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Climate change adaptation planning in large cities: A systematic global assessment

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ABSTRACT

Cities globally face significant risks from climate change, and are taking an increasingly active role in formulating and implementing climate change adaptation policy. However, there are few, if any, global assessments of adaptation taking place across cities. This study develops and applies a framework to track urban climate change adaptation policy using municipal adaptation reporting. From 401 local governments globally in urban areas with >1 m people, we find that only 61 cities (15%) report any adaptation initiatives, and 73 cities (18%) report on planning towards adaptation policy. We classified cities based on their adaptation reporting as *extensive adaptors, moderate adaptors, early stage adaptors,* and *non-reporting.* With few exceptions, *extensive adaptors* are large cities located in high-income countries in North America, Europe, and Oceania, and are adapting to a variety of expected impacts. *Moderate adaptors* usually address general disaster risk reduction rather than specific impacts, and are located in a mix of developed and developing countries. *Early stage adaptors* exhibit evidence of planning for adaptation, but do not report any initiatives. Our findings suggest that urban adaptation is in the early stages, but there are still substantive examples of governments taking leadership regardless of wealth levels and institutional barriers.

1. Introduction

Cities globally face significant risks from climate change (Revi et al., 2014). Urban areas are home to >50% of the world's population, are growing rapidly, and often concentrate economic activity, population, and infrastructure in high-risk locations. Many of the largest cities are located in coastal areas, for instance, and are thus exposed to projected increases in sea level, storm activity, and associated flooding (Hallegatte et al., 2013; Hanson et al., 2011). Given these threats, cities are taking an increasingly active role in climate policy action, with mitigation experiences well-documented (Castán Broto and Bulkeley, 2013; Bulkeley, 2010). There are also widely referenced examples of city leadership and action on adaptation (e.g. New York, London) (Rosenzweig and Solecki, 2014; Wilbanks, 2011). Yet there have been few, if any, global-scale analyses of what cities are doing to adapt: is adaptation taking place, where, by whom, and in what ways? (Berrang-Ford et al., 2011) The purpose of this article is to shed light on the emerging adaptation practices of cities globally.

Identifying, monitoring and evaluating adaptation at a large-scale presents significant conceptual and methodological challenges (Dupuis and Biesbroek 2013; Ford et al., 2013). Unlike mitigation, where greenhouse gas emissions can be measured to examine the effectiveness of policy initiatives, there are no similar 'off-the-shelf' metrics available for adaptation (Ford and Berrang-Ford, 2015). In the follow-up from a new international climate agreement in Paris, where cities are identified as important actors for mitigation and adaptation, it is thus of paramount importance to develop standards, methodologies, indicators and baselines for assessing progress towards adaptation goals (Ford et al., 2015; UNFCCC, 2015). We refer to such work as 'adaptation tracking', a subcomponent of monitoring and evaluation that seeks to systematically identify, characterize and compare adaptation across nations or cities and over time.

Adaptation tracking research has highlighted the need for comparative, systematic analysis of adaptation action and reporting across nations and cities. The major obstacle to such efforts remains the absence of appropriate data sources that fulfill the 4Cs

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of adaptation tracking: a *consistent* and operational conceptualization of adaptation, *comparable* units of analysis, *comprehensive* datasets on adaptation action, and *coherence* with our understanding of what constitutes adaptation (Ford and Berrang-Ford, 2015). Data and knowledge on adaptation are difficult to find, and we have to date relied on the reporting of adaptation as the only option currently available for systematic analysis (Berrang-Ford et al., 2014; Gagnon-Lebrun and Agrawala, 2007, Lesnikowski et al., 2015; Reckien et al., 2014). Though an imperfect proxy sample of adaptation on the ground, adaptation reporting is used to identify trends in adaptation action and planning (Berrang-Ford et al., 2014; Ford et al., 2013; Gagnon-Lebrun and Agrawala, 2007; Lesnikowski et al., 2015; Reckien et al., 2014). Reporting of adaptation in itself is an important proxy providing insight into how governments recognize and prioritize adaptation options (Austin et al., 2015). Limited reporting of adaptation programmes and actions may hinder sharing of experiences and best practices, transparency, and effective monitoring and evaluation.

Despite the importance of cities as administrative units where adaptation will be implemented, adaptation tracking studies have been undertaken predominantly at the national level (Lesnikowski et al., 2015). There is negligible comparative and systematic research available on the extent to which global cities are responding to, and reporting on, climate change adaptation. In response to this gap in baseline characterization of global urban adaptation, we develop a framework to characterize reporting on adaptation planning in urban areas globally over 1 million people, creating a descriptive classification of the types, extent, and nature of adaptations in diverse urban contexts.

