A critical review of cost-benefit analysis for climate change adaptation in cities

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Abstract

This study systematically reviews the scientific literature (n = 56) on cost-benefit analysis (CBA) of adaptation measures in cities and similar urban environments. The review is conducted to assess existing or proposed actions for dealing with impacts of drought, heat waves, sea-level rise, and pluvial and fluvial flooding. It includes over 30 measures related to structural, services, technological, informational and ecosystem-based approaches. The main findings demonstrate that CBA of adaptation measures across urban environments must contend with numerous long-term socioeconomic and climate change uncertainties. Subsequently, this has led to inconsistencies in valuation frameworks related to, for example, planning horizons, discount rates, non-market considerations and future scenarios. Results also indicate a clear gap in the literature on the economic valuation of adaptation measures in the Global South. Furthermore, few studies integrate equity dimensions while planning for adaptation. Extensions of CBA to account for key uncertainties will help policy makers to allocate (often scarce) resources more efficiently and limit the likelihood of maladaptation. Further inclusion of the magnitude and distributional effects of non-market impacts and greater civil society engagement in policy dialogues will also be vital for promoting just and equitable measures that balance adaptation alongside other policy goals such as mitigation, economic development, health and well-being.

Keywords: adaptation; climate change; cost-benefit analysis; economic valuation

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Introduction

While previous climate change adaptation research has centred predominantly around assessments of ecosystems and agriculture, of growing concern is the potentially devastating social and economic impacts of extreme weather events, such as floods, heat waves and droughts on cities. Cities are particularly susceptible to the impacts of climate change for a number of reasons. For one, because most cities are situated around coastal areas or close to riverbanks, they are highly vulnerable to the effects of sea-level rise and storm surge, affecting, or in some cases even displacing, large communities. In addition, the large extent of non-porous surfaces in cities makes it harder to deal with periods of high precipitation and river flooding, which can affect ecosystem services and critical infrastructures such as transport networks and social services. Cities are also prone to an urban heat island effect due to their high population densities and concentration of built infrastructure, which makes them significantly warmer than surrounding rural areas, causing increased health impacts and higher rates of morbidity and mortality, particularly among vulnerable or marginalised groups (de Murieta et al., 2014). These city impacts are of critical concern for policy discussions on climate change and adaptation not only due to growing urban populations (expected to reach 6.3 billion globally by 2050 from close to 3.4 billion today) (United Nations, 2009), but also because climate effects often act to amplify other social, environmental and economic drivers of risk (Revi et al., 2014).

Policy debates are now focusing much attention on how to help cities plan for adaptation, which requires detailed assessments of the costs and benefits of measures, as well as of the projected magnitude of impacts across diverse sectors and groups. Of special significance are cities in developing countries where much of predicted urban growth is expected to take place, and which often face an array of social, political and economic barriers to adaptation, such as equity concerns, infrastructure backlogs and severe financial and human resource constraints (Shi et al., 2016).

Cost-benefit analysis (CBA) is perhaps the most widely deployed tool for assessing the feasibility of both public and private adaptations to climate change. Its attractiveness stems predominantly from a common basis for comparison across projects, that is, an assessment of costs and benefits in monetary terms. This is especially beneficial for public sector decision-making in preventing inefficient spending of public money, in ensuring that regulatory costs are not inexplicably high or variable, and ensuring that resources are allocated effectively across diverse sectors and communities. CBA has also been argued to provide a more accountable, objective and transparent process for appraisal, since it requires all assumptions and uncertainties underlying decisions be revealed, and inputs to the analysis (e.g. expert judgements that may otherwise be difficult to comprehend) provided in a common and simplistic language that citizens are able to understand and contest. People naturally tend to consider budgets in everyday life, which makes the reading of cash flows in CBA familiar and easy to interpret.

Meta-analyses on adaptation has covered extensive ground thus far. Solecki et al. (2011) for example, investigate the links between disaster risk reduction and climate change adaptation in cities, and focus on three main areas of overlap related to event likelihood, impact parameters and societal responses. Carter (2011) conducts a qualitative appraisal of adaptation progress in European cities, and finds that policy frameworks and uncertainties related to climate science and institutional structures act as the main barriers to progress. In contrast, Reckien et al. (2017) provide an overview of the literature on climate change impacts, mitigation and adaptation in urban areas from an equity and environmental justice standpoint. Also noteworthy is Watkiss and Hunt's (2011) review of climate change impacts and adaptation in cities. While their review, including case studies from London and New York, is extensive, their work focuses on a synthesis of qualitative reports on adaptation, and quantitative assessments on climate impacts and risks. From an economic standpoint, Markandya and Watkiss (2009) review of economic assessments on the costs and benefits of adaptation remains an important contribution. However, their appraisal is focused on global and national studies, with a small selection of case studies at the sub-national and local levels.

Evidently therefore the literature still lacks systematic urban scale analyses on the economics of adaptation, particularly one that investigates the full implications of cost-benefit analyses when it comes to adaptation research, as well as the diverse economic, social and environmental perspectives on its use. This is particularly relevant in light of recent criticism of existing IPCC assessments, which calls for more evidence-based reviews of adaptation practices whose findings are transparent, clearly defined and limit reviewer/author bias (Ford and Pearce, 2010; Petticrew and McCartney, 2011). CBA is a frequently applied instrument in the economic assessment of public policy across all sectors, and while its usefulness as a tool in the area of urban adaptation is clear, there are other equally important factors besides cost, such as equity, effects on the environment, health and society, and the physical effectiveness of protection, that also require attention. As it stands, empirical data on the costs and benefits of adaptation remains scattered. Evidence-led research can help improve upon adaptation science for governance, assisting in the prioritisation of options and mainstreaming adaptation into local policy agendas. From these points a key research question arises, that is, how accurate is the information derived from CBA and, to what degree can it form a credible basis for adaptation plans and investment decisions in this field? This paper seeks to provide at least a partial answer to this question.

