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The use of urban climatology in local climate change strategies: a comparative perspective

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ABSTRACT
This paper discusses the extent to which the science of urban climatology has informed local climate change strategies in four city case studies – Stuttgart, Tokyo, New York City, and Manchester. The paper draws on historical and contemporary policy documents along with 60 interviews with practitioners, city officials, politicians, and academics in order to understand the use or non-use of urban climatology science in local climate change strategies. It explores the historic successes and failures of urban climate management of the cities and how the impact of global climate change and perception of risk, local competency and capacity, national programmes, and the involvement of cities in networks influences the application, stabilization, and institutionalization of urban climatology into climate change strategies. It concludes by highlighting the high levels of variability present and potential reasons for local policy engagement or non-engagement in the use of urban climatology science.

Introduction

Weather awareness now has a firm place on the planning agenda, with widespread acknowledgment that cities should play their part in greenhouse gas mitigation and make realistic preparation for the dangerous consequences of climate change (Hamin and Gurran 2009; O'Neill and Ebi 2009; Bambrick et al. 2011). The Intergovernmental Panel on Climate Change has for the first time included human settlements as a level of analysis (IPCC 2014) and successive events – Hurricane's Sandy and Katrina, Brisbane flooding, the European heat waves of 2003 and 2006, Indian power failures in 2012 – have all underlined the need for cities to engage in climate change mitigation and adaptation (UN-Habitat 2011). As a result attention is shifting to the methodological and institutional practicalities of collaboration across the domains of climate science, urbanism, and governance (Bulkeley 2005; Rosenzweig et al. 2011; Bulkeley and Betsill 2013).

This paper approaches the topic from an unfamiliar angle. It is not primarily concerned with the (relatively) recently detected phenomenon of anthropogenic climate change at the global scale, important though it is, but with the anthropogenic effects of climate change that occur within and around the immediate built environment of urban areas. The question it seeks to answer concerns the historic use or non-use of urban climatology science in local climate change strategies for

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the purposes of both adaptation and mitigation. Whether in desert or tundra, coastline or valley, each human settlement has a distinctive climate, modified by the form and mass of its buildings and by the configuration of its streets and open spaces. Its design markedly affects its temperature, humidity, air movement and even precipitation, and such interactions are the scientific object of urban climatology (Erell, Pearlmutter, and Williamson 2011). It begins by introducing the scientific field, discusses relevant literature on the coproduction of knowledge and practice, and proposes a comparative case study approach. It then considers the historical case for selecting the case study cities followed by an examination of how particular drivers of climate change strategies in each city influence the use of urban climatology. A discussion section considers how different city contexts may affect the use and coproduction of knowledge into policy, and draws conclusions concerning what Corburn (2009) calls the localization of environmental science.

Locating urban climatology

To date, understandings of climate change have heavily been influenced by macroclimatic modelling and the far from simple problems of down-scaling to the urban context (Wilby 2008; Corburn 2009). Less has been made of the models and data requirements for climatic analysis at the urban scale, and the contribution of such analysis to adaptation and mitigation strategies (Oke 1984, 2006; Eliasson 2000; Mills 2006; Satterthwaite et al. 2007). The microclimates of human settlements are determined ecologically by the interaction of regional weather with local physical topography, the three-dimensional configuration of buildings and spaces, and human behaviour within them. As such, the factors that determine human thermal comfort – solar radiation, wind, humidity, and ambient air temperature – are significantly affected by the form of the city, by its urban design. But whereas the significance of indoor environmental factors is well appreciated by building architects, town planners, and decision-makers are less accustomed to considering the implications for outdoor climate (Bosselmann et al. 1995; Ali-Toudert and Mayer 2007).

Erell (2008) summarizes the ways in which urban planning and design decisions impact the urban climate and can help cities to mitigate and adapt to climate change. Due to the complexity of factors (geography, time of day, building materials, people and movement patterns, etc.) that influence the urban microclimate, it is rarely possible to generalize results of interventions to all urban environments. He however emphasizes six key factors typically found under the remit of city planning departments that allow cities to better manage their urban climate; the level of urban density, street orientation, street aspect ratio, neighbourhood and building typology, size, type, and location of city parks, and building and paving materials (Erell 2008, 101–113). Following on from this, Lenzholzer (2015) has also developed a detailed breakdown of materials and techniques, classifying them by impact on temperature, air movement, precipitation, and human perception.

It has become possible therefore to identify and design interventions to optimize these factors and improve the urban climate quicker and more cheaply thanks to new techniques of automated data-collection and urban climatic modelling. The harder task is to incorporate such insights via regulation into everyday municipal practices of land use zoning, design codes, infrastructure specifications, master-plans for development areas, green-space reservations, and policies for the spatial structure of urban areas overall (Shaw, Colley, and Connell 2007; Erell 2008; Farr 2008). As such, urban climatic knowledge needs to be matched by both policy and regulatory application (Sippel and Jensen 2009).