2. Tracking urban adaptation to climate change

A number of studies have examined adaptation progress, compared different government systems, and proposed "best practices" for adaptation planning in urban areas (Revi et al., 2014). International climate policy has set an adaptation financing goal of $100b per year and so a key challenge will be to track adaptation to ensure accountability and transparency in governance processes (Adger 2003; Ford et al., 2015; Preston et al., 2011). Reporting on progress toward planning adaptation helps the public keep track of whether investments in adaptation are consistent with the outputs (Preston et al., 2011).

While many specific examples of adaptation are being documented, systematic global assessments of urban adaptation are scarce. Most comparative policy studies on urban adaptation have focused on districts within one city, comparing cities within one country or on a particular continent, but not globally (Austin et al., 2015; EEA, 2012; Heidrich et al., 2013; Reckien et al., 2014, 2015). City-specific and regional studies have analyzed barriers and enablers of adaptation progress. Other country-level and regional analyses meanwhile have used publically available municipal planning documents to assess the state of adaptation in multiple cities, mostly in developed contexts (Austin et al., 2015; Reckien et al., 2014). While these in-depth case studies and small-n comparative analyses provide important baseline information on whether adaptation is being considered in specific urban contexts, inference to the global scale requires research with larger sample sizes and seeking breadth to complement depth (Araos et al., 2015; Ford and Berrang-Ford, 2015).

Surveys have also been used to produce large scale assessments of adaptation (Aylett, 2015; Carmin et al., 2012b; CDP, 2014). These surveys assess the content of adaptation policies and the priorities of cities regarding different climate impacts (Aylett, 2015; Carmin et al., 2012b; CDP, 2014). Carmin et al. (2012b), for instance, offer a snapshot of adaptation policy-making in ICLEI member cities by quantifying reported progress on planning and challenges, such as the creation of vulnerability assessments and financing of adaptation projects. Aylett (2015) found that while a number of cities report integrating adaptation planning into their agendas, many sectoral agencies remain uninvolved in climate change planning (Aylett 2015). Surveys can be a powerful method to assess adaptation as researchers can ask focused questions to identify progress or pinpoint factors for adaptation success, and survey-based studies have so far been important contributions to the study of urban adaptation.

In this study we draw on publically available information on urban adaptation policy, with the presupposition that adaptation tracking initiatives and data sources should be guided by: 1) data sources that transparent and open-access datasets for open-source analysis; 2) consistent data collection strategies that facilitate longitudinal analysis of adaptation progress over time, and; 3) are consistent with the 4Cs of adaptation tracking. The goal is to build on existing studies that use expert knowledge and opinion with systematically collected publically available data from climate change planning documents.

3. Framework for tracking urban adaptation across cities globally

We developed a conceptualisation of urban adaptation that allows for comparative analysis, building on previous efforts described in Section 2 (see supplementary materials for detailed figures and further description of the framework components). We characterized urban adaptation along two axes, policy content and policy process, building on the literature evaluating urban adaptation and proposed frameworks for comparing local adaptation (Vogel and Henstra, 2015). In doing so, we are guided by best-practice approaches for systematic review in adaptation research (Berrang-Ford et al., 2015) and the 4Cs of adaptation tracking as proposed by Ford et al. (2015).

3.1. Defining adaptation for systematic review

One of the reported challenges to engage in comparative policy studies is to overcome the challenge of identifying what is being compared. Here we use the IPCC AR4 definition of planned adaptation as "Adaptation that is the result of a deliberate policy decision, based on awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state" (IPCC, 2007). Thus we gathered and analyzed government documents that reported on purposeful adaptation designed to reduce vulnerability to climate change, as per the literature on comparatives studies of adaptation (Dupuis and Biesbroek 2013; Heidrich et al., 2013; Reckien et al., 2014). In this study we focus on government-led adaptation, as municipalities have an important role in adaptation due to managing services and utilities, as well as having authority over important levers of adaptation such as land use regulation and building codes (Bulkeley et al., 2011). Nonetheless, we recognize that adaptation is frequently conceptualized as adjustments by individuals, communities, the private sector, and NGOs, among others. (Carmin et al., 2012a; Romero-Lankao and Dodman, 2011).

3.2. Policy content

Policy content refers to the thematic content of policy and the government's methods for implementing policy (Henstra, 2015; Howlett and Rayner, 2007). In this study we assessed policy content through a thematic and typological classification of adaptation initiatives in urban areas. An adaptation initiative is defined here as any individual adaptation program, action, or project reported by the municipality. We characterize these

adaptation initiatives according to whether they are groundwork initiatives or adaptation actions, according to adaptation policy typology, climate impacts, and affected human systems, building on prior work in the adaptation tracking scholarship that has used adaptation reporting as a data source (Lesnikowski et al., 2015). We assess whether initiatives are groundwork or action. Groundwork initiatives are intended to enable the conditions necessary for adaptation, but do not reduce vulnerability directly. Groundwork initiatives aim to build a context conducive to adaptation, while adaptation actions directly reduce vulnerability to climate change (Dupuis and Biesbroek 2013). For example, a research project identifying the most cost-effective type of permeable road surface will be classified as groundwork, while the installation of the new road type will be classified as an adaptation actions.