2. Methodology

Systematic review guidelines prescribed by Berrang-Ford et al. (2015) were used to evaluate recent cost-benefit analyses on adaptation in cities. In order to restrict the first phase of document selection to purely peer-reviewed works the Web of Knowledge (WoK) platform was used to scan articles under a set of broad search criteria so as to avoid excluding key literature sources. A keyword search was conducted on topic words (“economic valuation” OR “cost benefit analy*” OR “cost-benefit ratio*”) AND (adapt* AND drought OR flood* OR sea level rise OR coastal OR heat OR heat wave*). The search was restricted to include articles in the English language published between the years 2000 and 2017. 210 articles were selected for full-text review based on relevant titles and abstracts that fit the inclusion criteria (table 1). The search criteria were intended to draw out relevant studies conducted on adaptation measures proposed for dealing with drought, pluvial and fluvial flooding, sea-level rise and heat waves in cities. These included infrastructural, technological, behavioural, institutional, financial and informational responses. Implementation scales from building level to the city level were considered, and studies were refined according to CBA employed in the widest sense in terms of maximising or comparing welfare (Table 1). 22 articles which specifically fit the selection criteria presented in Table 1 were chosen for further analysis.

[Table 1 here]

Previous research has highlighted the inadequacy of basing research synthesis of complex research questions solely on keyword searches (Greenhalgh and Peacock, 2005). In order to provide a more exhaustive scope for review, the “cited by” and “related articles” functions offered by Google Scholar were used on each of the 22 articles. Following the same screening approach of titles and abstracts, this extra search process yielded an additional 34 articles fitting the inclusion criteria, resulting in a total of 56 articles for final review. Information pertaining to each article was then summarised in an excel spreadsheet. This involved developing a set of qualitative and quantitative criteria for homogenising and comparing the data through common metrics and terminologies. The objective here was to focus on prominent differences between studies related to uncertainties, impacts, scales, valuation methods and local dependencies. Standardisation techniques were then used to make the data comparable – for quantitative elements this including converting all monetary values into 2016 International Dollars ($) using the consumer price and purchasing power conversion factors provided by the World Bank, and by converting size values into common units of measure (e.g. from hectares or acres to m^2). For qualitative elements, generic terms were created to group the data into specific categories or concepts (i.e. whether scenarios considered 'variable' or 'extreme' climate changes). The final set included data on study aims, location, adaptation type and description, hazard type, temporal and spatial scales, scenarios, uncertainties, types of costs and benefits analysed, cost and benefit values, net-present values, benefit-cost ratios, discount rates, and currency units. Details of the studies considered in this review are shown in Table 2.

A further search was conducted on WoK to provide an insight into emerging economic tools (not derivatives of cost-benefit analysis) employed in adaptation assessments. A general framework based on new economic decision support tools for adaptation assessment identified by Watkiss et al. (2014) was used at this stage. These included approaches such as iterative risk management, real options analysis, robust decision making and portfolio analysis. This part of the study was conducted in order to explore the prevalence, strengths and weaknesses of alternative economic tools compared to cost-benefit analysis for adaptation assessments. Again, results were filtered according to articles published in the English language between the years 2000 and 2017, resulting in a total of 87 search results. After careful screening of relevant titles and abstracts, the final selection was refined to 36 articles on economic decision-support tools used for adaptation assessment.

[Table 2 here]

3. Results & discussion

3.1. Types of adaptation

3.1.1. Drought

The adaptation literature on drought in cities is limited to supply-side measures of rainwater harvesting systems and wastewater reuse and recycling systems with implementation scales ranging from the building/infrastructure- to the city-level. The limited coverage of drought measures in the literature is in line with previous research which cites inadequate information on the costs and benefits of impacts and measures as a major obstacle to the implementation of drought mitigation and adaptation strategies (Brenner, 1997). Many of the problems underlying cost-benefit analysis on drought stem from the challenge of quantifying a slow progression of impacts that are neither highly visible nor structural, which also means that few studies are conducted systematically. Studies on rainwater harvesting yield better consideration of benefits (i.e. in terms of avoided impacts) since they are also used as an adaptation to flooding. Therefore, avoided costs related to flood damage are commonly included in benefit appraisals for this technology (de Bruin et al., 2013; Jianbing et al., 2010; Mathew et al., 2012). Assessments on wastewater reuse and recycling on the other hand, are much more sporadic. Most studies consider both financial benefits (i.e. in terms of revenues from the sale of regenerated water and/or cost savings on fertilizers) and environmental benefits of avoided water pollution (Djukic et al., 2016; Fan et al., 2015; Molinos-Senante et al., 2013, 2011). Other benefits assessed include: avoided health care costs, increase of water availability (Godfrey et al., 2009; Liang and van Dijk, 2012, 2010), residential resettlement, increase of jobs (Liang and van Dijk, 2012, 2010), avoided overexploitation of groundwater, reuse of pollutants and avoided odour abatement costs (Godfrey et al., 2009). The drought measures identified in this review relate to measures able to deal with long-term issues of warmer temperatures and water scarcity caused by climate change. Cost-benefit analysis of measures that deal with droughts as short-lived events are not as prevalent in the literature. Short-term measures might involve, for example, agricultural irrigation management and other forms of rationing (e.g. limiting water-use to specific cash crops and irrigation scheduling), administering public aid to critically affected areas, and distributing short-term financial measures for helping farmers cope with reduced incomes caused by lowered crop yields (Dziegielewski, 2003).

