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Perspective

Cities and Climate Change

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Abstract: This review paper considers the disjuncture between the rapid pace of climate change and the more sluggish ability of cities to fully implement effective strategies of climate change adaptation and mitigation. We will refer to this as the 'slow city–quick climate change' dilemma. Climate change is accelerating, quickly rendering obsolete previous urban forms inadequate, while structural adjustments to cities are slower moving. Cities around the world were largely built for previous climate regimes. In the short to medium term, there is a mismatch between the climate regime that cities were designed for and the climate regime they now inhabit. The paper is divided into four parts: a brief review of climate change in general; climate change in cities; a review of climate change adaptation and mitigation in cities; and finally, a discussion of urban futures in the time of climate regime change.

Keywords: climate change; cities; adaptation; mitigation; climate regime change; extreme weather events; urban futures

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1. Climate Change

It is now indisputable that climate change is not only real but accelerating. The sixth and most recent report of the Intergovernmental Panel on Climate Change (IPCC) noted that climate change is widespread, rapid, and intensifying [1]. Warming is twice as high in polar regions leading to liquefying of permafrost, loss of seasonal snow cover, and the melting of glaciers and ice sheets. The impacts on the ground are varied. Global warming is leading to increasing heat waves, longer warm seasons, and shorter cold seasons. There is likely to be more intense rainfall and associated flooding in some regions of the world as well as more drought in others leading to desertification. The impacts are also complex. In higher latitudes, warming will mean shorter snow seasons, but because warmer air holds more moisture, the warmer winter air can result in more intense snowfalls. Therefore, while the winter season may be shorter, snowstorms may be more intense. Rainfall is likely to decrease over large parts of subtropical areas. Coastal areas are threatened by sea level rise. The maritime regions of the world will be impacted by marine heatwaves, ocean acidification, reduced oxygen levels and more intense hurricanes and typhoons. The overall warming trend will have multiple expressions in different parts of the world from melting permafrost, to increased snowfall, to more drought, greater incidence of flooding, and in general, more extreme weather events. We are entering a new climate regime.

There are now a number of studies that show the negative impacts of this regime change across a wide range of issues, including—and this is just a tiny sample—algae blooms [2], economic performance [3], global supply chains [4], flooding and increased precipitation [5], human health [6], migration [7], plant productivity and ecosystem sustainability [8], poverty [9], and tourism [10].

2. Climate Change in Cities

In this paper, we discuss some recent research on climate change in cities. A range of studies is presented on Table S1 (see Supplementary Material) under the following categories: general impacts, mitigation in cities, extreme events in cities, adaptation in cities, and possible future scenarios. The discussion is framed around the assertion that while climate change impacts on cities are accelerating, and cities are responding, the structural responses especially in terms of adaptation are often too slow and/or costly. The result is what we term the 'slow city–quick climate change' dilemma.

Cities are an important arena for discussion of climate change. A relentless urbanization means the majority of the world's population now lives in cities. Cities house more than half the world's population; they consume 75 percent of the world's energy and emit 80 percent of the world's greenhouse gasses. Urbanization has also wrought a general environmental transformation from the clearance of vegetation to reductions in wildlife habitats, more air pollution, and warmer urban heat islands [11]. These and associated environmental changes heighten the impacts of climate change. The buildup in urban infrastructure is the primary driver of risk to environmental hazards while the high densities of cities and their recent rapid growth make them a prime site of climate vulnerability.

Climate change is accelerating while structural adjustments to cities are slower moving. Cities are complex, slow moving constructs compared to the speed and directness of climate change. The disparity is the result of different temporal processes. The evolution and construction of individual cities is a long-term process, in some cases over centuries and at least decades. Cities are the result of long-term political, socio-economic, and environmental trends and contestations. Climate change, on the other hand, is a much more recent external phenomenon. While climate change impacts are immediate and increasing, the ability to change the form of cities is more complex, difficult, and longer term. Climate change is immediate and direct, while the ability to adapt cities is hindered by the complex array of competing interests, power centers, and historical legacies. The ability to adapt city form to new climate regimes is limited by the historical and economic context of cities. Cities are slow changing, negotiated socio-economic constructs faced with a direct relentless and rapidly accelerating existential challenge.