We also classified initiatives according to their policy typology. Adaptation policy typology provides a way to identify how governments prioritize different types of policies. We adapted Biagini et al.'s (2014) typology categories and classified each adaptation initiative (both groundwork and actions) into one of five categories: capacity building; management, planning, and policy; practice and behaviour; information; and financing. This classification system provides insight into what adaptation looks like in practical terms (Howlett and Rayner 2007).

To understand what motivates cities to adapt and to contextualise the type of adaptation initiatives identified, we characterize initiatives according IPCC-defined climate change impacts and affected sectors in urban areas. The five direct and indirect climate change impacts in urban areas identified in the IPCC's Fifth Assessment Report (AR5) were used for this classification: heat spells, drought, coastal exposure, inland flooding, and human health issues (Revi et al., 2014). The first four impacts are extreme weather events, expected to increase in frequency intensity and duration with climate change. The IPCC AR5 also outlines six urban sectors exposed to climate change impacts: water supply; energy supply; transportation and telecommunications; the built environment; green infrastructure and ecosystem services; and human and social services (Revi et al., 2014). We use these sectors to specify which impacts and systems are being addressed and prioritized by each city, identifying gaps in adaptation policy.

3.3. Policy process

The axis of policy process refers to the *steps taken* by governments to plan and implement adaptation policy. Although there are many components of a policy process, we base this axis on a review of existing components of the adaptation decision-making process (Hinkel et al., 2013; Mukheibir and Ziervogel 2006; Prutsch et al., 2014). The following indicators measure policy process: a) evidence of analysis of climate projections; b) evidence of preparation of vulnerability assessments; c) consideration of multiple sectors; d) re-assessment of development priorities in the face of climate change; e) the creation of a climate change planning documents; f) usage of consultative tools and stakeholder engagement; g) management of barriers and uncertainty; h) and monitoring and evaluation of adaptation activities. Although these steps resemble the stages in a policy process, they are not necessarily sequential in practice (Vogel and Henstra, 2015). Nonetheless, a focus on components of the municipal planning process has been proposed as heuristic to facilitate municipal adaptation planning and enable the characterisation of the state of urban adaptation (Mukheibir and Ziervogel, 2006).

4. Methods

To assess the state of urban adaptation we used systematic data collection and analysis methods (Berrang-Ford et al., 2015). We used web-based climate change planning documents from cities as a proxy for identifying and characterizing adaptation taking place. Information was retrieved from urban municipalities selected on the basis of population and language of official documents (see Appendix A in Supplementary materials for inclusion criteria and reference list of reviewed documents). Adaptation information was retrieved from Municipal Adaptation Plans, Climate Action Plans, and government projects in partnership with NGOs. The documents were retrieved on a city-by-city basis using the search engine Google with a two-stepped process. First, we identified the city's municipal website, then scanned the site for adaptation planning documents, either on the website itself or linked from the website. For the second step, if no adaptation documents were found on the website, we performed another Google search using the search terms *climate change* and the city's name. We reviewed the first fifty results (5 pages) based on title and page description. From the retrieved documents we extracted discrete individual initiatives to form a database. We used this dataset to produce a set of descriptive statistics to outline global trends in urban adaptation. Our use of official government documents is consistent with adaptation tracking research in other sectors and scales (Carmin et al., 2012b; CDP, 2014; Heidrich et al., 2013; Reckien et al., 2014), and underpins consistency in the data source as all documents were published by municipal government. Consistency in the source of data is a key consideration in studies tracking adaptation (Ford and Berrang-Ford, 2015).

We focused on urban areas with over 1 million inhabitants, as per the United Nations definition of "urban agglomeration" (Heilig, 2012). UN-reported urban agglomerations often encompass several municipalities (Heilig, 2012). For the majority of agglomerations we collected and analyzed data for the central municipality. In some highly fragmented urban areas, however, we accessed the website of the urban region's (i.e. metropolitan area) government. Municipalities were included for analysis where a language was spoken in at least five cities with over 1 million inhabitants. This included: English, French, and Spanish (spoken by the research team), and Chinese, Arabic, Russian, German, Portuguese, Farsi, Korean, Japanese, Turkish, and Indonesian (using hired translators). Cities with languages spoken in <5 cities were excluded due to the logistical constraints of hiring translators for a small number of observations.

The final dataset contains 401 urban areas covering 1.3 billion people: 33 cities in Africa, 164 in Asia, 33 in Europe, 63 in South and Central America, 50 in North America, and 6 in Oceania. Chinese cities with over 1 million inhabitants comprise nearly a quarter of all cities in the study ($n = 92$). Data were collected between early January and the end of March 2014. Any documents published online after this date were excluded. We accessed 2 metropolitan government websites (Santiago, Chile; London, UK), and the remainder are municipal government websites.