3.1.2. Pluvial and fluvial flooding

Proposed adaptations for flooding in cities include: social measures such as community preparedness and capacity building, climate proofing houses, early warning systems and resettlement of flood prone communities; hard infrastructure measures such as watershed management, construction of dikes, levees and flood barriers, land elevation and spatial planning, urban drainage systems and rainwater harvesting systems; and 'green' measures such as floodplain conservation, green roofs, and other green infrastructures such as greenways and urban green areas.

Assessments of pluvial and fluvial flooding make up 66 percent of the total number of studies considered in the review. The prevalence of appraisals to do with inland flooding is unsurprising. When assessing the impacts of climate change on global river flood risk, Arnell and Gosling (2016) find that in 2050, what is today considered a 100-year flood event, would be twice as frequent across 40% of the globe, affecting around 450 million people in flood-prone areas and 430,000 km^2 of cropland worldwide. The wide range of measures besides hard approaches represented here also supports previous assertions that traditional engineering methods alone will unlikely be able to provide adequate levels of protection in the future (Ashley et al., 2005).

3.1.3. Sea-level rise and storm-surge

Measures for adapting to sea-level rise and extreme storm events (causing coastal flooding or beach erosion) include: soft adaptations such as beach nourishment, resettlement of affected communities and changes in building regulations, and hard adaptations such as construction of bulkheads, groins, levees, revetments, sea walls, and land elevation and spatial planning. Strategies are also being designed that combine both hard and soft measures, such as: the construction of hard defences (i.e. seawalls), beach nourishment and the use of revetments with geotextiles. Certainly, the integration of hard and soft approaches is useful for gaining the benefits of both the flexibility of hard approaches (e.g. raising wall levels) with the reversibility of soft approaches, which makes them better suited for dealing with high levels of future uncertainty (Hallegatte, 2009).

3.1.4. Heat waves

The literature on adaptation to heat waves in cities only covers green measures, such as green facades, green roofs and urban green areas. The attractiveness of these green themes lies in their potential to artificially reverse the effect of the urban heat island effect in urban areas by replacing impervious built surfaces with previously lost vegetative cover. These types of adaptations provide a host of benefits such as cool shading, evaporative cooling, rainwater interception and storage, air pollution removal, habitat creation and biodiversity, as well as aesthetic and recreational values. Indeed as (Carter, 2011, p. 195) notes: 'strategies and actions developed exclusively to promote adaptation goals are unlikely to be as effective as measures that integrate adaptation alongside the progression of other agendas, such as climate change mitigation, health and wellbeing, or enhancing the economic competitiveness of cities.' The systemic literature search adopted in this study was unable to identify measures for dealing with heat waves as temporary, short-lived events. Such measures might include installing air-conditioning or cooling systems in building and transport infrastructures, establishing emergency relief centres, early warning systems, property-level measures (e.g. external window shutters and painting external walls or roofs a lighter colour) and informational campaigns for citizens on how to manage heat stresses (Zuo et al., 2015).

3.2. Contextual Settings

The literature covers a total of 24 countries across Europe, Asia, North America, the Middle East and North Africa (MENA), Australia and West Africa. Although these findings are generally consistent with the distribution of adaptation efforts observed worldwide, the limited coverage of adaptation in African regions (Figure 1) is surprising given that between 2006 and 2009 the second-most number of activities on adaptation were reported to take place in Africa (Berrang-Ford et al., 2011). This disparity points to the challenges of conducting economic assessments of adaptation in developing countries. Certainly cost-benefit analysis is often financially and human-resource intensive, time consuming and requires considerable expertise (Ackerman and Heinzerling, 2002), which restricts its application in certain regions. On top of this, CBA for adaptation faces considerable criticism, particularly from developing nations, in the way it quantifies non-market values, especially through estimates of willingness to pay (WTP). For one, the notion of WTP raises concerns over considerations of distributional equity. Since the rich are more able and more willing, to pay more for environmental protection, this means that protective programs are likely to favour richer communities over poorer ones. Secondly, CBA tends to consider risk in an 'acontextual' manner – that is, it tends to ignore important contextual information, for example, on patterns of economic and social inequality. Thus, CBA fails to adequately integrate issues of equity, rights and morality that cannot be reduced to monetary worth, making its application in developing regions challenging and its consideration of different income groups within regions problematic.

[Figure 1 here]

Affordability plays a major role in how we value non-market items, and researchers have been gravely concerned for some time now with how to consider these valuations within CBA in a fair and equitable manner. Alternatives such as Willingness to Accept (WTA), which measures the amount a person is willing to accept as compensation, i.e. for environmental degradation or to forgo environmental benefits, have since been proposed. But large disparities between WTP and WTA estimates have alluded to other equally problematic factors. While the amount one is willing to pay for (or to avoid) something is constrained by the limits of his or her budget, the sum one might be willing to accept as compensation for something could be infinite. The nature of WTA means that an individual's actual loss cannot be separated from what they *believe* their loss to be. This essentially gives every loser the power of veto, since the efficiency outcome of CBA can be swayed by one infinitesimal value. When using WTA, economists often exclude stated values that are extreme as ´outliers´ and not consistent with the concept of rational decision-making. But imposing limits on WTA means not fully accounting to the true concerns and preferences of people, and by implicitly suggesting that – those who believe that some things are priceless – are irrational, CBA risks losing its political authority as well as its moral legitimacy (Adams, 1993). Recent work in this area has demonstrated that with careful survey design and use in appropriate contexts, WTA can in fact be elicited without much bias and extreme values. As a result a number of researchers recommend using WTA rather than WTP when losses are being valued (Lloyd-Smith and Adamowicz, 2018; Villanueva et al., 2017; Whittington et al., 2017).