The research approach

In order to understand the interaction between science and policy, a coproduction framework is adopted for this paper. The origins of coproduction lay in the fields of political economy and public administration with a focus on citizen involvement in government decision-making, whereby Ostrom (1996, 1073) defined coproduction as ‘the process through which inputs used to produce a good or service are contributed by individuals who are not "in" the same organization'. As such the concept refers to a symbiotic relationship so that 'coproduction plans and delivers in mutually beneficial ways and acknowledges and rewards local "lay" experience while continuing to value professional expertise' (Boyle and Harris 2009, 15). Over time, ideas of coproduction have been modified and used to explain the difficulties and opportunities of translating 'expert' scientific knowledge into policy, as too often scientific knowledge is presented and viewed as inaccessible to policy-makers and politicians as well as used as a tool to limit accountability and public debate (Jasanoff 2003). Lemos and Morehouse (2005) have discussed that in order for coproduction of scientific knowledge to be successful, there is a need for a more dynamic interaction between scientist and policy-maker so that scientific results are not merely discussed with policy-makers but rather integrated into policy development in a sustained and iterative manner that allows for the creation of effective science-informed policy. Increasingly, researchers have used the concept of coproduction to explore the relationship between knowledge-making and wider socio-political decisions, particularly in relation to environmental science and policy (see, for example Jasanoff and Martello 2004; Miller 2004; Whitehead 2009; Lövbrand 2011). These studies placed particular emphasis on exploring the local environment in which scientific knowledge is developed and how it is used to inform macro policy deliberations, such as global climate change. Yet such discussions often neglect to explore how locally derived scientific knowledge is used to inform local policy discussions, as opposed to national and global policy discussions.

Corburn (2009) has, however, explored coproduction with a particular emphasis on the interaction between urban climatic knowledge and local public policy through a local coproduction of environmental science framework. For him, the application of scientific knowledge cannot be separated from the social processes that are inevitably linked to the implementation of local climate change policies. Science and social factors must not be viewed as mutually exclusive, but rather dynamic and interconnected. In this way, the interface between scientific knowledge and social processes requires that a level of negotiation and collaboration occurs, both in relation to the identity of practices – the science and the policy – and the actors – the scientists and the policy-makers (Tuinstra, Hordijk, and Kroeze 2006). This interaction means that coproduction 'not only aims to bring the social back into science policy-making, but also to explore how this knowledge is applied, stabilised and institutionalized over time' (Corburn 2009, 415). This paper seeks to explore the latter of these concepts through a very specific type of knowledge – urban climatology – and the extent and manner in which it has been applied, stabilized and institutionalized within climate change strategies over time dependent on four key concerns that drive local governments' response to climate change as identified by Alber and Kern (2008, 171):

- The impact of global climate change at the local level … and the perception of these regional vulnerabilities and risks by citizens and policy-makers;
- A city's competences and authority to regulate climate-relevant issue areas, its commitment to fight global climate change and its capacity to do so;
- National programmes that support local initiatives, in particular initiatives of local authorities that lack the resources to follow the pioneers; and
- The involvement of cities in national and transnational networks, which facilitate the exchange of experience, the transfer of best practice and the joint development of innovative solutions.

The influence of these drivers on the integration of urban climatology into climate change mitigation and adaptation strategies is explored through a comparative case study approach of four cities – Stuttgart, Germany; Tokyo, Japan; New York City, USA; and Manchester, UK. The case studies vary in size but have been chosen due to their shared history of institutionalizing climate science into local policy. This historical view allows for reflection on the variable processes of entrenchment and disengagement of urban climate science in each of the cities over time as well as an exploration of how it is being re-discovered in these cities due to the threat of climate change. Desk studies based on historical and contemporary documentary analysis were supplemented by more than 60 interviews with practitioners, city officials, politicians, and academics undertaken between April 2010 and July 2011.[1] The focus of the study on the application, stabilization, and institutionalization of urban climatology into climate change strategies as a response to the aforementioned key drivers necessities a historical perspective in order to understand how the relationship between scientist and policy-maker has evolved over time.

Historical urban climate management

Case studies have been chosen to reflect cities that have a recent historical engagement in the application of urban climatology to city planning for the purposes of climate change adaptation and mitigation. German cities, for example, lead the world in urban climate management (Hebbert and MacKillop 2013), and Stuttgart is pre-eminent in Germany with climate change mitigation and adaptation strategies deeply integrated into urban planning practice (Hebbert and Webb 2011). Stuttgart, state capital of Baden-Württemberg is the warmest city in Germany and its air quality is among the poorest, thanks to its setting on the floor of a valley with frequent temperature inversions and weak natural ventilation. Climate policy in Stuttgart began as far back as 1938 when a municipal meteorologist was hired to manage the pollution-related components of the city's 1935 Urban Construction By-Law.

The contemporary basis for urban climate management in Stuttgart was laid in 1953 with the municipal publication of the *Regulations for the Implementation of Functions in Climatology* that formalized the administrative status of the city's in-house meteorologists and the application of their science. In response to public health concerns over worsening air pollution they developed innovative monitoring facilities using infrared thermography and multi-component air quality units to measure levels of sulphur dioxide, carbon monoxide, particulates, and nitrous gases. As well as leading on smoke control orders and emissions regulations, the climatology unit contributed significantly to the drafting and subsequent revisions of the city's development plan as well as to the metropolitan structure plan of 2009.

Similar to Stuttgart, awareness of urban climate in Japan's largest city of Tokyo has some long antecedents, heightened by twentieth century concerns with fire and earthquake, chemical warfare and incendiary bombing, the intense atmospheric pollution created by the post-war drive for rapid industrialization, the building of freeways over river beds (e.g. through central Tokyo for the 1962 Olympics), and most recently, radiation plumes and climate warming. Since 1900 the average temperature in Tokyo has risen 3°C, double the rate of New York City though comparable to Seoul. As temperatures increased due to the urban heat island effect, public and scientific concern also grew, yet as will be explained later the connection between the scientific investigations of the urban climate have not always been suitably linked into city and national government policy.

