or responses in general. However, looking at the results, there is a gap between urban climate challenges and responses, as more NDCs mention responses than challenges at the urban level.

In fact, NDCs describe actions, projects, programs, or policies to address climate-related issues that haven't been properly identified and

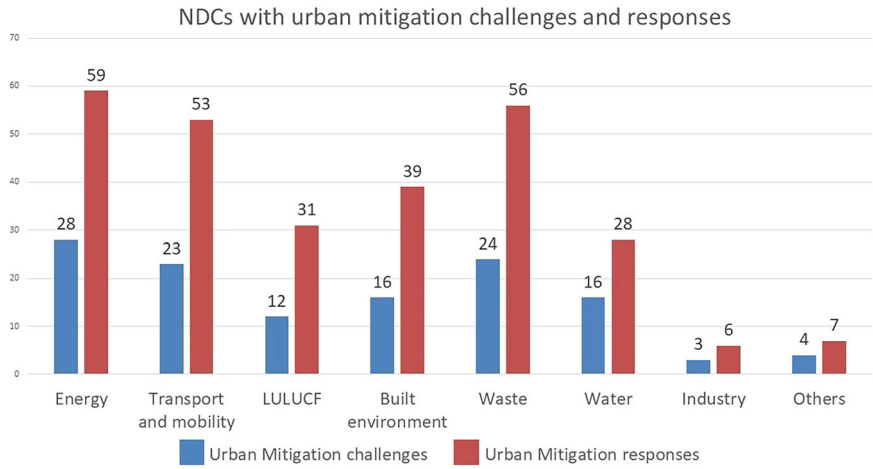

Fig. 7 | Urban challenges vs responses per sector. NDCs with urban mitigation challenges and responses per sector.

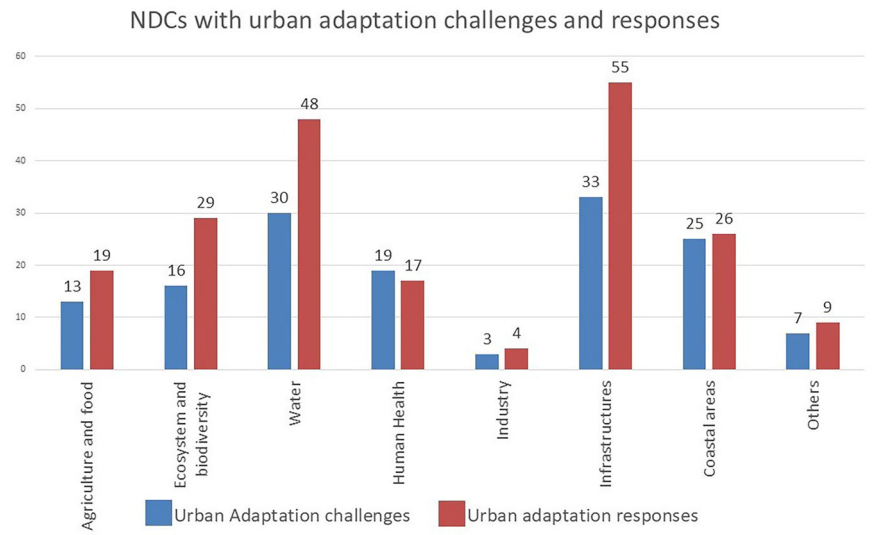

Fig. 8 | NDCs with urban adaptation challenges and responses per sector.

quantified in the NDC. This might be a complication when assessing the outputs, outcomes and impact of a project, policy, initiative or action.

Regarding sectors in urban mitigation (Fig. 7), NDCs appear to mention energy the most, followed by waste, transport and mobility. Interestingly, while waste, transport and mobility are typically urban matters, cities, excluding a minority of cases, usually do not have decisional power over energy, as this is often a national or state matter. In the NDCs, local production, distribution and access to energy seem to be important for mitigation, possibly reiterating the importance of including cities in climate policy design[2,47]. An issue that is usually under the direct control of cities is the built environment and building regulations[48]. However, according to the results of the study, only 16 NDCs mention it as a mitigation challenge, and 39 NDCs provide responses to this challenge.

Looking at adaptation (Fig. 8), responses are more frequently mentioned than challenges.