Perhaps more promising is an approach that incorporates equity concerns directly into CBA, whereby the effect on incomes of different societal groups (the distribution effect) is considered alongside the effect on resource allocation (the efficiency effect). One way to do this would be to assign distributional weights to reflect the relative incomes of those people receiving the benefits or bearing the costs of an investment. By using this approach, those with lower incomes can be assigned greater weights to increase their relative importance within decision-making. This method dates back to the 1960s when Weisbrod (1968) began stressing the importance of distributional impacts to policy-makers. Despite its inclusion in cost-benefit manuals during that time, its use within CBA ceased in subsequent years with decreasing concerns over income distributions although interest in it has re-emerged recently in guidelines on Cost Benefit Analysis (Treasury, 2018).

The dominance of private, building or neighbourhood level adaptations such as rainwater harvesting systems, green roofs, green facades, urban green areas, and property-level measures against flooding in primarily richer states (Figure 1), also alludes to the predisposition of private individuals or groups in wealthier regions to invest in adaptation. This raises questions as to how economic frameworks such as CBA can ensure equitable distribution of decision-making power and benefits of action across diverse contexts. Engaging community or social advocacy groups within policy dialogues on adaptation would ensure greater representation of minority voices and needs, however some authors have signalled a post-political shift[1] in urban governance when it comes to decision-making on climate change (Chu et al., 2018). The little attention granted to dimensions of equity, inclusiveness and justice within climate policy development not only makes it difficult to address specific needs of disadvantaged groups, but also limits the potential for adaptation to be systematically mainstreamed into local development and management policies (Shi et al., 2016).

The matter of ensuring equitable adaptation processes is one that concerns decision-makers at all levels of governance. Adaptation is a broad term extending across various sectors, locations, scales and actors. This makes defining the exact roles and responsibilities of citizens, communities, corporations, public and private organisations, governments and international institutions challenging. There is a great need to better understand the current opportunities and constraints of adaptation within diverse contexts and at various levels of decision-making with the aim of reducing overall vulnerability and enhancing adaptive capacity. From a global perspective, this might require an investigation into the current state of institutions and infrastructures, and access to capital, technology and information across nations. At a local-level, it means identifying especially vulnerable groups and demographics, communities reliant on climate resources, specific areas of social and cultural conflict, and the need for civil society for mediating between policy-makers and the public. Improving upon this knowledge will help those with power and access to resources at local, national or international levels ensure that vulnerable nations, sectors and communities have access to those critical economic, social and informational resources for building capacity and resilience in the face of climate change. One can see such data and its analysis as complementary to that used in any benefit cost analysis and would enrich it greatly (see conclusions section).

3.3. Time horizons and climate change scenarios

Figure 2 presents the range of time scales and discount rates adopted in cost-benefit analyses on adaptation. The

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[1] Post-politics in this context refers to the critique, by urban geographers and sociologists, of increasingly non-traditional and apolitical forms of urban governance largely reliant on aspects such as scientific expertise, bureaucracy and epistemic knowledge. Critics argue that the lack of negotiation and discussion on different urban interests may result in (often neoliberal) governance outcomes that lead to the disenfranchisement of minority voices and needs (Chu et al., 2018).

figure clearly shows that the bulk of appraisals favour short to medium time horizons, i.e. between 1 and 50 years (80 percent), with few extending past 60 years. These short time frames tend to reflect the lifecycles of green infrastructures (i.e. green roofs and green facades) and technological adaptations (i.e. rainwater harvesting and wastewater reuse systems), which commonly last between 30 to 50 years, and 10 to 30 years, respectively. There are several potential reasons for the consideration of short-term time periods within adaptation assessments. Firstly, decision-making on adaptation must be made within certain political horizons, wherein policy-makers often struggle to balance the long-term need for sustainable development against the short-term need for economic and policy development. When resources are scarce, short-term interests tend to prevail and it becomes harder to persuade stakeholders to make long-term provisions for adaptation that might have few immediate gains. Secondly, continuing climate shocks in the form of extreme events that reduce the coping capacity of regions, may cause them to seek immediate risk-management strategies before considering longer-term solutions to future and more gradual climate changes. But the reliance on reactive responses runs the risk of reinforcing short-term strategies at the expense of long-term precautionary adaptations. This in turn may limit the capacity of regions to reduce vulnerability improve resilience to future, potentially more severe, climate risks. Where adaptation is incremental, policies should aim to adopt strategies of adaptive management, whereby short-term actions are reassessed as new information about future impacts comes to light. Adaptation interventions that are able to address both short-term economic uncertainty and climate vulnerability as well as long-term strategic objectives to reduce climate risk, are likely to maximise the probability of achieving sustained benefits in the future (Burton et al., 2005).