Like Stuttgart, New York City in the mid-twentieth century saw a flurry of investigation into toxic smogs caused by street traffic, industrial emissions, and domestic oil burning. Urban climate quality became a headline issue during the mayoralty of John Lindsay (1966–1973) whose leadership was put to the test by snowstorms in 1969 and summer smogs the following year (Bach 1972). Lindsay employed meteorologists in City Hall, set up a New York City weather station network in 1967, and encouraged research on urban form and breeze systems through a partnership with scientists at Columbia, NYU Bronx, and Cooper Union. For a time, New York City led the world in the investigation of urban windflow and the thermal dynamics of street canyons (Bornstein 1968; Bornstein and Thompson 1981). But as air pollution eased through environmental controls and deindustrialization, the issue slipped off the political agenda, weather stations were dismantled and urban climate research discontinued. From then onwards, New York City showed little interest in the environmental agenda when other U.S. cities in the 1990s, such as Seattle and Chicago, were busy seeking out ways to address climate change.

Similar to New York City, the world's original industrial city has a record of environmental investigation and activism. Manchester's uncontrolled smokestack emissions prompted the discovery of acid rain in the mid-1800s and through this work the advancement of 'sanitary science' with an emphasis on highlighting the human impact of activities on climate and the development of new methods of studying the urban climate (Smith 1852). During the Second World War, Gordon Manley (1944) was able to draw on these records in his work on the role of topography in urban climate. The municipality put such knowledge to practical purposes in the *City of Manchester Plan* of 1945 which incorporated an altitude and rainfall analysis and an extended discussion of atmospheric pollution, its distribution, and remedies (Nicholas 1945). Within the city's universities urban climate research remained a significant scientific specialism. But as in New York, both the academic community and the policy-makers lost interest in anthropogenic climate effects after the 1970s.

Now, as climate change looms many cities have recognized the need to re-engage in the science of urban climatology and revive its use in the development of policy through new climate change mitigation and adaptation strategies. Drawing on Alber and Kern's (2008) four key drivers, the remainder of this paper discusses how these factors are influencing the coproduction of urban climate science and local policy in Stuttgart, Tokyo, New York City, and Manchester and ultimately reflects on the potential for this coproduced knowledge to be applied, stabilized, and institutionalized in the long-term given their current responses.

The impact of global climate change at the local level and perception of risks

While climate change projections are often modelled at the macro scale, it is at the local scale where the impacts are most often felt. Climate projections for Stuttgart's Baden-Württemberg region show an increase in temperature of 2°C in winter and 1.5°C in summer by 2050, along with a 30% increase in the number of days with temperatures exceeding 25°C and a doubling of days exceeding 30°C (City of Stuttgart 2010). Further climate concerns related to precipitation are expected with reductions in rainfall by 10% in the summer and increases of up to 35% in winter. The city's climate change strategy of 2010 was framed as 'a challenge to urban climatology', and its approach both to mitigation and adaptation draws heavily upon the expertize of the long established in-house climate unit, and the range of sectoral and spatial policy tools developed over the previous half-century (City of Stuttgart 2010). Although ultimately rising to be of national interest, the attention to issues of climate management began as a bottom-up phenomenon:

> [it started in the] 1970s and 1980s with the environmental movement which was stronger than elsewhere. There was the rise of the Greens and widespread environmental awareness – or *angst.* (Prof Dr Detlef Kurth (DK), Hocheschule für Technik Stuttgart)

This environmental concern can be linked to political values of *Heimat*, environmental respect and weather-sensitivity amongst the population at large (Hoppe et al. 2002).

Unlike Stuttgart, New York City was a late starter to the contemporary impacts of climate change despite projections for the year 2050 showing a possible temperature increase of up to 2.8°C, 10% increase in precipitation, and a dramatic rise in the number of days per year with a temperature over 32°C, from an average of 14 days a year to anywhere from 29 to 45 days (NPCC 2009). With nearly 578 miles of coastline and more than half a million people living within a flood plain there were major concerns about projections of a 30 cm rise in sea level by 2050 and a dramatic increase in the probability of a 100 year flood occurring once every 19 years (NPCC 2009). Former mayor Michael Bloomberg, first elected in 2002, put climate mitigation and adaptation at the centre of his agenda resulting in a resurgence of interest in urban climatology science and its link to policy:

> The real breakthrough in New York climate policy – transforming knowledge into action – came with the Bloomberg administration and the setting up of the NYC Panel on Climate Change. (Joyce Klein Rosenthal, Assistant Professor of Urban Planning, Graduate School of Design, Harvard University)

In 2007, Bloomberg released his PlaNYC initiative designed to deal with projected population growth of one million people by 2030, the renewal of aging infrastructure, and to develop a plan to reduce greenhouse gas emissions by 30% by 2030 (City of New York 2007). The plan emphasized preparedness, risk assessment, and resilience planning which was amply justified in November of 2012 as Hurricane Sandy demonstrated the need to consider the severe impact climatic events could have on the city. Such events raised the perception of risk among policy-makers and citizens throughout the city.