In terms of sectoral responses, infrastructure, water, and ecosystems and biodiversity are respectively mentioned in the highest number of NDCs. However, looking at adaptation challenges, the most frequently mentioned are infrastructure and water, so in line with adaptation responses, but coastal areas are more frequently mentioned than ecosystems and biodiversity. Despite sea level rise, saline intrusion, coastal erosion and coastal floods being issues faced by coastal areas[49], only 25 NDCs mention challenges for coastal cities, and only 26 provide responses. This is surprising given the high number of cities located within 100 Km from the coast and the 10% of the global population living in coastal areas[50,51]. While the presence of sectoral references does not guarantee implementation, their absence may signal institutional blind spots with implications for policy coherence and resource allocation. Ideally, all sectors affected by or engaged in urban mitigation and adaptation challenges and responses should be included in the NDCs, given that NDCs are the flagship climate action plans that each UN member presents to the UNFCCC.

Across all NDCs, we have found urban mitigation challenges and responses mentioned 405 times cumulatively, while urban adaptation challenges and responses are mentioned 353 times. This reinforces that adaptation efforts often lag behind mitigation ones, even though cities are claimed to be more suitable for addressing adaptation rather than mitigation, which seems to be more of a national climate policy matter.

The synergy between urban mitigation and adaptation is especially important given that cities are responsible for a great share of the emissions that drive climate change and, at the same time, are increasingly exposed and vulnerable to its adverse impact. The scientific literature provides numerous examples of synergies between urban climate mitigation and adaptation. These include green walls and façades, which enhance thermal insulation, reduce heat stress, and improve building microclimates (adaptation), while simultaneously lowering energy demand, reducing emissions from heating and cooling, and sequestering carbon (mitigation). Similarly, urban agriculture, community gardens, and allotments contribute to local food security and urban cooling (adaptation), while also enhancing social

resilience and delivering mitigation co-benefits through carbon sequestration, reduced transport-related emissions, and potential waste reduction. In addition, compact, mixed-use urban development and shifts towards public and active transport are identified as key demand-side interventions that reduce transport-related emissions while improving accessibility, health outcomes, and resilience to climate-related risks, thereby generating combined mitigation and adaptation benefits[44,52,53]. Hence, cities need to embrace climate resilience, which combines mitigation and adaptation considerations, together with sustainability, disaster preparedness and response. To integrate climate mitigation and adaptation, there is a need to consider the limitations of resources and capacities of local governments required to go beyond silos thinking[44].

While almost three out of four NDCs request complete or partial international support for the NDC implementation, at the urban level, only 22% of the NDCs with urban content request support for MoI (finance, technology, and capacity building) at the urban level. NDCs could be leveraged to highlight the need for international support at the urban level, especially given that making cities climate-resilient requires substantial financial resources[30,54].

We concluded that, overall, urban areas, despite their critical contribution and vulnerability to climate change, are not adequately represented in the NDCs. Moreover, urban climate responses in both mitigation and adaptation are more frequently mentioned than challenges, signalling a disconnection between the identification of the urban climate issue to be targeted, and the policy, actions, projects or initiatives (response) listed in the NDC. Among the NDCs that include urban climate content, only 28 NDCs (22% of these) include dedicated MoI, and therefore enabling conditions. Ideally, NDCs should include urban climate challenges, respective responses, and dedicated MoI to allow for effective monitoring and evaluation of implementation, progress, outputs and outcomes of their urban climate responses.

More recent NDC updates display growing recognition of local governments and urban areas, especially in adaptation sections[46], yet these often lack clear mandates, fiscal instruments, or institutional mechanisms to translate national ambition into urban implementation[55]. From a multilevel governance perspective, this distinction is critical: symbolic recognition of cities differs fundamentally from embedded vertical governance, which requires authority, resources, data flows, and accountability across levels[56].

While cities are widely recognised as key actors in climate mitigation and adaptation, their decisional power varies considerably across sectors and across countries[16,23]. For instance, cities in highly centralized states might have low decisional power compared to city-states such as Singapore and Monaco[2,57]. Cities often have limited direct authority over national energy systems, including energy generation, transmission, and pricing, which are typically governed at the national or supranational level[29,58]. However, through land-use planning, building codes, zoning regulations, public procurement, and the design of urban mobility systems, cities exert substantial influence over energy demand and consumption patterns and, therefore, mitigation[59]. Similarly, cities play a central role in adaptation through spatial planning, urban greening, water management, and the provision of critical infrastructure and services[33]. From this perspective, the explicit recognition of urban sectors in NDCs is not a claim about municipal control over all policy levers, but rather about acknowledging where urban governments can meaningfully contribute to national climate objectives and where supportive national frameworks are required.

