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Measuring the adaptation gap: A framework for evaluating climate hazards and opportunities in urban areas

Chen Chen[a,b,1,*], Meghan Doherty[a,1], Joyce Coffee[a], Theodore Wong[a], Jessica Hellmann[c]

[a] Notre Dame Global Adaptation Initiative (ND-GAIN), University of Notre Dame, South Bend, 46617 IN, United States
[b] Notre Dame Initiative for Global Development (NDIGD), University of Notre Dame, Notre Dame, 46556 IN, United States
[c] Institute on the Environment, University of Minnesota, 1954 Buford Ave, St. Paul, 55108 Minneapolis, MN, United States

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ABSTRACT

Urban areas are increasingly seen as having distinct need for climate adaptation. Further, as resources are limited, it is essential to prioritize adaptation actions. At the municipal scale, we suggest that priorities be placed where there is a gap between adaption need and existing adaptation effort. Taking Seattle, USA, as an example, we present this gap in terms of four categories of adaptation options (no-regret, primary, secondary, and tertiary) for the three primary urban hazards—flooding, heat wave, and drought. To do so, we first establish current adaptation need by identifying and categorizing adaptation options. Next, we consider for each option the number of hazards addressed and benefit to and beyond climate adaptation, the projected magnitude of the hazards addressed, the projection's uncertainty, and the required scale and irreversibility of investment. Third, we assessed Seattle's current adaptation efforts by reviewing adaptation plans and related materials. Finally, we identify the distance or "gap" as the proportion of adaptation options not identified by existing adaptation plans.
For Seattle, we categorized seven options as no-regret adaptation, five as primary, two as secondary, and three as tertiary. Each level's adaptation gap highlights significant opportunities to take steps to reduce climate risks in key areas.

1. Introduction

Four out of five of the top global risks in the next 10 years as identified by the World Economic Forum (2016) are related to climate change (World Economic Forum, 2016). Though these are global problems often discussed at the national scale, urban areas are increasingly seen as having a distinct role on the climate agenda, in terms of both mitigation and adaptation. The 21st session of the Conference of the Parties (COP 21), for example, highlighted the need to establish a global goal on adaptation to enhance adaptive capacity, to strengthen resilience and to reduce vulnerability to climate change. The Paris agreement references cities as relevant actors by acknowledging the need for non-Party stakeholders to address and respond to climate change (UNFCCC, 2015). Further, as of 2014, 81% of the US population (and more than 50% worldwide) resided in cities, making urban adaptation of particular importance. Vast urbanization is expected to continue and by 2050, the world will be one-third rural and two-thirds urban (United Nations, 2014).

1.1. Adaptation in cities

Along with their high concentration of people, there are several characteristics of urban areas that make them inherently vulnerable to climate risks and, therefore, important targets for adaptation. For example, the urban heat island makes cities more susceptible than surrounding rural areas to elevated temperature (Carter et al., 2015; Gartland, 2008; Smith et al., 2009). Urban impervious surfaces reduce infiltration and accelerate runoff so that cities are at heightened risk for flooding (Carter et al., 2015; Gill et al., 2007). And coastal city development often occurs in areas with high exposure to storms and sea level rise (Carter et al., 2015; Wilbanks et al., 2007).

In addition, there are unique benefits to focusing on urban level adaptation efforts as adaptation decisions are often made on the local level and require locality-specific actions (Adger, 2003). The

* Corresponding author at: Notre Dame Global Adaptation Initiative (ND-GAIN), University of Notre Dame, South Bend, 46617 IN, United States.
E-mail addresses: cchen8@nd.edu (C. Chen), mdohert4@nd.edu (M. Doherty), joyce@climateresilienceconsulting.com (J. Coffee), tgwong@gmail.com (T. Wong), hellmann@umn.edu (J. Hellmann).
[1] These authors contributed equally to this work.

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small scale of adaptation matches well with municipal government (Eriksen and Kelly, 2007).

To understand adaptation at the urban scale, it is important to recognize that climate change can manifest in both long-term stresses, such as water scarcity, and short-term shocks, such as extreme events with higher frequency, intensity and variability (IPCC, 2012; Venton and La Trobe, 2008). Therefore, urban adaptation includes a multitude of responses to climate change that range from generalized activities, such as reprioritized development, to highly specialized actions that address a particular climate impact, such as sea wall installation (McGray et al., 2007). As cities act on a variety of concerns, a means to prioritize adaptation strategies is helpful to efficiently address both short and long-term impacts. Prioritization at the government level helps leverage resources to address relevant climate risks (either through direct engagement or indirectly through funding or collaborating with private or non-profit sector), and promotes investments in activities with great efficiency and ancillary benefits.

1.2. Adaptation options and categories

We identify four categories of adaptation options: no-regret, primary, secondary, and tertiary adaptation. To place adaptation options in these categories, we consider the number of hazards each option addresses and its benefit to and beyond climate adaptation, the projected magnitude of the hazards addressed, the uncertainty of future hazard projections, and the required scale and irreversibility of investment.