In contrast, longer time scales, greater than 50 years, tend to be associated with hard infrastructures for dealing with inland and coastal flooding such as urban drainage systems, land elevation, and hard defences, such as dikes, groins and sea walls. Explaining this are the various scenarios of sea-level rise and future damages frequently adopted in these appraisals, which require long term assessments of risk and vulnerability. The uncertainties underpinning future sea-level changes however, have resulted in highly variable scenarios of sea-level rise. Taking the US as an example, Kirshen et al. (2012) calculate coastal impacts for Maine based on low (0.1m by 2030 and 0.17m by 2050) and high (0.22m by 2030 and 0.37m by 2050) SLR estimates taken from Rahmstorf (2007). For Florida, Lu et al. (2014) base their SLR projections on the Federal Highway Administration (2010) estimates of 0.3m (in the next 50 years) and 0.6m (in the next 100 years) for the Gulf of Mexico. While for the West coast, King et al. (2016) calculate the impacts of SLR in California based on 3 scenarios of 1m (Cayan B1), 1.4m (Cayan A2)[2] and 2m (Pfeffer et al., 2008) by the year 2100. SLR scenarios for the UK are similarly varied. For London, Penning-Rowsell et al. (2013) consider a rise in sea-levels of just over 1m by 2105 (based on DEFRA06 recommendations), while Woodward et al. (2011) use the more conservative low (0.28m), medium (0.345m) and high (0.425m) climate change scenarios for 2100 taken from the UKCP09 climate change projections for the UK.

[Figure 2 here]

The consideration of 'worse case' SLR scenarios applied across regions highlights the increasing attention being placed on potentially catastrophic impacts, with several of the aforementioned studies considering ranges in line with, or extending past, the RCP 6.0 (0.33-0.63m by 2100) and RCP 8.5 (0.45-0.0.82m by 2100) estimates provided by the latest IPCC Fifth Assessment Report. Taking a risk-averse stance when planning for adaptation seems practical, especially in light of recent studies showcasing the devastating impacts of low-probability, high-impact climate change events. Based on probability distribution functions of future SLR for 120 coastal cities under RCP 2.6, 4.5 and 8.5 scenarios, Abadie et al. (2016) estimate economic losses caused by low-probability high-impact events to be between 139 percent and 746 percent higher than mean expected values. Similarly, when considering the impacts of 21st century climate change on global financial assets, Dietz et al. (2016) find that while 'climate value at risk' (VaR) amounts to around 1.8 percent, or $2.5 trillion, under a business-as-usual emissions path, much of the risk lies in the tail with VaR estimated at 16.9 percent, or $24.2 trillion, in the 99th percentile. These findings have important implications for policy-makers and investors, who must decide not just how much they can afford to spend, but how much they can afford to risk when it comes to climate change.

The application of climate change scenario ranges is an important addition to CBA, which has long been criticised for its limited ability to account for the magnitude of climate change uncertainties and in extrapolating change that goes far beyond past experience. Indeed, CBA tends to typically incorporate climate change through probabilistic risks. As Table 3 shows, most cost-benefit analyses use simplistic approaches for dealing with uncertainty, for example through sensitivity analyses (of discount rates, time horizons, implementation scales etc.) and benefit-to-cost (BCR) ranges. Few studies consider the timing and type of

[2] These scenario estimates for California are taken from Cayan et al. (2008).

investments based on future information, or actually report the robustness of the BCR with respect to parameters that are uncertain or for which no probability distributions exist.

[Table 3 here]

New economic decision-making tools, that can be used independently or as extensions of CBA, have emerged over recent years to address these challenges (Figure 3) [3]. These include, for example, adaptation pathways, robust decision-making and real-options analysis, which have been designed for the development of flexible adaptation plans that can be tailored to specific contexts or adjusted in light of new information or future changes in the environment (Buurman and Babovic, 2016). Such approaches are rare as it stands, and their potential for more widespread application is yet to be established.

[Figure 3 here]

3.4. Discount rates and non-market costs and benefits

Environmental economists have stressed the importance of using near-zero discount rates, primarily as an ethical and immediate responsibility towards future generations, but also for encouraging more effective and progressive policy design (Stern, 2007). It is interesting therefore, that so few studies (12.5 percent) actually employ rates below 2 percent, that so many (30 percent) use rates of 5 percent or higher, and that only two studies consider declining rates (Woodward et al., 2014, 2011).

Certainly the often long time scales associated with climate change imply that conventional discounting practices, i.e. based on market rates, are inadequate for valuing residual costs and the benefits of avoiding future climate impacts. The higher the rate the more rapid the decline in the value of costs and benefits over time, making it harder to account for future risks that aren't probabilistic, i.e. extreme or irreversible events. The use of market rates also raises ethical concerns as to whether it is right to discount non-market values such as lives saved, health and wellbeing, species preservation, the welfare of future generations, biodiversity and nature, in the same way we do financial returns. What makes this particularly problematic is that there are likely to be considerable monetary, environmental, social and health benefits of protective action, which are expected to

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[3] The drop in studies for 2017 is due to incomplete data for this year

occur in the distant, rather than immediate, future. The most logical argument in favour of discounting is that we would expect as people get wealthier over time they will be able to spend more to save their lives and to preserve the environment. The fundamental problem with this idea lies in the fact that the environmental problems we are facing will extend far into the future, meaning that the decisions we make today will not only impact ourselves but also those who come after us, in some cases irreversibly. Indeed, climate research has been warning us of the potential for catastrophic and irreversible environmental losses such as the melting of polar ice caps, the destruction of coral reefs, ocean acidification, increased coastal flooding and erosion due to rising sea-levels, species extinction, and the growing impact on crop production and migration in certain parts of the world. As shown in the previous section (with 80 percent of studies favouring short-medium timescales), programs designed for the near term are often considered more desirable than programs designed for the long-term, giving priority to immediate economic gains over, for example, the environmental, health or social outcomes of projects.