However, the absence of urban content in one-third of NDCs does not indicate that the respective countries are failing to address climate change in their cities. Simply, their NDC does not reflect their urban climate policies, programs, or actions. For instance, while the NDC of the EU countries doesn't have urban content, most of them have national mitigation and adaptation plans that do contain measures dedicated to cities[29,44]. Moreover, it is important to notice that our study did not judge the effectiveness or adequacy of the urban climate responses included in the NDCs, as this was not the purpose of the study; rather, we focused on the presence or absence of these. Another limitation is that the data gathering was performed by six researchers. As this is a semi-quantitative study that involves reading documents and extracting information deemed pertinent and relevant, despite the protocol, the double checks and consultations, there might still be a margin for error.

Our study offers an in-depth analysis of the level of urban content in the NDCs, as well as its quantification and qualification. While the study was conducted on the NDCs submitted till June 2023, and since then some countries have updated their NDCs, the findings are still relevant because, to the best of our knowledge, no other study has investigated all 194 NDCs and has analysed the urban content per sector. Moreover, it is relevant for the work of the Coalition for High Ambition Multilevel Partnership (CHAMP) initiative.

Conclusion

This review of the urban content of NDCs highlights a well-known critical issue in supporting long-term climate resilience, namely the scarcity of the involvement of local governments in shaping them[43]. Integrating mitigation and adaptation across levels and scales is an ongoing conversation in academic literature, but institutional frameworks fostering local climate resilience seem to be still under-developed.

The main conclusion of this research is that the interdependence of climate-related issues and responses across administrative scales and governance levels is still not fully acknowledged at the national level. To meet climate protection targets with increasing ambition, national governments must be supported by the subnational levels in formulating, executing, and reporting on mitigation and adaptation policies. This is mainly because national governments can fully address climate change only with the cooperation of local players and authorities, since each governmental level has unique potential and constraints[60]. To illustrate this point, the national government is responsible for translating international climate change commitments into coherent national policies, while the regional government provides support and information on the socioeconomic and geographic features necessary for the planning of climate policies. Local governments, in turn, facilitate the scaling up of mitigation and adaptation measures for communities by highlighting the challenges and capacities that are specific to each location. This situation underscores the need for multilevel governance to operationalise NDCs and incorporate provisions for urban areas. Multilevel governance provides a holistic approach, thereby avoiding policy fragmentation, and improves the accountability and transparency of the decision-making process[61].

In the climate change context, multilevel governance has been defined as the "structural and institutional setting in which different levels of government distribute roles and responsibilities, coordinate and cooperate on climate action, as well as the specific instruments that are implemented at different levels of government to support and implement local climate action"[62]. The implementation of climate actions is accelerated by the enhancement of their effectiveness and efficiency, thereby contributing to procedural and distributional equity. This is achieved by addressing the needs of local communities, with a particular focus on those disproportionately vulnerable to the consequences of climate change. Multilevel climate governance engages a diverse array of actors, including public entities at various levels of government, as well as non-state and private entities such as companies, civil society organisations, and research institutions. These actors collaborate to support the objectives outlined in the Paris Agreement. The overarching objective of multilevel governance is to establish connections between national policies and local actions, disseminate climate initiatives across various levels of government, and foster collaboration across communities, groups, and citizens[63]. Integrating multilevel governance in climate actions requires coordinated action between various government levels by enhancing vertical and horizontal coordination[64]. The horizontal dimension pertains to the collaboration between local or regional governmental bodies. Conversely, the vertical dimension concerns the relationships between higher and lower levels of government, thereby prompting inquiries into the role of local action in attaining international and national climate objectives, as well as the way

national governments facilitate local action through financial, technological, and institutional capacities.

Moving to the policy side, supporting multilevel climate governance at the global level calls for a deep understanding of the wide range of different political contexts[65]. As challenges and opportunities differ across countries and cities, multilevel climate governance must deal with a wide range of political contexts, from those where municipal authorities have significant autonomy to those where local autonomy is more limited.

Despite the absence of a universally applicable multilevel climate governance solution, due to the heterogeneity of political, institutional and socio-economic contexts across countries, the capacity of local governments to implement effective climate measures can be enhanced. The coordination of national, regional and local authorities that multilevel governance fosters creates enabling conditions that improve the feasibility of both mitigation and adaptation options. This ensures that climate policies are more context-specific, inclusive and actionable at the urban level[66]. The enhancement of governance structures has been demonstrated to facilitate a more integrated and coherent policy framework, thereby ensuring a more effective alignment between national climate commitments and local implementation. The findings of this study offer valuable insights for policymakers and practitioners seeking to refine their country's NDCs by improving the articulation of national urban climate policies and ensuring that urban considerations are better integrated into sectoral policies. By leveraging these insights, decision-makers can enhance the alignment between NDCs and urban climate priorities, ultimately fostering a more robust multilevel climate governance framework that supports ambitious and effective climate action at all levels of government.