We developed a coding system based on the framework for tracking urban adaptation categories listed in Section 3 (for detailed description of coding categories and examples from city documents see Appendix B in Supplementary materials). The coding system classified each adaptation initiative according to the climate impact and affected sector motivating the initiative, as well as its policy type. Further, each city was assigned a *process score* based on how many elements of the process indicators are reported, from the list presented in Section 3. Once the coding was completed, cities were classified according to their reported adaptation status (see Table 1 for classification criteria). Cities were classified relative to each other, rather than to an objective standard of what constitutes extensive or moderate levels of adaptation due to a the lack of consensus in defining 'successful' adaptation.

4.1. Limitations

Our focus on government-led adaptation does not eliminate reporting bias. Even where adaptation is occurring, it may not be reported, and this bias may result in under-reporting of adaptation initiatives in low-income nations. Our focus on large urban centres – often the most technologically advanced hubs in even poorer nations – mediates some but not all of this bias. Evaluating the potential impact of reporting bias is a grand challenge in adaptation tracking research. The central challenge is that it is difficult to establish how closely aligned adaptation *reporting* is with the on-the-ground implementation. We thus sought to evaluate the potential role of reporting bias in affecting our results. There are limited data available, however, at the city level for global urban centres that provide proxy measures of reporting capacity (e.g. technological capacity). Variables such as mobile phone coverage or electricity coverage, for example, are available for only 8–12% of global cities in our dataset. We thus tested and present the impact of wealth and urban population size on adaptation status, and discuss implications of reporting bias in adaptation tracking research. Beyond reporting bias, we also acknowledge that we do not capture urban-related adaptation led by governments other than municipalities. While local governments plan and implement concrete strategies, national governments in some cases dictate broad policy directions for urban-related climate change concerns. In Bangladesh, for instance, the National of Adaptation Programme of Action urges to raise capacity in local governments to enhance the resilience of urban infrastructure (Government of Bangladesh, 2005). Local governments, in turn, will then have an increased capacity to integrate climate change concerns when upgrading or building new urban infrastructure. Lastly, each city's adaptation efforts will be affected by how urgent and widespread are the threats from climate change. Lack of available data on vulnerability for the 401 cities in our analysis precludes an analysis of the relationship between the adaptation planning and the risks a city faces.

5. Results

5.1. Global trends

We retrieved and analyzed 997 adaptation initiatives reported from 74 large cities in 80 countries. Only 18% of all cities analyzed report any adaptation activity, and for most of the 401 cities evaluated (81%, n = 327) we found no evidence of adaptation policy (neither *policy content* nor *process*) taking place (Fig. 1). 72% of the initiatives documented are directly and intentionally targeted reductions of vulnerability or resilience building (i.e. adaptation actions), as opposed to 28% for groundwork responses (i.e. those building capacity to enable adaptation actions).

Most governments report undertaking direct forms of adaptation activities such as management, planning, policy, and behaviour changes (62% of total initiatives) rather than capacity building, financing, or research (38%). These findings, although descriptive, appear to support the argument by Adger et al. (2005) that local scales deliver direct adaptation (management, planning, policy, and practice and behaviour functions), while higher level jurisdictions deliver enabling policy to create supportive institutional environments (Adger et al., 2005; Austin et al., 2015).

Climate change impacts and sectors targeted vary across cities, but initiatives targeting coastal impacts, the built environment and green infrastructure are most frequent. Only 142 initiatives (14%) target health and social services, while the rest focus on protecting physical infrastructure. The study design allowed for classification of initiatives into more than one category, but the majority (97%) of initiatives do not target more than one impact at a time, and none of the initiatives address more than one sector at a time. Serrao-Neumann et al. (2014) argue that adaptation must be integrated across sectors to deal with sectoral trade offs, suggesting that the mono-sectoral initiatives identified here can be limited in their effectiveness. With regards to policy *process*, cities performed overall slightly better than on policy *content*. Over half (60%) of cities reporting on adaptation (reporting either any initiatives or any planning process score, n = 74) scored over three in adaptation planning process (reporting undertaking over three of the eight components of adaptation planning process described in the methods), while 40% scored between one and three. Broken down by the adaptation planning process components, a majority of adapting cities show evidence of a climate projection (89%) and vulnerability assessments (87%). On the lower end, less than half of city governments report undertaking monitoring and evaluation of adaptation initiatives (49%), engaging with stakeholders (48%), and acknowledging barriers or uncertainties in the adaptation policy-making process (32%).

There was a positive correlation ($r = 0.49$, $p < 0.001$) between cities' policy process score and the number of adaptation initiatives

Table 1
Cities and their adaptation classifications.