Cities both cause climate change through greenhouse gas emissions and are in turn impacted by climate change. There is a burgeoning literature that examines this nexus of relationships between climate change and cities [12–19]. While our knowledge of climate in cities is increasing, there is still a need for comprehensive and globally comparative urban data, the need for global urban observatories and for more surveillance of climate change in the global urban South [20]. While we have lots of data on cities in the global North, such as London [21] and other European cities [22], data on climate change in cities of sub-Saharan Africa is still patchy although a study of four African cities, Cape Town, Lagos, Maputo, and Port Said found that in the future, they will likely have fewer wet days and more dry days. Only Lagos was likely to see an increase in more extreme precipitation events [23].

One study of 520 major cities across the world shows that by 2050 around 77 percent of all cities will experience a change in their climate regime. Almost 22 percent of cities will exist in climate regimes that do not currently exist and only 23 percent will remain in similar climate regimes [24]. In the more tropical cities, the wet months will become wetter and the dry months drier creating conditions for both flooding in winter months and drought in the warmer months. Cities in northern latitudes will experience the greatest changes with warmer summers and winters. European cities, for example, will get warmer by between 4.5 and 4.7 °F in summer and winter, respectively. By 2050, London's weather will be similar to current weather conditions in Barcelona. A study of 571 European cities predicted more heatwaves, droughts, and flooding (pluvial, fluvial, and coastal) [22].

Extreme Climate Events in Cities

The change in urban climate regimes is most apparent in the greater incidence of extreme weather events. Cities are experiencing more weather-related disasters. A study of New York City, for example, showed a rising mean number of hazards per decade, especially flooding and heat waves [25]. Cities are now at greater risk of extreme weather events [26,27]. These include floods [28–32] and wildfires [33,34].

The link between climate change and environmental hazards is socially mediated. Consider the case of increasing wildfires impacting towns and cities in the western USA [35]. The wildfire season is getting longer with more damaging fires. There are numerous reasons. There is a policy of fire suppression that means a buildup of forest debris that is a highly combustible fuel. Climate change is also making the American west hotter, drier, and more vulnerable to fire. There is also the enlargement of the Wildland–Urban interface (WUI) of new residential areas close to existing woodlands [36] in areas subject to increasing risk of fire [37]. So much money has to be spent on protecting property in the WUI that programs for preventing wildfires and protecting habitats and wildlife are much reduced. Protecting property owners in the WUI makes forest fires more likely [38].

Extreme weather events are impacting urban livability. A study of 288 cities in China found more heatwaves and extreme precipitation in the cities of southern China and more cold weather impacts in cities of the northern areas [39].

Extreme climate events in cities have a greater impact on the poor and the marginal. The searing image of poor Blacks left stranded in New Orleans during Hurricane Katrina in 2005 represented the income and racial inequalities exacerbated by the differential vulnerabilities to environmental hazards caused by climate change [40]. The negative impacts of climate change in cities, whether in drought, flooding, heatwaves, or landslides, impact the poor more than the rich. The poorer groups in society experience more environmental risk as they are more vulnerable to the effects of flooding, landslides, and other environmental hazards. They have fewer resources to leave before an extreme event and fewer resources to recover after an extreme event [41]. Governments tend to listen more to the well-connected and the powerful than the marginal and the weak. Climate change when mediated through the socioeconomic realities of city living reinforces the inequalities in society.