While perhaps new to New York, the perception of risk in Tokyo has long been present, as heat island temperatures have continued to rise since the 1900s, generating a strong awareness of the urban heat island phenomenon amongst the population (Ashie et al. 2016). This has grown only stronger in recent years as public perception, subsequently confirmed by scientific research, led to concerns over the impact of the relaxation of height controls in the 2000s. This relaxation encouraged development of tall towers which had the effect of blocking the sea breezes that flowed into the city from the bay. The effect was severe, bringing an average 35 days of night-time temperatures in excess of 25°C. Air conditioning solutions aggravated thermal emissions and the loading of an energy system that was already overstretched. Public awareness and press coverage of urban heat problems was heightened by the knowledge that Tokyo was about to enter a long phase of demographic shrinkage and a rapidly growing proportion of elderly vulnerable to excessive heat events.

Compared to the other cities, climate change concerns in Manchester were largely triggered from above by the UK government's national commitments under the Kyoto Protocol (Smith, Cavan, and Lindley 2016). This national commitment led to statutory requirements to meet particular targets and in 2009 resulted in the *Greater Manchester Local Climate Impacts Profile* being published which compiled a historical list of extreme weather events since 1945 (Manchester City Council, Eco-Cities, and the Red Rose Forest 2009). The same year saw the publication of *Manchester, A Certain Future*, a set of 100 adaptation measures, with target dates, developed through extensive consultation with a wide range of stakeholders (Manchester City Council 2011). The aim was to bring together multiple projects, research, and initiatives ongoing in the city and focus them towards meeting specific outcomes. 'Climate' was defined in terms of future weather probabilities without measurement or modelling of current patterns – the only maps of summer surface temperature were small-scale, city-wide, related to long-term forecasts, and came from a PhD thesis of 2008. The same limitations applied to the third policy outcome, a *Greater Manchester Climate Strategy* published for the metropolitan area in 2011 (AGMA 2011). Its preparation involved a GIS-based compilation of datasets from multiple agencies across the boundaries of the 10 councils – no mean feat – but the strategy itself had no spatial basis, and was framed in terms of generic sectoral policies for construction, energy, transport, and green infrastructure. At the time, the lack of local-scale climate change projections made it difficult to quantify the local-scale risk of climate change in Manchester in contrast to the other cities studied.

Competences, authority, and capacity to regulate climate-relevant issue areas

The ability of cities to implement policies to adapt and mitigate climate change is highly variable and often dependent on the competences transferred to cities from higher level governments or constitutional norms. The post-war constitution of the federal republic of Germany for example facilitated an active response on the part of Stuttgart. The city has the status of *Stadtkreis*, a form of self-administrating urban county in Germany run by an elected city council based on a party system with a directly elected mayor. The core city (600,000 population) played a lead role in governance of the wider metropolitan region of 2.7 million and it drew on its significant fiscal autonomy and wide-ranging regulatory powers for city planning and environmental management to support an explicit policy for urban climate.

The city used a mix of sectoral and spatial instruments, publishing an environmental design guide, the *Climate Booklet for Urban Development* (City of Stuttgart 2008) with recommendations for fresh-air ventilation, mitigation of air pollutants and greenhouse gases, open space provision, tree-planting, façade greening of buildings (including suggested criteria for the selection of plants), and green roof design. The document covered a range of topics from domestic heating to highway design for traffic-calmed neighbourhoods, and provided not just design principles but also detailed techniques for measurement and calculation of the mitigation required by different categories of development, thereby linking development and infrastructure provision to the achievement of climate change mitigation and adaption.

These generic guidelines were complemented by a second type of instrument which is Stuttgart's most distinctive contribution to the field. This is the climate atlas or *Klimaatlas*, a spatial document that maps the physical structure of the urban climate and derives site-specific policy recommendations (Ng and Ren 2016). The first *Klimaatlas* was published in 1992, and a revised and expanded version followed for the entire Metropolitan Region in 2008. Weather observation campaigns and atmospheric modelling were combined with three-dimensional mapping and GIS data to provide detailed and accurate mapping of characteristic 'climatopes', with equally detailed mapping of cold-air production areas; cold-air catchment areas; stagnant cold-air/slope zones; and ground inversion zones. Additional data on air exchanges within the valley system, wind roses and the grouping of three grades of air pollution, traffic emissions, business and industry emissions, and domestic fire emissions, were also included in the climate atlas. The amount of local level data allowed the city to develop small-scale interventions rather than relying on regional climatological data.

By clustering microclimate environments and categorizing salient conditions across the range of diurnal and seasonal variation, the atlas translates complex meteorological data into a form that planners could more easily understand:

> Climate atlases … are important tools for communication, they can be understood by politicians and planners. They are based on limited measurements and extensive modelling – 'intelligent extrapolation' for the whole area. Maps make the climate tangible. Decision-makers can relate to visualization. (Dr Ulrich Reuter, Section of Urban Climatology of the Office for Environmental Protection, Stuttgart)

Planning decisions were further supported by recommendations in the climate atlas based on the site-specific climatopes and aerotopes. The climatic guidelines were regarded as authoritative, shaping development opportunities and land values, especially within designated 'taboo-zones' where tall buildings were banned, irrespective of property market factors that might dictate otherwise. In this way Stuttgart utilized the wide range of authority at its disposal as a self-administering city to regulate development and implement measures to mitigate and adapt to climate change, often in difference to the demands of market forces.