Classification	Criteria and description	Cities (see sup. mat. for document references)
Extensive adaptors	• Top quartile of both adaptation initiatives and process score (>17 initiatives, >6 process score) • Adapting to all IPCC-identified impacts • Global leaders	Birmingham, Boston, Cape Town, Hamburg, London, Marseille, Melbourne, Minneapolis, New York, Sacramento, Semarang, Toronto, and Vancouver.
Moderate adaptors (high)	• Above median of adaptation initiatives and process score (>7 adaptation initiatives, >5 process score), excluding extensive adaptors • Substantial effort to produce adaptation policy, but not the *extensive adaptors*	Adelaide, Baltimore, Chicago, Dublin, Durban, Glasgow, Los Angeles, Manchester, Mexico City, Paris, Portland, Quito, Santa Cruz, Santiago, Seattle, Seoul, Singapore, Surabaya, Sao Paulo, Wenzhou, and Yangzhou.
Moderate adaptors (low)	• Either <7 adaptation initiatives (median) or <5 process score (median) based on web reporting • Reporting suggests limited, ad-hoc, and often tokenistic efforts to integrate climate change into city planning	Austin, Berlin, Bridgeport, Brisbane, Buenos Aires, Caracas, Chongqing, Cincinnati, Edmonton, Grande Vitoria, Haerbin, Handan, Hong Kong, Jingzhou, Johannesburg, Kaohsiung, Leeds, Linyi, Lyon, Miami, Montreal, Nantong, Ottawa, Port Elizabeth, San Francisco, Shanghai, Tokyo, Vereeniging, and Zhongshan.
Early stage adaptors	• Zero adaptation initiatives reported on-line, but >0 process score. • Exhibit evidence of planning for adaptation, but report no adaptation initiatives	Auckland, Bogota, Calgary, Cleveland, Fuzhou, Philadelphia, Pretoria, San Diego, Sydney, Tai'an, and Taichung.
Non- reporting	• Zero reported initiatives and zero process score reported • No reported, web-based evidence of adaptation policy-making	See Appendix C for full list (n = 328)