As it stands, only 34 percent of studies consider the indirect costs of adaptation and only 54 percent, 46 percent and 13 percent consider the environmental, social and health benefits of adaptation, respectively. The latter is particularly surprising, given the potential magnitude of climate change impacts on health. Taking Europe as an example, climate change is expected to cause growing thermal stresses due to heat waves, increases in diseases related to air pollution, increases in mortality and morbidity due to extreme events and flooding, excess cases of Lyme disease and tick-born encephalitis, and increases in leishmaniosis in Mediterranean regions (Markandya and Chiabai, 2009). In terms of economic impacts, Kovats et al. (2011) find that climate change induced health costs across Europe, related to heat and salmonellosis, could range anywhere between €46 billion to €147 billion by the year 2080. In a study on the projected economic impacts of climate change in sectors of the European Union (EU) based on bottom-up analysis, Watkiss et al. (2009) estimate that under a projected warming of 3.9 °C by the year 2100, the additional heat-related deaths for 27 EU member countries will near 107,000 annually during 2071-2100. By the year 2080, the authors estimate that the costs associated with these deaths could range from €50 billion annually, when valuing each excess death, to €118 billion, when valuing the loss of a year of life. Ex-post studies showing actual impacts of specific climate events are also rife. Hunt et al. (2007) calculate the cost of the 2003 summer heat wave in the UK which resulted in 2,157 deaths and an excess of 1,650 hospital admissions, to be approximately £41 million (with a cost range of between £14 million and £2.6 billion[4] depending on whether a value of life year or value of a prevented fatality is used). A complete synthesis of European studies can be found in Hutton and Menne (2014), who examine the economic evidence on climate change health impacts and adaptation across 53 countries of the World Health Organisation (WHO) European Region. For worldwide estimates, Markandya and Chiabai (2009) examine the health impacts of climate change by region, and provide a cost-effectiveness index for alternative health adaptation interventions based on estimates of total costs from the literature.

As evidenced above, using CBA to value health adaptation programmes can be challenging because it implies introducing savings or losses in terms of affected lives. This means either estimating the value of life itself or placing a value on each year of life saved or lost. The methods developed to measure life have resulted in considerable debate and disparities between study estimates. While some choose to value life differently for different countries (more or less relative to real per capita GDP), others choose to apply the same value to all lives irrespective of country or context. The use of country-specific values for life has caused political tension in the past, since lower values of life tend to be ascribed to developing regions (Viscusi and Aldy, 2003). Taking a study on wastewater reuse in residential schools in Madhya Pradesh as an example, Godfrey et al. (2009) calculate that the value of loss-of-life[5] based on the discounted productive years lost (21.9 years), the age standard mortality rate (150 per 100,000) and the opportunity cost per year of life lost (INR 30,000 per year), amounts to a value of $70,912[6] for each life lost. If we were to conduct this study in the UK by comparison, then the value of loss-of-life (using the same valuation method) would amount to approximately $470,000 for each life lost[7].

Issues arise from both approaches, making the consideration of health impacts within CBA problematic. In spite of these challenges, health impacts are likely to represent significant values in the context of climate change and adaptation, making their disregard within CBA unjustifiable. The same holds true for the

[4] This is equivalent to an average of €52 million (with a cost range between €18 million and €3.3 billion) in 2018 prices using the Purchasing Power Parities and Consumer Price Indices provided by the OECD databank: https://data.oecd.org/

[5] This was calculated as a benefit of wastewater reuse and recycling systems – estimated from the avoided deaths occurring from diarrhoea due to water contamination

[6] Calculated in 2016 USD using the CPI and PPP provided by the World Bank databank

[7] This calculation was based on the UK minimum wage rate of GBP 7.38/hour, assuming 170 hours per month (https://www.gov.uk/minimum-wage-different-types-work/paid-an-annual-salary) and converted to USD using current exchange rates.

evaluation of environmental and social impacts. The Stern Review (2007) calculates that with a 2°C warming, around 15-40 percent of land species could face extinction, with most major species groups, biodiversity hotspots and vast areas of tundra and forest affected. Additionally, we can expect to see coral bleaching in many areas beyond recovery, affecting tens of millions of people that rely on coral reefs for their livelihood and food supply. At this rate of warming, resources affected by climate change may drop below a critical threshold, forcing many communities to migrate, and spurring further economic, social and cultural divides that reinforce existing inequalities.

The limited consideration of these values within CBA is problematic, since assessments based solely on goods and services with market values or proxies will encompass only a fraction of the total value of climate change and adaptation. In practice, public sectors have multiple (economic, environmental, health and social) objectives, and applying profit maximisation techniques such as CBA means that many public needs may be ignored as a result. Of course, integrating such values into CBA is incredibly challenging. Differences in valuation methods are known to heavily impact outcomes and emerging research has shown that different valuation methods are needed for eliciting diverse value-types, all of which still have blind spots (Jacobs et al., 2018). International bodies such as the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) have encouraged the use of 'integrated valuation' when it comes to the environment. This approach aims to capture three main value-dimensions, non-anthropocentric, relational and instrumental values, through diverse (socio-cultural, biophysical, monetary and synthesising valuation) methods. As Jacobs et al. (2018) assert, while single-value methods might seem more cost-efficient, they have a reduced capacity to provide information about multiple values that could have risky implications for decision-making in human-nature contexts making them inefficient and ineffective. Assessing the suitability of 21 valuation methods for 11 value-types, the authors find that integrated valuation can be achieved by using a set of complimentary methods, and without spending excessive resources. While this approach is still new and there are no CBA studies that adopt it, it represents a promising effort to capture a more holistic value of nature's contribution to people.