3. Adaptation and Mitigation in Cities

Climate change policies are shaped by and in the arena of national and urban politics [42–46]. There are the usual machinations of material interest but what is distinctive about urban climate change politics is the importance of the bottom-up movement from urban residents demanding a better quality of urban life. City residents not only have an immediate experience of their urban livability such as the poor air quality, flooding, and heatwaves, they also have a more immediate and greater ability to leverage local policies that affect change. As Short [47] has argued, whereas the nation state can be both too big to deal with urban issues and too small to affect global affairs, cities provide easier access for progressive social movements to pull levers that allow for progressive social change. Cities are now being judged by both by their citizens and international opinion by the size and quality of their sustainable policies [48]. There is not only inter-urban competition but also inter-urban cooperation as cities also learn from each other through the discursive circuits of the urban global network [49–51]. There is a growing alliance of cities devoted to creating a more sustainable urban future, such as the C40 group [52]. Many of these networks connect the large global cities but there is also cooperation at more local level. There are also more focused groups, such as the Extreme Heat Resilience Alliance which includes the cities of Athens, Chennai, Melbourne, Mexico City, and Tel Aviv [53].

Cities are important platforms for climate change adaptation and mitigation. Bulkeley [54] reviews a wide body of material on the mitigation in low carbon cities and the adaptation to climate resilient cities. Mitigation focuses on reducing the concentrations of greenhouse gases by using alternative energy sources, encouraging greater energy efficiency and conservation, and while mitigation is happening, it can do little to affect the immediate effect of extreme climate events on cities over the next fifty years. Climate change impacts in cities now and over the next half century are the result of carbon emissions already in the atmosphere. Mitigation will have its greatest impacts in trying to stop carbon emissions increasing from their current high levels. Therefore, while mitigation is a useful long-term strategy, it does little to reduce climate change impacts on cities in the short to medium term.

Adaptation involves restructuring cities to meet the demand of a new climate regime, greater environmental vulnerability, and higher risk of extreme weather events including drought, flooding, extreme heat, more deadly storms, greater precipitation, and the risk of wildfires. There are detailed studies that look at future land cover scenarios [55], transport [56], nature-based solutions [57], adaptation to urban flooding [58], and possible synergies between adaptation and mitigation [59]. There are also many case studies including adaption to urban climate change in cities in China [60] and the combination of adaptation and mitigation in climate change plans in cities of Europe [61] and in Italy [62]. The city of Chicago, for example, has developed policies anticipating a hotter and wetter climate by repaving with permeable materials, planting more trees, and offering tax incentives to 'green' office roofs [63].

The problem is that while climate change is accelerating, cities are social ecological ensembles built over years, decades, and in some cases centuries, so changing land cover, creating new buildings designs, retrofitting buildings, reducing the risk of flooding and the impacts of heatwaves, and the general hardening of cities against extreme events takes either money or time. We have already stated the case of Hurricane Katrina that inundated the city of New Orleans in 2015 and resulted in 100 billion USD in damages and over 2000 people dead. The tragedy was public enough to force federal intervention and a 14 billion USD, 350-milem decade-long program to improve the levees to protect the city from flooding was completed in 2018 [40]. However, the USA is one of the richest countries in the world. Equally vulnerable urban dwellers of the global South are unlikely to receive such a fiscal commitment from their governments. Adapting cities to new climate regimes is expensive and few countries can undertake such fast infrastructure investment without a global commitment.

Not only is infrastructure investment expensive, it also takes time. Adapting cities to deal with drought [64], reduce the number of impermeable surfaces in cities to reduce the risk of flooding and increasing temperatures of the urban heat island will take decades to plan, finance, and build. In the meantime, of course, climate change and the risk of extreme weather events impacting urban residents is increasing now. Consider the case of Europe where almost 75 percent of buildings are not energy efficient but most will still be in operation in 2050. A plan that assumes the most optimistic of estimates suggests that the built form will only be changed at the rate of 2% a year which means that it will take 50 years to completely rebuild our cities to make them sustainable and resilient in new climate regimes [65], and that is in one of the wealthiest regions of the world.

To be sure, cities can make immediate changes such as the greater use of early warning systems to warn residents of extreme weather events or make better arrangements to immediately help residents in the event of extreme climate-related events such as excess heat, flooding, and wildfires. However, the mismatch between the complex, costly, and time-consuming nature of climate change adaptation and the speed of climate change already baked into the system creates the slow city–quick climate change dilemma. Over the next fifty years, the mismatch will only increase.