In contrast, responding to market forces was exactly the focus of Japanese Prime Minister Junichiro Koizumi's economic stimulus package:

> In 2002 an 'urban renaissance' was initiated by Prime Minister Junichiro Koizumi as part of an economic stimulus package. It involved incentives for large projects, and deregulation of the bureaucratic controls that had previously hindered major development. (Dr Hiroto Kobayashi, Keio University)

The resulting property boom, particularly in Tokyo, was a significant factor in national economic recovery (Sorensen 2003). Many of the city's measures for climate management are non-geographical, and applied to sectors of development irrespective of spatial location. The *Tokyo Green Building Program* (Environment of Tokyo 2002) for buildings with floorspace over 5000 m^2 set generic standards for energy efficiency, thermal emissions, insulation, and air ventilation. Similarly, the city developed generic polices for green roofs, porous pavements, the planting of a million street trees, and innovative *Wall Greening Guidelines* (Tokyo Metropolitan Government 2006a). Such measures bear comparison with environmental codes of many other world cities.

What is distinctive, however, were measures that reflected the spatial input of urban climatology. The *Tokyo Heat Environment Map,* at 500-m resolution, plotted the core ward area into five climatic categories with matching control measures. *Tokyo's Big Change,* the 10-year plan developed in 2006 in connection with the city's candidacy for the 2016 Olympic Games, included a spatial strategy for breeze pathways, defined as corridors with average wind velocities in excess of 4 m/s at 50 m height above datum (Tokyo Metropolitan Government 2006b). Strategic breeze management took a prominent place alongside stormwater drainage in Governor Ishihara's vision of Tokyo as an 'Environmentally Advanced City'. These initiatives came just as the property boom was gathering momentum. Designation of tall building 'taboo-zones' was never an option in this city, where the property-owner's freedom to build enjoys strong constitutional protection, and the real estate sector had all the impetus of Premier Koizumi's recovery package. Tokyo Metropolitan Government's wind-path policy therefore assumed large-scale development and did not adequately take into account the aggregate impact of development:

> The environmental assessment process for a tall building proposal generally includes wind tunnel modelling and critical decision factor (CDF) modelling by environmental consultants. If the scheme leads to strong winds on ground level, developers will adjust design and include mitigation measures, typically vegetation. But the composite effect of multiple buildings is not controlled and is highly complex, given that wind direction is always changing. (Dr Tatsuo Akashi, Director, City Planning Research Division, National Institute for Land & Infrastructure Management, Tsukuba Science City)

The design guidelines were revised annually and in 2009–2010 researchers proposed revisions that included detailed specifications related to building height. The Tokyo Metropolitan Government declined to engage in regulatory action that could depress profitability, instead simplifying the volume bonus rules for provision of greenery and creation of tree-planted spaces. The real estate industry has been content to play to these voluntary rules:

> I have observed a change in the attitude of developers. Traditionally they were willing to invest in energy-savings that benefited the bottom line but not in measures to enhance summer comfort out-of-doors. Six years ago I presented to a major development company without response. Today the quality of environment is regarded by leading companies as a basic aspect of corporate social responsibility. It has become a brand issue. (Dr Shinji Yamamura, Nikken Seikkei Research Institute)

While the city sought to better manage its outdoor climate, Tokyo and the national government have continued to remain cautious in implementing mandatory climate change adaptation and mitigation measures which might decrease economic growth or limit new development.

New York City has a wide range of regulatory powers at its disposal but unlike the Japanese capital it has only recently begun to heavily utilize them to implement *PlaNYC* (City of New York 2007). The annually reviewed strategy was flanked by an array of supportive documents, notably the report of the New York City Panel on Climate Change (2010) and the report of the Green Codes Task Force (Urban Green Council 2010). The first phase involved 127 initiatives, almost all launched within a year of the plan's release and nearly two-thirds progressing to target two years on (City of New York 2011a). The 2011 update set out 132 initiatives and over 400 specific milestones for 31 December 2013 (City of New York 2011b) and was unabashed in its use of its regulatory tools to enforce outcomes:

> PlaNYC is a 'doorway to many small steps', and despite some failures – especially the retreat from congestion pricing – it will be the most successful achievement of Bloomberg's term, with significant policy outcomes: building code reform, obligatory energy audits, mandatory submetering for commercial tenants, initiatives to upgrade the yellow taxi fleet and reduce heating oil pollution. (William D. Solecki (WS), Professor of Geography, CUNY Hunter College)

The Green Codes Task Force was explicitly sectoral. Mobilising 200 building experts it thoroughly overhauled the regulatory apparatus of the municipality, identifying system-wide opportunities to enhance energy efficiency and promote sustainability in the buildings sector. The entire rule-book was updated and the new standards applied through mandatory energy audits and a requirement for all retrofits to be code compliant (City of New York 2011b). Unlike Stuttgart's spatially focused interventions and Tokyo's light touch regulations, New York City's approach lay not in spatial considerations – such as the effect of building height on the windflow in a particular location – but on aggregate calculation of the effect of sector-wide changes on the balances in the model designed to collectively achieve the targets of *PlaNYC*.