3.5. Benefit-cost ratios

A breakdown of benefit-cost for each adaptation measure and their relative ranking disaggregated by climate hazard is shown in Table 4. It should be noted at the outset that most of these values represent *ex ante* estimates of benefits and costs. To date *ex post* estimates of BCRs are scarce as virtually all projects have not completed implementation. Of course, short-term responses to stochastic events such as storms, heat waves or droughts will have already happened, but not all of these measures will have been labelled as an adaptation to climate change. This important gap will only be filled over time. It is also worth mentioning that the BCR of adaptation options seems to be greatly influenced by aspects such as the choice of discount rate, time horizons, implementation scale, and the consideration of certain costs and benefits. As it stands, the current sample size does not permit a complete understanding of whether these factors are specific to certain hazards or measures. Differences in these critical parameters makes it difficult to draw comparisons between studies when it comes to their efficiency. For these reasons, the BCR estimates for these solutions are tentative and the results presented in this section are intended for illustrative purposes. Adaptations that are considered very effective, effective and ineffective are discussed below. These classifications are based solely on a simplistic evaluation of lower, middle and upper-bound estimates of BCRs as well as their relative rankings within hazard types, the standard deviation and variance for each measure should be taken into account.

3.5.1. Very effective measures

Soft defences, namely artificial nourishment of beaches, appear to be among the most effective measures for dealing with the impacts of sea-level rise and storm surges. The higher ranking of these measures compared to a combination of hard and soft approaches and hard defences alone could be attributed to their lesser impact (or perceived impact) on the environmental and on the social values of beach sites. Whilst often considered places of ecological and environmental importance, beaches also tend to be recognised for the high touristic, recreational, and aesthetic benefits that they accrue. Despite the potentially large environmental and social benefits associated with soft measures, the literature seems to place greater attention on the valuation of hard defences for sea-level rise and extreme storm events. This could be due to the fact that hard engineering options for adaptation are easier to cost and are subsequently preferred or given greater priority within decision-making processes compared to soft or behavioural alternatives (Markandya and Watkiss, 2009). But the inherent bias toward harder options might adversely affect critical soft approaches with important innovative and technological components (Markandya and Galarraga, 2011). In fact, less than 25 percent of hard infrastructure assessments actually consider costs and benefits of adaptation beyond those internalised by the market. These may include social effects such as impacts on well-being, recreation and aesthetic values, or environmental effects such as impacts on habitats, biodiversity and ecosystem services. This calls into question the sustainability of hard adaptations, moving beyond direct costs towards more holistic assessments of the values associated with these measures will help to address this issue.

3.5.2. Effective measures

Although less studied, behavioural options such as community preparedness, early warning systems and property-level measures, also stand out as effective adaptation responses. The positive performance of these adaptations is likely linked to their low costs (e.g. related to training vulnerable communities for emergency management, establishing climate-sensitive building regulations and designs, and encouraging households to climate-proof homes), as well as their effectiveness in engaging and empowering individuals to take action on climate change for themselves. This shift in decision-making power from policy-makers to the individual, so-called 'governing by enabling', not only facilitates awareness-raising of climate change issues, but also motivates positive behavioural changes among decision-makers and affected stakeholder groups (Carter, 2011), The long-term sustainability of these options will rely on building human and institutional capacity for adaptation and enabling direct engagement with local governments, which can accelerate implementation rates and improve upon urban adaptation outcomes (Revi et al., 2014).

Green measures, such as building urban parks, greening the sides of buildings and roofs, conserving floodplains, and establishing climate-robust ecological networks, are not found to rank especially high compared to their alternatives for heat waves and flooding in cities. This result is particularly surprising when considering the many positive health effects linked to green spaces and infrastructures, which include: increased life expectancy of senior citizens' (Takano et al., 2002; Tanaka et al., 1996), increased activity levels and perceptions of health and relaxation (Korpela et al., 2001; Payne et al., 1998), decreased levels of stress and anxiety (Ulrich et al., 1991), improved concentration and attention levels (Hartig et al., 1991; Taylor et al., 2001; Wells, 2000), lowered blood pressure levels (Hartig et al., 2003), and reduced mental fatigue (Kuo and Sullivan, 2001). Limits in valuation approaches for non-market items might explain this finding, since (sometimes large) values that are harder to quantify, such as protecting public health, might be disregarded from assessments. This impression is supported by the less than 24 percent of green adaptation studies that consider health benefits in their assessments.

While not found to rank especially high, technological adaptations for water storage and management such as rainwater harvesting and wastewater reuse and recycling are on the whole considered to be economically efficient solutions. These results tend to be based on short-time frames, but higher BCRs could be expected with longer time considerations. Certainly, water storage and management will become increasingly important with rising temperatures. An estimated 2°C rise in global temperature could result water shortages affecting between 1 and 4 billion people, predominantly in parts of Africa, the Middle East, Southern Europe and South and Central America. At the same time, higher levels of rainfall and flooding, especially in parts of South and East Asia, could affect between 1 and 5 billion people (Warren et al., 2006). Improvements in design, materials and construction techniques can improve the resilience of water infrastructures and lead to more efficient water management and storage technologies (at lower-cost) in the future. Scientific and technological progress can also be expected to improve climate predictions and weather forecasts, enabling the design of more effective adaptation responses in the coming years (Stern, 2007).