4. Urban Futures in Times of Climate Change

There are at least two possible recommendations to, if not solve, at least manage the dilemma. The first is a real need for accurate data on the relationship between climate change and cities [66]. A recent study, for example, using satellite data at the 250-m resolution revealed that the number of people living in flood-prone areas increased between 2000 and 2015 by 58 million to 86 million. Most of the increase was due to rapid urbanization in flood-prone regions. The more accurate methodology showed that almost 255–290 million people were directly affected by floods, more than ten times the total suggested by traditional estimates [67]. Better data and more accurate methodologies are vital to grasp the extent of climate change impact on cities now and in the near future.

Assessing a city's carbon footprint is a good place to start on how cities contribute to and are impacted by climate change [68]. A city's carbon footprint is the total amount of greenhouse gases that it produces. One study measured the carbon footprint of Beijing, Jakarta, London, Los Angeles, Manila, Mexico City, New Delhi, New York, São Paulo, Seoul, Singapore, and Tokyo [69]. Another study measured the carbon footprint of the largest 100 metro areas in the US [70]. The higher density metro areas had the smallest footprint. Another study found that households in suburban areas in the US had a much higher footprint than those in the larger cities [71]. It is clear from the research that certain urban forms reduce the carbon footprint. The larger cities have smaller carbon footprints than smaller cities. Higher density cities have lower carbon footprints than lower density cities. Urban policies that include encouraging more compact urban growth, more sustainable transportation, more mass transit, and greater reliance on sustainable energy can help to reduce a city's carbon footprint.

Other metrics are also being developed include the ecological footprint and the water footprint of a city [72,73]. These metrics are still in the early stages of development. Ideally, we need to develop a comprehensive city sustainability index. A robust city sustainability index would benchmark where we are now and provide a measure of progress in the future.

The real-time monitoring adopted by a "smart city" can help to create a more resilient city. Monitors in cities that provide data on a range of phenomena such as water leakage from pipes, flooding of roads, pollution, traffic buildup, and increased heat and drought conditions are vital to a proper assessment of climate change consequences in cities [74–77]. A smart city would also involve an improved risk management system. We need to combine the practices of the smart city with the goals of the resilient city.

The second is the need for a global program of financing urban infrastructure that deals with adaptation especially that addresses the vulnerability of low-income communities in cities around the world and especially in cities of the global South. The climate crisis is also a social justice issue that highlights the disparity between rich and poor nations and rich and poor people. There is a huge difference between the impacts of climate change and the ability to pay for adequate and resilient adaptation. Richer countries can meet many of the costs of refitting their cities for new climate regimes. Cities in the global South, in contrast, have a greater vulnerability to climate-induced extreme weather events yet less ability to find the necessary monies to effect rapid transformations. We should give immediate attention to how to fund the climate crisis. A mixture of public and private investment is urgent and using proceeds from a global carbon tax may provide much-needed funds [78].

Finally, we should note that while the dilemma exists and is a rapidly approaching existential crisis, there are some positive signs. The cost reduction of renewable energies, improvements, and efficiencies all have the capacity to reduce greenhouse gas emissions and hence slow global warming. There are a range of innovations from electric cars to greater use of renewable energy sources to the greening of our economy and society. There is a renewed concern with building a sustainable society. In the short to medium term, however, the crisis is already impacting cities with more extreme weather events. Climate change adaptation in cities is running up against the fast pace of global warming and accelerating climate change.