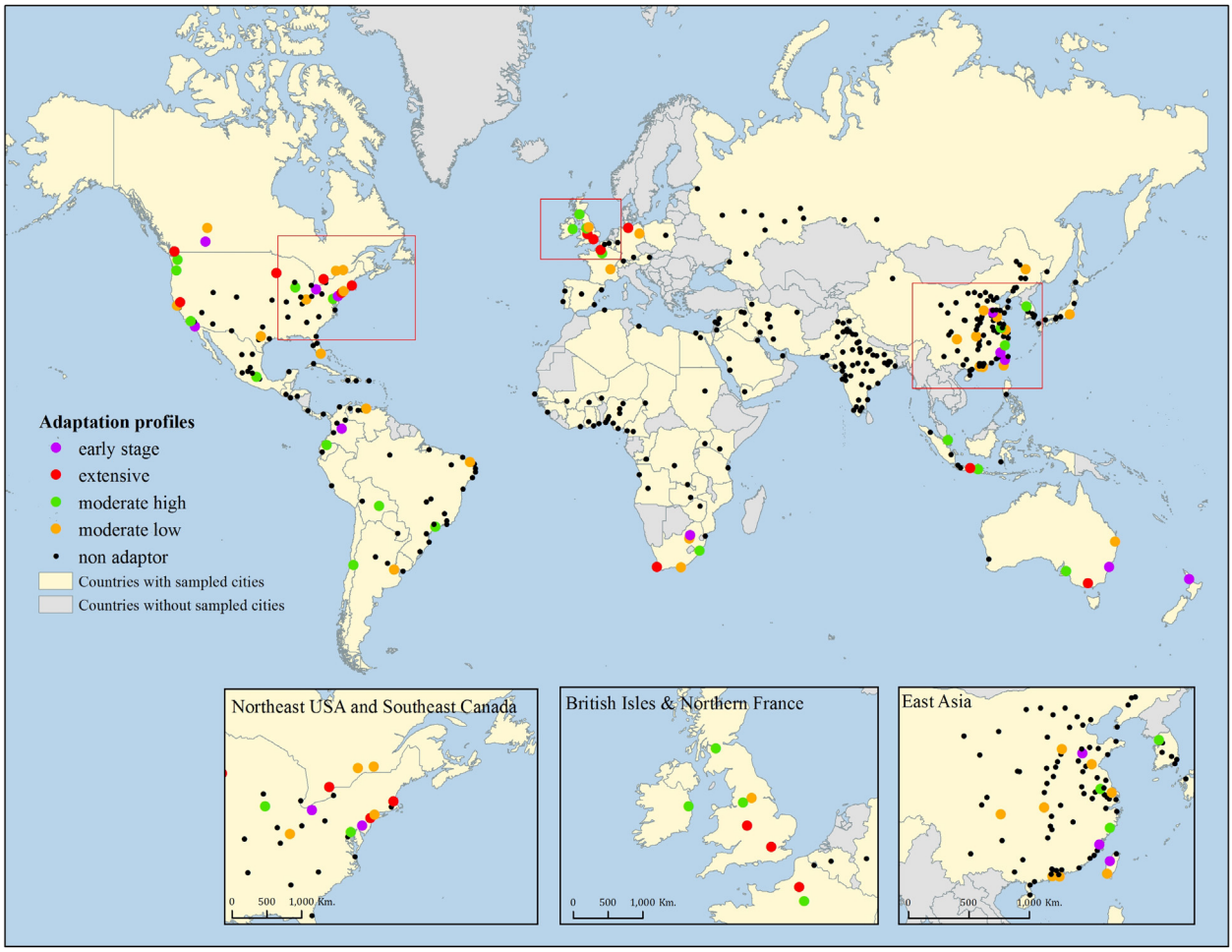

Fig. 1. Map of global urban adaptation.

reported, excluding New York. The U.S. city was excluded because it is a significant outlier with 243 reported initiatives, over a quarter of the total adaptation initiatives identified globally (Fig. 2). Notably, many cities showed evidence of progress on policy process yet did not report – or reported few – adaptation initiatives, implying early phase engagement with adaptation. The inverse did not occur, however: with few exceptions, cities did not report adaptation initiatives in the absence of adaptation process.

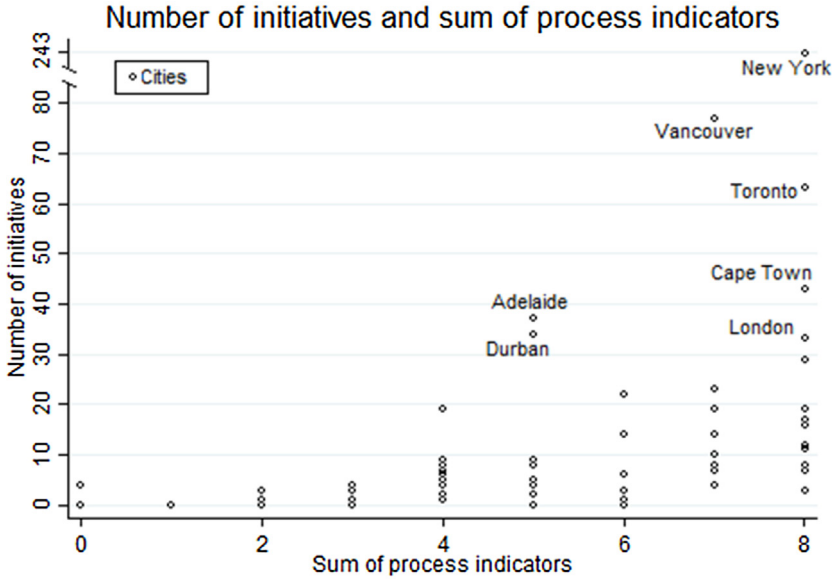

Fig. 2. Relationship between number of initiatives and process indicators (cities with 30+ initiatives labelled to highlight highest performers).

The distribution of adaptation activity *within* continents is heavily skewed. New York City represents over half of North America's initiatives and South Africa is the only African country with cities reporting adaptation online. In Asia there are also outliers. Singapore reports 15 discrete initiatives. In contrast, adaptation in Latin American cities is more dispersed, with large capital cities usually reporting some adaptation. Many cities in low and middle income countries report adaptation initiatives above the global median (7 initiatives), such as Cape Town, Semarang, Quito, Santa Cruz, Surabaya, Wenzhou, and Yangzhou.

5.2. City adaptation classification

We classified adapting cities into *extensive adaptors*, *moderate adaptors*, *early stage adaptors*, and *non-reporting* based on a classification of reported initiatives and policy process (Table 1).

5.2.1. Extensive adaptors

Extensive adaptors (n = 13) represent cities reporting in the top quartile of number of adaptation initiatives (> 17 initiatives) and reported evidence of planning for adaptation, and include two global mega-cities (New York and London) (Table 1). *Extensive adaptors* frequently undertake concrete initiatives explicitly aimed at reducing climate change vulnerability. Often, *extensive adaptors* report adaptation in the form of dedicated policy documents such as adaptation plans or as distinct sections of climate change strategies. With the exception of Cape Town and Durban in South Africa and Semarang in Indonesia, all extensive adaptors were located in North America, Europe, or Oceania. Cities in this classification frequently took actions regarding expected coastal impacts, the urban environment, green infrastructure, and urban water supply. Management, planning, and policy, as well as practice and behaviour initiatives compose the bulk of adaptation activity among extensive adaptors.