In our framework, options that address multiple climate hazards and non-climate related common city issues are considered *no-regret adaptation options*. As the non-climate issues constitute city priorities that will persist regardless of climate change, these options can typically be justified under various climate scenarios (Hallegatte, 2009; Willows and Connell, 2003; World Bank, 2013) and at various levels of investment. Because of this broad coverage, cities could consider the no-regret options as a top priority when allocating budgets.

Next, *primary adaptation options* are designed to address a specific future climate hazard where there is a projected increase in hazard magnitude compared to the historical baseline and where there is low degree of uncertainty around these projections. There are many sources of uncertainty related to climate change, including, but not limited to, the social and economic development pathways and hence carbon emission scenarios, the uncertainty of nature climate variability, or the uncertainty of catastrophic events like the shutdown of North Atlantic Circulations. In addition, climate models vary in their capacities to project the future in a reliable manner. The degree to which climate models agree with one another in terms of the future projection is therefore valuable in understanding uncertainties embedded in climate modeling. Options addressing a hazard with a projected increase in magnitude where climate models show a high degree of agreement are therefore considered *primary adaptation*, in our framework, as investment to address this type of hazard allows for lower likelihood of resource wasting.

If there is not both an increase in projected magnitude and high agreement among climate models, we argue that an option's amount of investment should be considered. This leads to the *secondary* and *tertiary adaptation* categories. If the option does not entail large-scale or irreversible investment, risk-averse decision makers may still wish to take action to cope with future risks. These are categorized as *secondary adaptation*. Finally, there are the *tertiary adaptation options* where an option does entail large-scale investment and irreversible outcomes. As irreversible adaptation investments are usually long-lived, these options entail high fixed cost, sunk cost and adjustment costs (Reilly and Schimmelpfennig, 2000). Therefore, irreversibility and investment cost usually are considered concurrently and in our framework irreversibility only applies to large-scale adaptation investment with high cost.

While we argue that no-regret options should be the top priorities for cities, primary, secondary, and tertiary options are more open to interpretation; a city can evaluate its own situation and prioritize accordingly. Here we provide a starting point for exploring adaptation options and an order for their pursuit.

1.3. Adaptation gap

Another way to prioritize adaptation actions is by identifying an "adaptation gap." There are many ways to define and quantify the "gap," such as the difference between existing adaptation efforts, and adaptation potential (Climate Analytics, 2015) or a societal set goal for adaptation (UNEP, 2014). We define "adaptation gap" as *the difference between existing adaptation efforts and adaptation need*. Gap analysis is helpful for multiple reasons. First, it is easily integrated in current procedures and operational structures when it comes to the climate policy planning and evaluation (UNEP, 2014). In addition, gap analysis is flexible and can be easily modified to fit the specific needs and risks of a particular city; a city may choose to re-rank or exclude individual options given their city's context and their local knowledge. For example, the categorization of "no-regret" adaptation options prioritizes a consideration of an option's value over its cost, which a city may elect to change.

Second, gap analysis points to actionable outputs. Linking information to decisions and then to actions is a significant challenge to overcome in the implementation of climate change adaptation (Mastrandrea et al., 2010). The gap analysis approach relies on vulnerability assessment through indicators that imply key adaptation actions. The resulting "gap" measured against these actions points to priorities for a city to consider. Finally, gap analysis also allows for tracking over time. Persistent gaps exist between knowledge of adaptation challenges, resilience policy and actual implementation (Lemos et al., 2012). The progress of adaptation therefore needs to be continuously reviewed, and repeated gap analysis provides one method of such review (Davoudi et al., 2011). If needed, the framework provided by this study can be repeated in future years to track the progress made in reducing the adaptation gap.

An adaptation gap analysis approach is not without its challenges. It is difficult to apply uniformly across cities due to diverse climate risks and varied city context (UNEP, 2014), and there is no level of perfect adaptation to measure against. There has been progress made in measuring one kind of adaptation gap equivalent to the distance between financial need and financial provisions (UNEP, 2015), but a general gap assessment framework for adaptation actions is still lacking. This project, therefore, helps to further protocols for adaptation gap analyses and creates a useable framework despite these challenges.

This paper measures the adaptation gap for an example city by comparing adaptation options with the city's adaptation planning materials. "Gaps" represent the proportion of the identified options that are not yet covered by the plans. This gap measurement therefore provides an assessment of the city's preparedness for future climate hazards as well as suggesting opportunities for improvement. The analysis focuses on the primary urban hazards (flooding, heat wave, and drought) (Hunt et al., 2011) but could be expanded to other hazards. The methodology presented here could be augmented to include other types of climate-related hazards, such as wind hazard, extreme winter weather or exacerbated air or water pollution, given available data. The hazards we consider follow readily from global