We should, in conclusion, recall a Greek myth. Prometheus stole fire (read fossil fuels) from heaven to give humanity heat and light. To punish humanity for taking such a valuable resource from the gods, the chief deity, Zeus, gave the first woman, called Pandora, a box that she was told never to open. Of course, being a myth, she did indeed open it and let loose all the troubles into the world (read climate change). However, the box also contained one sprite, named Elpis, usually translated as Hope. Pandora's box opened up a host of problems but also the tantalizing possibility of hope. If we focus for a moment on Elpis rather than the other troubles released from the box, we should note that there is now greater awareness of the climate crisis and its impact on the home of the majority of the human population, the cities of the world. It is in cities of the world where adaptation and mitigation policies are being most tried and tested [79]. That leaves us with the intriguing possibility that cities are both the cause of many of our problems of climate change but could also be a solution [80,81]. The future is just too bleak to consider without the possibility of Elpis.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/earth2040061/s1, Table S1. Recent studies on cities and climate change.

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Table S1. Recent studies on cities and climate change.

General Climate Change Impacts
IPCC, 2021 [1]
Gobler, 2020 [2]
Diaz & Moore, 2017 [3]
Ghadge et al., 2020 [4]
Tabari, 2020 [5]
Watts et al., 2018 [6]
Kaczan, & Orgill-Meyer, 2020 [7]
Pareek et al., 2020 [8]
Hallegatte et al., 2018 [9]
Semenza & Ebi, 2019 [10]
Climate Change Mitigation in Cities
Sari, 2021 [11]
Hobbie & Grimm, 2020 [12]
Huang-Lachmann et al., 2018 [13]
Hughes et al., 2018 [14]
Jones, 2017 [15]
Kalafatis, 2017 [16]
Kalesnikaite, 2019 [17]
Koop & van Leeuwen, 2017 [18]
Reckien et al., 2018 [19]
Bai et al., 2018 [20]
Dawson et al., 2017 [21]
Tapia et al., 2017 [22]
Climate Change and Extreme Weather Events
Abiodun et al., 2017 [23]
Bastin et al., 2019 [24]
Depietri & McPhearson, 2018 [25]
Kron et al., 2019 [26]
McPhillips et al., 2018 [27]
Zhou et al., 2017 [28]
Hadipour et al., 2020 [29]
Skougaard Kaspersen et al., 2017 [30]
Zhou et al., 2019 [31]
Zhou et al., 2018 [32]
Goss et al., 2020 [33]
Westerling, 2018 [34]
Short, 2015 [35]
Martinuzzi et al., 2015 [36]
Theobald & Romme, 2007 [37]
Gorte, 2013 [38]
Liang, et al., 2020 [39]
Short, 2021 [40]
Benevolenza & DeRigne, 2019 [41]

Climate Change Adaptation in Cities
Broto, 2017 [42]
Bulkeley, 2021 [43]
Göpfert et al., 2019 [44]
Wamsler et al., 2020 [45]
Patterson & Huitema, 2019 [46]
Short, 2015 [47]
Jabareen, 2013 [48]
Goh et al., 2020 [49]
Göpfert et al., 2019 [50]
Frantzeskaki & Rok, 2018 [51]
C40, 2021 [52]
McLeod, 2020 [53]
Bulkeley, 2013 [54]
Carter, 2018 [55]
Ford et al., 2018 [56]
Frantzeskaki et al., 2019 [57]
Silva & Costa, 2018 [58]
Sharifi, 2021 [59]
Ng & Ren, 2018 [60]
Grafakos et al., 2020 [61]
Pietrapertosa et al., 2019 [62]
City of Chicago, [63]
Cremades et al., 2021 [64]
European Commission, 2021 [65]

Climate Change and Future Impact on Cities
Ortiz et al., 2021 [66]
Tellman et al., 2021 [67]
Short, 2015 [68]
Sovacool & Brown, 2010 [69]
Brown et al., 2009 [70]
Jones & Kammen, 2011 [71]
Vanham & Bidoglio, 2014 [72]
Zhao et al., 2011 [73]
Hatuka et al., 2018 [74]
Arafah et al., 2018 [75]
Mundula & Auci, 2019 [76]
Bibri & Krogstie, 2017 [77]
Geroe, 2019 [78]
Chu et al., 2019 [79]
Escalante et al., 2020 [80]
Frantzeskaki et al., 2018 [81]