3.5.3. Ineffective measures

Resettlement options for flood-prone communities are ranked among the least attractive solutions for dealing with climate change impacts. Governments that pursue this solution might offer incentives for relocation or aim to establish mandatory resettlement programmes for vulnerable groups. For countries most at-risk from the impacts of climate change, i.e. islands in the Pacific, resettlement programmes are already being pursued as a matter of national policy. But this type of adaptation is often justified as a last resort solution. Not only do these measures involve considerable direct implementation costs, but they also come at potentially high social, economic and environmental cost. Displaced communities might suffer from loss of livelihood, debt and disintegration as a direct result of relocation. But mass migrations caused by climate change could also lead to spill over effects in neighbouring regions – political instability, economic and social pressures, and environmental degradation are among the potential adverse effects of such policies. Policy frameworks at various local, regional and international levels of governance should explore existing capacity and latent outcomes if they are to avoid the worse effects of climate-induced migration. For host nations, this might require thinking about infrastructure capacities, impacts on labour demand and supply, and how to best integrate migrant communities into society. International bodies should also strive for a global re-think of existing and prospective channels of voluntary migration, funding mechanisms, the need for humanitarian assistance, how to best deal with conflict resolution and emergency preparedness, and innovative mechanisms for linking migration to labour, sectoral or demographic deficits in countries.

[Table 4 here]

3.5.4. A note on the ranking of options

Differences in discounting practices, economic and climate change scenarios, uncertainty treatments, non-market considerations, temporal and spatial scales, and equity, can raise uncertainty when deciding between options and subsequently weaken the case for action. This leads us to question whether, as it stands, CBA is an appropriate and justifiable means for prioritising options. CBA undoubtedly has its limitations, but in most cases it is the most comprehensive and consistent available information for supporting decision-making. Findings also show that many adaptation actions have huge benefits compared to costs in spite of the limited basis on which they are calculated. Future assessments should strive to limit uncertainties and strengthen CBA outcomes by complementing analyses with other types of information – cost-effectiveness, multi-criteria, real-options and robust decision-making approaches will help to provide more complete evaluations in this regard. Users of CBA itself can also aim for more holistic considerations with respect to externalities, distributional effects, and how to best integrate issues of intra- and intergenerational equity within their assessments. Indeed, some of these aspects are included at least qualitatively in many CBA studies. A more complete treatment of these factors, however, will be fundamental for assessing the true value of adaptation and in supporting decision-making. This is particularly important now, as a time where cities are already undertaking adaptation plans and making serious investment decisions[8] that will condition (positively or negatively) future resilience.

4. Conclusion

Cost-benefit analysis of adaptation measures in urban environments faces a number of challenges pertaining to timescales, discount rates, scenarios, uncertainties, and the valuation of non-market costs and benefits. As a result, a number of issues arise that highlight the inadequacies of CBA for dealing with aspects such as equity, environmental justice, extreme or irreversible climatic events, and the sustainability of options.

Even so, the widespread and consistent use of CBA makes it an important economic tool for climate change adaptation. Its main advantage lies in its common basis for comparison (money), which enables

[8] A great deal of infrastructure investment will be decided in the following 20 years, accounting for up to US$ 90 trillion (Economy, 2016)

decision-makers to assess the feasibility of a proposed policy or program. CBA also acts as a screening device against inefficient proposals (where the costs far outweigh the benefits), which is particularly useful in public sectors for preventing inefficient public spending. Indeed, some have argued that current regulatory costs remain widely variable and unacceptably high (Tengs et al., 1995; Tengs and Graham, 1996) and better allocation of resources could be achieved with properly implemented CBA. CBA also supposedly increases transparency and accountability in decision-making by offering a common and simplistic language for users and stakeholders to understand. This also limits politically contentious decisions by requiring that all assumptions and uncertainties underlying analyses be revealed.

While there are numerous advantages to cost-benefit analysis, its application to environmental matters remains widely debated. As highlighted in this study, a major limitation of CBA relates to the numerous discrepancies between authors on how to handle aspects such as inter- and intra-generational equity, low-probability high-impact risks, distributional effects, and the integration of important non-market factors related to aspects such as human health, well-being, and the environment. More often than not, these aspects are disregarded within CBA due to quantification issues, which for many options may skew decision-making against protection and may adversely affect already marginalised groups. At present few studies apply extensions of CBA, such as multi-criteria analysis, adaptive pathways and real options analysis, which can help address some of these challenges. However, this is changing and more studies using these tools can be expected in the future.

It is also important to note that these conclusions are based on a relatively small sample of the literature on adaptation. Furthermore, it is difficult to compare CBA across such diverse adaptation measures and contexts. Greater research into these distinct adaptations will no doubt provide more detailed and meaningful results. In addition, more work ought to be done on how to address the challenges of economic assessments of adaptation in developing regions, which as it stands, are underrepresented by the literature. Innovative financing for adaptation that shifts the burden of costs from victims to polluters, for example, will help developing cities utilise restricted resources and push beyond planning through to implementation. Future scholarship also needs to explore the potential magnitude of non-market costs and benefits of adaptation. Striving for more integrated valuation within assessments can help in this respect. Finally, gaining a more holistic perspective on the distributional effects of non-market impacts will help limit the likelihood of maladaptation and encourage measures that balance adaptation alongside other policy goals such as mitigation, economic development, health and wellbeing.

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Tables:

Table 1: identification, inclusion and exclusion criteria used in the literature search phase

Table 2: Literature reviewed on cost-benefit analysis of climate change adaptation in cities

Table 3: Uncertainty considerations within cost-benefit analyses of adaptation[9]

Table 4: mean benefit-cost ratios, ranks, standard deviations, variance and number of studies considered for each measure.

Figures:

Fig 1: Distribution of adaptations at various scales of implementation covered in the literature*

*1=building/infrastructure level, 2=district/neighbourhood level, 3=city/regional level

Fig 2: Time horizons and discount rates considered by the literature

Fig 3: Time series of cost-benefit analysis against other emerging economic tools for valuing adaptation

[9] Note that percentages do not sum due to rounding errors