5.2.2. Moderate adaptors

Moderate adaptors reflect cities reporting some adaptation initiatives and process indicators, but below the top quartile (Table 1). Given the global absence of evidence of adaptation action (83% of cities classified as non-reporting), *moderate adaptors* reflect a range of cities producing adaptation initiatives and engaging in the policy-making process. We identify 2 sub-categories of *moderate adaptors*: *high moderate adaptors* (44%, n = 21) and *low moderate adaptors* (56%, n = 30). *High moderate adaptors* typically engage in a small number of initiatives that may reflect emerging and recent efforts to build a foundation for more adaptation activity on a pathway towards increased adaptation (i.e. towards *extensive adaptors)*. *Low moderate adaptors* are cities with limited, ad-hoc, and often tokenistic efforts to integrate climate change into city planning. Miami in the United States, for example, reports air quality improvements and storm water management as adaptation initiatives, but present no evidence or suggestion that policy is being enhanced within the specific context of climate change impacts.

5.2.3. Early stage adaptors

Early stage adaptors (n = 11) are cities showing evidence of adaptation policy-making (*policy process)* but not reporting any adaptation initiatives (*policy content*). We infer that some of these cities have taken first steps on their way to more substantial adaptation. Philadelphia and Cleveland in the United States, for example, report extensively on mitigation initiatives, but have not developed the adaptation portion of their climate change action document. Climate projection and vulnerability assessments are reported along with the need to develop adaptation strategies, but they report no initiatives thus far. The most common process reported by *early stage adaptors* is the assessment of future climate trends and vulnerability assessments, suggesting that city governments are aware of the impacts and vulnerabilities they face, but have not begun planning specific initiatives.

5.2.4. Non-reporting

Cities reporting no adaptation activity in government plans, either *policy content* or *process*, were categorized as *non-reporting*, and this category captured the majority of cities in the dataset (81%, n = 328/401) (Table 1). *Non-reporting* cities are globally distributed, with cities in all regions and all income levels reporting no publically-available documentation of adaptation. Of 43 Indian cities in our dataset, for example, we found no examples of municipal government adaptation being reported. Ninety-two percent (185/202) of cities in Asia do not report adaptation initiatives, 89%% (42/47) in Africa (all in South Africa), and 87% (55/63) in Latin America. By contrast, in our dataset 71% (24/34) of cities in Europe report adaptation, as well as 62% (31/50) of cities in North America, and 50% in Oceania (3/6 of these in Australia).

5.2.5. Adaptation reporting vs. adaptation action

Cities reporting adaptation initiatives (adaptors) were significantly wealthier and larger than cities reporting no adaptations (non-reporting).[1] Population was largely associated with adaptation status due to its collinearity with wealth (larger cities are poorer on average, and poorer cities typically reported fewer or no adaption initiatives), indicating that wealth is the more important determinant of adaptation reporting. Indeed, other studies testing drivers of urban adaptation have found that larger cities were more likely to have an adaptation plan (Reckien et al., 2015). These associations were robust when using adaptor classification, number of initiatives, process score, and when removing outliers (e.g. New York). These results are consistent with research on the determinants of adaptation, highlighting wealth as a likely common driver of both adaptation action and adaptation reporting (Berrang-Ford et al., 2014). Despite inclusion of a range of languages and translators, English-speaking cities were more likely to be adaptors.[2]

6. Discussion

To our knowledge, this paper provides the first systematic global assessment of adaptation reporting in large urban areas, using web-based reporting as our data source. The methods used in the study rely on publically available data on urban adaptation policies, rather than expert opinions and impressions or the normative selection of 'best practices'. Municipal reporting of adaptation indicates that most cities with >1 million people do not yet report planning for climate change, yet some cities exhibit significant progress. We classified cities as *extensive adaptors, moderate adaptors, early stage adaptors,* and *non-reporting.* With few exceptions, *extensive* and *moderate adaptors* are cities located in countries in North America, Europe, and Oceania, and are adapting to a variety of expected impacts. *Moderate adaptors* are divided into two sub-classifications to distinguish between cities reporting above median levels of adaptation and those adapting but scoring below median levels of policy *content* and *process*. *Early stage adaptors* are those reporting components of adaptation planning (*policy process*) but at the time of data collection did not report any concrete adaptation initiatives. This classification

[1] GDP per capita: chi-squared for Kruskal-Wallis = 13.00, $p < 0.01$, n = 187; log of total population: chi-squared for Kruskal-Wallis = 9.23, $p < 0.01$, n = 401

[2] Chi-squared 18.7, $p < 0.01$

reflects cities at the preparatory stages of adaptation planning, but do not show evidence of implementing adaptation initiatives. This study finds similar results to those from Carmin et al. (2012b) survey of 468 cities, where 18% reported implementing adaptation planning. Self-reported global surveys have shown much higher rates of engagement with adaptation previous to the implementation phase: the same Carmin et al. survey (Carmin et al., 2012b) found that 68% are engaged with adaptation planning of some type (e.g. plan development), and Aylett found that 75% of cities are integrating adaptation into long-range or sectoral plans (Aylett 2015).