Of the four cities studied, Manchester was perhaps the most characteristic of local governments worldwide – working as best it could with few powers and limited resources in a complex intergovernmental environment. A consequence of the institutional constraints is that many of the policy initiatives were localized and area-based allowing progress to be demonstrated on limited means. For example, a short stretch of one of Manchester's key corridors, Oxford Road, containing the universities and teaching hospitals had been showcased as a 'low carbon laboratory' with a cluster of environmental experiments and monitoring projects (Evans and Karvonen 2011). Spatial initiatives of this sort offered symbolic political benefits but they had no rationale in terms of urban climatology, large-scale climate adaptation or mitigation, and limited awareness amongst the population at large.

At the city level, Manchester engaged in a variety of one-off demonstration projects and third party research initiatives that sought to provide a better understanding of the city's urban climate and how it could effectively achieve it's climate change targets. The city drew on a Green City team that was originally charged with meeting nationally defined climate change goals known as NI 188. NI 188 identified five levels of preparedness, from zero to a full set of adaptation programmes with monitoring arrangements:

> Manchester City Council achieved Level 1 in 2010 having carried out an LCLIP (Local Climate Impact Profile) with the University of Manchester's Eco Cities Programme. The City Council hoped to reach level 2 in May 2011 but the Coalition Government's abolition of the mandatory NI188 return will slow progress in a context of slashed budgets. (Corin Bell, Green City Team, Neighbourhood Services, Manchester City Council)

In November 2014, the national government announced that Greater Manchester was to have an elected executive mayor with powers over transport, social care, and housing. These changes hold potential for a more coordinated approach to climate change adaptation and mitigation.

National programmes that support local initiatives

As with city competency, there was much variation in how national governments supported urban climatology initiatives in the cities studied. Many initiatives were developed in partnership with national agencies, arms length bodies and universities rather than central government. In the United States, federal climate change policy had been largely absent due to persistent legislative disagreements between the House of Representatives, Senate and the Office of the President (Goulder and Stavins 2011). As a result, individual states and municipalities were more active in the development of climate change strategies, particularly in the regulation of greenhouse gas emissions and the development of clean energy.

Engagement at the national level in the USA was largely left to individual cooperation with federal agencies such as the U.S. Forest Service which partnered with New York City's Parks Department to develop a *MillionTreesNYC* initiative. The goal focused on planting a million trees, 60% in parks and public spaces and the remaining 40% on private land. The planting strategy was based on public health and poverty criteria rather than a spatial analysis of breeze-paths (as in Tokyo) or cold-air reservoirs (as in Stuttgart). Most of the first tranche of 100,000 trees went to housing projects, on social grounds, and subsequent priorities included a 'restoration sample' to replenish the tree stock in parks, and a 'street tree sample' with its own sectoral advisory board. Mitigation benefits were calculated for carbon emissions, summer temperatures, air quality and stormwater run-off (City of New York 2011b).

Certainly the trees enhanced microclimates, but that was not their primary rationale unlike those explicitly targeted to the reduction of the urban heat island as in Tokyo where the metropolitan government worked with Teikyo University to set up a network of 120 weather stations in 2002. The result was the publication of the city's first *Heat Environment Map* three years later to help identify, where mitigation and adaptation was most necessary to reduce the urban heat island (Yamamoto 2006). In 2006, the observation network was enlarged to 200 stations in a grid across the whole metropolitan area. Linked to this initiative and as a result of a 2004 inter-ministerial steering group of the Japanese Government, a *Policy Framework to Mitigate Urban Heat Island Effects* was developed which recommended cities to pursue a mix of sectoral measures (e.g. green roofs) and spatial interventions (e.g. protection of breeze paths) in partnership with the Japan Meteorological Agency (Yamamoto 2006).

This limited engagement highlighted the national government's preference to distance itself from top-down measures as it continued an environmental strategy based upon large-scale property development leading to controversy between the local and national levels of government (Sorensen 2011). In addition, there were warnings about the impacts of tall buildings on wind patterns as:

> Variable building height has significant turbulence effects. Uniform building height creates low resistance but when we disturb the skyline the drag increases tremendously. Even a few isolated tall buildings can exert a severe effect on global-scale resistance. (Professor Manabu Kanda, Tokyo Institute of Technology)

Longitudinal studies of the Tokyo wind system from 1880 to 1990 indicated a progressive weakening of the system of sea breezes which provided ventilation as the city warmed up on hot summer days. Large-scale modelling further suggested that the vertical atmospheric mixing induced by downtown high-rise towers was delaying the arrival of cooler air from Tokyo Bay which relieved the summer heat load on inland parts of the Tama area and Saitama Prefecture. A severe depletion of airflow at street level was linked to turbulence in the lee of skyscrapers and intense episodes of precipitation ('spot-downpours'), summer flooding and heat deaths:

> The issue remains an urgent matter of concern. There were more than 53,000 ambulance (heat shock) call-outs and fatalities in 2010, three or four times higher than 2008. The topic attracts much political interest. (Takashi Ohmura, Ministry of the Environment, Government of Japan)

As a result, these issues were being debated not just in scientific papers but also on the floor of the national parliament.

While debate on the role of the national government in urban climate management existed in Japan, in Germany there was a bottom-up integration into national standards rather than top-down support and development of urban climate initiatives. Based on positive outcomes in Stuttgart and other German cities, on the 1 January 1977, Germany's Federal Construction Law (now called the Federal Building Code) was revised to include air and climate in the list of factors that must be considered during the planning process (Baumuller and Reuter 2016). In addition, in 1993, the *Klimaatlas* methodology was adopted as a German national standard by the Verein Deutscher Ingenieure (VDI-3787) highlighting the key role played by Stuttgart in the development of innovative urban climate management strategies.