Methods

Urban content

The present research is based on the qualitative documents content analysis[67,68], i.e. "the longest established method of text analysis"[69]. The desk research is performed on all the latest versions of the NDCs submitted to the UNFCCC Secretariat and available on the UNFCCC NDC Registry portal until 27 June 2023 (download day).

Since 2015, some countries submitted only the first version of the NDC, others countries have updated the first submission, and others have submitted the second generation NDCs. All the NDCs were downloaded on 27 June 2023, and the most updated versions available to that date were analysed for this research (Supplementary Table 3).

In this research, urban areas are defined as per the OECD definition[70]. To identify the content in each NDC that could be considered as urban, we have referred to the terms "city/ies", "town(s)", "urban settlement(s)", "metropolis", "metropolitan area(s)", "capital (city)" and "urban". Also, content referring to named cities has been included. Considerations related to "municipality/ies", "municipal area(s)", general "settlement(s)" non-specifically referred to urban, and "village(s)" have been disregarded as these terms might refer to areas that are not urban as per the OECD definition of urban area. Simple mentions referring to the urbanization rate or the urban population have not been accounted as urban content in this research, as these are general statements related to urban, national or demographic statistics.

Therefore, in this study, urban content refers to all the urban climate-related issues in mitigation and adaptation, as well as actions taken to contrast these in the NDCs. "Challenges" refers to urban climate-induced issues that affect the urban areas' capacity to mitigate climate change (mitigation challenges) or to adapt to the changing climate (adaptation challenges). On the other hand, "responses" refers to actions listed to mitigate climate change (mitigation response) or to adapt to changes in climate (adaptation response) at the urban level.

To answer the RQs, the following steps have been taken:

Analysis of scientific and grey literature

The first step consisted of the analysis of scientific articles and grey literature on the topic of urban climate mitigation, adaptation, resilience, and disaster risk reduction in urban areas and the analysis of NDCs. Scientific articles have been extracted from Scopus, Web of Science, or Scholar to identify the knowledge gap and analyse methodologies used in similar studies. The keywords "NDC", "nationally determined contributions" and "local" have been used. "City", "cities", "urban areas" have been excluded because too restrictive and produced too few results. The used keywords allowed us to include studies on all subnational levels and select those relevant to the scope of our study. All publications in English published between 2015 (the year when the Paris Agreement was adopted) and 2023 have been considered.

This phase aimed at identifying knowledge gaps and specific needs in national policies regarding urban areas.

Grey literature was analysed to determine the key urban mitigation and adaptation sectors and the overall knowledge gap. Supplementary Table 4 provides the list of the analysed reports, technical documents and toolboxes.

Definition of key sectors in urban climate mitigation and adaptation

Based on phase 1, the guidelines for NDCs provided by the UN itself[71], the IPCC Assessment Report 6 Working Group II Impact, Adaptation and Vulnerability, and Group III Mitigation of Climate Change, we selected the key sectors for urban mitigation and adaptation to be used as analytical categories. A list of candidate categories has been compiled independently by each researcher and discussed within the team to reach the final list. The analytical categories used in this study are energy, transport and mobility, Land Use, Land-use Change and Forestry (LULUCF), built environment, waste, water, and industry in urban mitigation. For urban adaptation, we used agriculture and food, ecosystems and biodiversity, water, human health, industry, infrastructure, and coastal areas. Each analytical category has been operationalized through a binary yes/no coding scheme to record presence/absence of sector-specific information in the NDC. For example, the analytical category "Energy" was coded as "yes" if the NDC contained explicit discussion of the urban energy sector, and "no" otherwise. This approach is an established practice in climate policy and NDC analysis[29,31,32] and allows for a systematic comparative qualitative assessment of how urban mitigation and adaptation sectors are addressed across NDCs, without implying quantitative measurement of policy ambition or performance (Supplementary Table 1).

Database architecture

The database to store and extracted data from the NDC documents was created with MS Access. Each key sector in Supplementary table 1 represents the climate-related issues that the NDC is supposed to describe (challenge) and address (response). For instance, transport and mobility is a key sector represented by the homonymous analytical category for challenges and responses in mitigation. Since the categories are coded as yes/no and display the presence/absence of the related content, each category had a yes/no dropdown button and a dedicated comment section where the researchers stored the reference to the paragraph and page in the NDC document and the related text that would justify the yes/no choice.