It is difficult to disentangle lack of adaptation from lack of reporting, and the results likely bias against the capture of adaptation in lower income cities. This is supported by our finding of an association between wealth and adaptation reporting. This association does not, however, tell us whether wealthier cities have greater capacity to undertake adaptation, or simply greater capacity to report on their adaptation undertakings; the answer is most likely a combination of both, making quantitative assessment of reporting bias difficult. Significant enough regional variation exists in our findings, however, to suggest that country wealth is not a sufficient explanation of differences in urban adaptation progress. Good governance has also been suggested as a driver of adaptation activity in Berrang-Ford et al. (2014). At the national level, a measure of good governance (the Corruption Perception Index) was found to affect the relationship between population size and adaptation activity. Specifically, in countries with higher than average governance, population has a statistically significant relationship to adaptation activity. We could not test this relationship in this study due to lack of comprehensive indicators of good governance at the city-level. In this context, integrated case-studies and pilot methods to validate the extent to which web-based records differentially proxy on-the-ground adaptation is a priority for future research.

Beyond reporting bias, differences in municipal responsibilities across cities affect how and if climate planning is divulged. In many cases, city governments themselves are not the key agents of climate action within their jurisdiction and cannot be expected to report on the topic. Well-documented examples of adaptation action at the metropolitan level, such as in Bogota, Colombia, show that local governments are not always the locus of adaptation planning (Lampis 2013). In India, the state of Maharastra has been responsible for Mumbai's adaptation planning, highlighting the role of the state in Indian environmental planning (Boyd et al., 2015). These examples show that state structures particular to each country may affect how urban adaptation planning is carried out, and solely focusing on municipal action may omit other forms of adaptation by higher levels of government. The challenge of finding suitable data sources from which to identify, characterize, and monitor adaptation across underscores the need to utilize multiple data sources from which to examine adaptation (Ford et al., 2013). Differences in municipal autonomy may also account for high variation in adaptation reporting *within* regions with similar income levels and population. Especially notable are cases where cities in low income countries report adaptation initiatives and planning. Some cities classified here as *extensive* and *moderate* adaptors are in low and middle income countries (as defined by the World Bank), such as Quito, Ecuador, Santa Cruz, Bolivia, Cape Town and Durban, South Africa, and Semarang, Indonesia. This suggests that cities with limited financial resources are still able to plan and report adaptation activities. Similarly, the availability of financial resources is not a sufficient condition for cities to plan and report adaptation activity. Cities such as Calgary, Canada, and Auckland, New Zealand, which face significant climatic-risks, are not constrained by limited financial resources or institutional capacity – relative to other cities globally – yet they do not report adaptation initiatives. Another concern is the type of adaptation policy that makes its way into climate change plans. Shi et al. (2016) note that a minority of municipalities engage with communities or social advocacy groups in planning adaptation, and in cases where planners do involve citizens in adaptation planning, it tends to be for the development of vulnerability assessments and not for the design or framing of adaptation strategies. The absence of integration of citizen concerns suggests that the needs of marginalized and the most vulnerable groups may not be adequately included in plans.

Our findings suggest that while most cities do not report adaption planning, there are substantive examples of governments taking leadership regardless of wealth levels and institutional barriers. For cities wanting to engage in adaptation planning, cities with extensive adaptation activity can act as focal points for learning. Although vulnerabilities and government capacities are different across income levels, past successes and failures in other cities can provide valuable information on how to plan for future climate risk. The growth of international networks for city-level action on climate change, such as C40 Cities Climate Leadership Group, shows that cities are interested in sharing knowledge and experiences with climate policy. However, a number of cities reporting extensive adaptation action, such as Hamburg, Sacramento, and Minneapolis among others, are not part of C40 Cities (2016). Thus there are still unexamined opportunities for cities to learn from each other about adaptation policy.

Cities with extensive adaptation experience generally exhibit a mix of policy types, undertaking direct and concrete activities such as legislation changes as well as soft policies such as capacity building and research activities. Our results support previous studies (Berrang-Ford et al., 2011; Bizikova et al., 2014; Ford et al., 2014; Sud et al., 2015), implying that government-led adaptation is predominantly occurring in wealthy countries, despite low-income countries being the most vulnerable. This study only considers government-led adaptation, but while doing so we acknowledge that adaptation can be unplanned, at the household level, community-based or originating from the private sector. Future research should seek to expand the systematic study of urban adaptation to these sectors and so enhance our understanding of global trends in urban adaptation, particularly in middle- and low-income countries. Efforts to systematically track non-government adaptation and understand the nature and contexts of adaptation in the global south should ideally be based on approaches that are comprehensive, comparable, consistent, and coherent (Ford and Berrang-Ford 2015). Potential avenues for future work in urban adaptation monitoring and evaluation include systematic ground-truthing, where the findings of global assessments such as this study could be validated by in-depth case research. The value of this complementary approach lies in its ability to capture vulnerability-reductive activities that are not explicitly defined as "adaptation" and as such improve our frameworks for tracking urban adaptation systematically.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2016.06.009.

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