In sharp contrast to New York City and Stuttgart, it is the national government of the UK that was the most influential in encouraging, though not necessarily incentivising, Greater Manchester to develop climate change mitigation and adaptation strategies in the 2000s. The Climate Change Act of 2008 set targets for mitigation of greenhouse gas emissions which were distributed to lower level governments in the form of environmental performance targets. Prior to the mandatory removal of the targets, the vast majority of local authority effort was focused on meeting the specific mandated outcomes. National programmes to support these local initiatives were limited and often targeted at individual incentives rather than large-scale support for local authority programmes. The national programmes that did exist were largely abandoned with the arrival of a new government in 2010. In an age of financial austerity for local governments in the UK, the lack of financial incentives led to ever more limited engagement in climate change initiatives.

The involvement of cities in national and transnational networks

In response to a lack of national level programmes designed to support local government, many have turned to national and transnational networks. Former Mayor Bloomberg's climate programme transformed New York City from a late starter to a field leader as it sought to engage in national and global debates. In the American context New York City became the main protagonist in the *Climate Protection Agreement* at the U.S. Conference of Mayors (2011) as well as a key regional partner:

> New York's response to climate resilience has revived interest in regional cooperation. Building on existing arrangements for emergency management – hurricane strikes, disaster housing, etc. – in the Tri-State area a regional consortium of 9 cities, 2 states, and 4 metro planning organisations have received a grant for a Federal Regional Communities Planning Grant to assist integrated planning for sustainable development. (Alex Washburn, Chief Urban Designer, Department of City Planning, New York City)

Internationally Bloomberg exercized global sway as chair of C40, the summit conference which brought together the mayors of the 59 largest cities in the world, from November 2010 to December 2013. New York City maintains a substantial research collaboration with Columbia University and the City University of New York which acted as the prototype for a worldwide *Urban Climate Change Research Network* (UCCRN). In 2011 UCCRN published its first periodic assessment report under the title *Climate Change and Cities,* with contributions from some 100 authors, an extensive bibliography, and numerous case studies from around the world. While the report was a scientific landmark in terms of connecting City Hall into the IPCC global climate modelling process, it made little reference to the modelling and mapping of anthropogenic climate effects within the field of urban climatology.

Stuttgart's experimental approach to applied urban climatology has been widely influential. In 1976, the city's techniques of wind-path protection were featured in a documentary film as part of the German government's contribution to the first UN-Habitat Conference in Vancouver, BC. The municipal climatology unit has a high scientific profile, regularly hosting foreign local government officials interested in their urban climatology approaches and is active in intergovernmental networks worldwide (Ren, Ng, and Katzschner 2011):

> The department receives many visitors - Korea, Hong Kong, Japan. I visited … Hong Kong in 2008 and Stuttgart climate maps have been influential there. Within Germany we have engaged with Freiburg, Essen, Kassel, and Munich while in Europe – Spain, Portugal … Lisbon and Bilbao. (Dr Ulrich Reuter, Section of Urban Climatology of the Office for Environmental Protection, Stuttgart)

There was also a significant level of knowledge exchange between German cities. Berlin led the way in integrating meteorological analysis with a physiological model to show how residents will experience heat, cold, and comfort, and several universities in Germany created centres of excellence which work closely with city governments.

Japan, meanwhile, is the only country to rival Germany in breadth and depth of academic expertize in urban climatology. Many of its leading practitioners studied in Germany, building a continuing web of connections that stretches back for decades (Yoshino 1975). The national as well as Tokyo Metropolitan Government regularly commissioned work from academics to help it better understand the local climate issues. Tokyo Metropolitan Government also co-sponsored a high-resolution digital model, run on the Earth Simulator super-computer in Tsukuba Science City, which simulated Tokyo's meso-climate in 5 billion pixels.

Left largely isolated amongst the cities examined in regard to national and transnational connections, Manchester struggled to advance a comprehensive climate change strategy due to a lack of fiscal and administrative autonomy. Having no in-house science capacity, the basic research was contracted to academia and consultancies leaving little desire or capacity to engage with national and international research networks. The loose confederal structure of Greater Manchester added another layer of complexity to the coordination of policy. For example a project to study the urban heat island encountered resistance:

> The main problem with this study … was getting authorization from the 10 city councils that make up the Greater Manchester area – each had different conditions, Manchester Council being the most amenable. However, National Indicator 186 [measuring per capita reduction in CO_2 emissions in the LA area from a 2005 baseline] is encouraging greater awareness among councils. (Prof Geoff Levermore, University of Manchester)

Greater Manchester's administrative structure of lightly staffed commissions for the economy, environment, planning, waste and transport also often resulted in the compartmentalization of policy sectors at the metropolitan level with little understanding of the interconnections between policy spheres.

Discussion and conclusion

The preceding discussion sought to explore the extent and manner in which urban climatology was applied, stabilized and institutionalized within climate change strategies over time. Four key drivers were used to explore this process. The results suggest variability, with each city reacting to the drivers with differing types of techniques employed and the extent of coproduction across science and policy being highly localized depending on the geographic and climatic context of the city in question as well as the political and public dynamics present (see Table 1).