Data collection

We drafted a protocol with the taxonomy for urban mitigation and adaptation challenges and responses (Supplementary Table 1) to minimise the interpretation bias.

All the NDC documents in English, Spanish, and French have been analysed in their original language; however, if an official English version was available, this has been preferred. For NDCs not available in one of these three languages, an automatic English translation has been analysed. Supplementary Table 1 provides a summary of the mitigation and adaptation challenges in urban areas with a related example extracted from various NDCs. The mitigation and adaptation responses are equivalent.

Moreover, information related to the conditionality or unconditionality of the NDC at the national level was collected. If the NDC had urban

mitigation and/or adaptation responses with a related budget, information on conditionality or unconditionality was collected at the urban level as well. In case the NDC was not unconditional, we collected information on the type of MoI request: finance, technology, and/or capacity building (Supplementary table 2).

To avoid interpretation bias, each researcher analysed 3 NDCs assigned randomly in a trial exercise and collected all the information, marking yes/no for each category according to the presence/absence of the related information in the NDC document. For instance, analysing the NDC of country X, a "yes" related to urban mitigation challenges for energy (category "energy" in mitigation challenges) means that the NDC of country X has identified the energy sector as a mitigation challenge at urban level. A "no" for urban adaptation responses in coastal areas (category "coastal areas" in adaptation responses) means that the NDC did not include any response/project/action/initiative dedicated to adaptation in coastal areas at urban level. In the trial exercise, each researcher presented his work to the rest of the team. The work was discussed by the whole team, which provided feedback to make sure that all had the same approach to data collection and interpretation. The data collection from the 194 NDCs was performed by a team of 6 researchers between 27 June 2023 and mid-September 2023. The team manually read and extracted the information from the NDC documents and compiled the MS Access Database. During this period, each researcher would double-check 5 randomly assigned NDCs analysed by a colleague and provide feedback to correct and avoid interpretation bias. Hence, about 15% of the NDCs have been double-checked. When in doubt on whether certain information was substantial enough to mark it as a "yes", the researcher would discuss this with the team. Moreover, once the data collection was completed, a series of check queries on all NDCs were performed to ensure consistency and completeness of the data before moving to data analysis. Whenever a doubt on interpretation arose, we would update the protocol, and eventually all the analysed NDCs to ensure consistency.

Data analysis

Once the database was complete and all the data had been cross-checked and corrected, the data was analysed with MS Excel to answer the RQs by counting the number of NDCs that had mitigation and/or adaptation challenges and/or responses.

To evaluate the level of urban content, we have considered:

- Whether the NDC had a chapter or section dedicated specifically to urban areas, or the NDC clearly stated that urban areas are a priority for climate action,
- Whether the NDC had urban mitigation and/or adaptation challenges and/or responses, and whether there was a gap between challenges and responses,
- Whether urban mitigation and/or adaptation responses were supported by dedicated MoI.

According to the collected information, NDCs have been classified into the following 3 clusters:

- Cluster A: strong urban content. NDCs with one or more sections specifically dedicated to urban areas, and/or NDCs in which urban areas are explicitly identified as priority sectors, excluding NDCs that are not backing up the prioritization with a clear identification of specific urban challenges and/or responses.
- Cluster B: moderate urban content. NDCs with urban mitigation and/or adaptation challenges and/or responses that have not explicitly identified urban areas as a priority sector nor have a dedicated section to urban areas.
- Cluster C: low to no urban content. NDCs with low or no explicit urban mention within the text.

An exception was made for the NDCs belonging to the city-states of Vatican City (Holy See), Singapore, and Monaco. Their content was considered urban by definition and, therefore, assigned to cluster A.

Data availability

The dataset generated and analysed during the current study is not publicly available because the University of Southern Denmark detains the intellectual property. However, the minimal dataset necessary to interpret, replicate and build upon methods and findings in this article is available from the corresponding author on reasonable request.

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Author contributions

N.T.: principal investigator. P.G., M.P., and Y.L.: conducted the study. P.G. took the lead in writing the article and revising the initial draft. S.G., O.C., D.S., M.M.C., and J.M.: served as advisors to the study and to the initial draft of the article.

Competing interests

The authors declare no competing interests. Author David Simon is an editorial board member of NJP Urban Sustainability. Dr. David Simon was not involved in the journal's review of, or decisions related to this manuscript.

Additional information

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