Of the cities discussed Stuttgart has perhaps the most sustained and institutionalized connection between the science of urban climatology and city policy. This institutionalization originally occurred in response to concerns of air pollution but was reoriented to address climate change and the resultant urban heat island effect. The city's struggle to manage its air pollution created a public that was keenly aware of the impact of the urban climate on their lives and the risks of climate change. As a self-administering city, Stuttgart utilized its regulatory powers to develop policies for the management of development and infrastructure which explicitly drew on the science of urban climatology. The urban climatologists advise on the development of the city's urban environment, establishing a strong link with the city planners and politicians.

As a city that has benefitted from knowledge exchange with Stuttgart, Tokyo gained an appreciation for the ways in which urban climatology could be used to address the impacts of a rising urban heat island and the increasing number of tall buildings which block windflow. Increases in summer flooding and heat deaths raised the public's awareness of climate change leading to local and national debates on the urban heat island effect, such as through the national inter-ministerial panel on the urban heat island, and national funding programmes for academic research on the issue. Despite this, economic concerns remained paramount resulting in a focus on market friendly generic standards and guidelines rather than regulatory and localized urban climatology measures to reduce the impacts of the urban heat island. The city also lacked a detailed internal knowledge of urban climatology science, with environmental assessments often undertaken by consultants and meteorological studies undertaken by external researchers.

New York City engaged differently with the use of urban climatology in their climate change strategy, with little explicit consideration of the science and its urban impact. Rather the city's approach cast the net wider as it sought to manage risk associated with climate change, including increased energy demands, flooding and extreme weather – heightened in the public's eye by Hurricane Sandy. Based on the aggregate impact of both regulatory measures and guidelines implemented by multiple city agencies and departments in cooperation with researchers, consultants, and non-governmental organizations (NGOs) the city aimed to meet a wide range of climate change mitigation and adaptation objectives. Much of the city's work was due to the initiative of the Mayor's office rather than through national programmes, although some federal agencies and departments have sought to cooperate on specific projects. New York City has gone on to lead Tri-State regional cooperation, undertaken work with the C40 cities as well as a range of other international networks as the national level of government has not, until quite recently, taken a leadership role in climate change debates.

In the case of Manchester, it was wider national greenhouse gas targets that resulted in preliminary exploration of the local climate, although without a specific urban climatology focus. This exploration has however been piecemeal resulting in a less developed understanding of local-scale climate change impacts compared to the other cities discussed. The lack of comprehensive approach to the use of urban climatology in the city's climate change adaptation and mitigation

Table 1. Case study summaries.

	Stuttgart	Tokyo	New York	Manchester
The impact of global climate change at the local level and perception of risks	- Long established use of urban climatology has been reoriented to manage urban heat island effects; Acute local and cultural weather awareness	- Urban heat island effects worsening due to climate change and tall buildings; Strong public awareness of issue and need to manage impacts	- Impact largely ignored until recently with focus on greenhouse gas reductions and adaptation; Perception of risk heightened by energy demands, flooding, and extreme weather	- Local-scale climate change impacts poorly understood; Perception of risk relatively low and impetus to combat originally driven from central government
Competences, authority, and capacity to regulate climate-relevant issue areas	- Utilises regulatory powers to link urban climatology knowledge to planning, development, and infrastructure provision; Institutionalized urban climatology unit within city government to advise on policy issues	- Focus on generic standards, guidelines, and market forces rather than regulatory and localized measures; Environmental assessments generally undertaken by consultants but some policy developed with researchers	- Wide range of regulatory measures updated and detailed outcomes set; Relies on the aggregate impact of measures implemented by multiple agencies and city departments in cooperation with researchers, consultants, and NGOs	- Largely lacks authority to regulate or set standards without national government approval; Limited in-house capacity, largely relies on researchers and consultants for analytical capacity
National programmes that support local initiatives	- Bottom-up implementation of local government approaches to urban climate management through changes to federal legislation	- National involvement related to the mitigation of urban heat island effects; Some support for academic research projects due to strong national awareness of urban heat island	- Limited national programmes Bespoke initiatives with federal agencies and departments exist however	- Top-down setting of targets by national government for local government; Previously mandatory but no longer, leading to less impetus for action
The involvement of cities in national and transnational networks	- Extensive involvement in knowledge exchange with other cities in Germany and around the world Involvement in a range of transnational networks	- Well established network between Tokyo and Stuttgart as well as within and between academic researchers in the two cities; Strong involvement in national level discussions on the urban heat island	- Tri-State regional cooperation; Involvement in the C40 cities network as well as other international networks on climate change resilience	- Knowledge exchange largely left to academics to expand national and international networks; Coordination difficulties exist between the local authorities that make up the region
The coproduction of urban climate science and local climate change policy	- Scientists and policy-makers are highly integrated within local government creating a long-term institutionalized concern for urban climatology issues	- Scientists have long contributed to the identification of the urban heat island effect but city lacks an in-house group of urban climatologists to advise on policy development	- New commitment to multi-stakeholder engagement of scientists, consultants, other stakeholders, and government departments but lack of explicit integration of urban climatology concerns into policy-making process	- Piecemeal engagement with scientists and consultants leading to overall lack of recent institutionalization of urban climatology

strategies was in part the result of a lack of regulatory authority and financial capacity. The absence of financial capability also limited the in-house capacity available to study local climate issues leading to a dependence on university researchers and consultants for expertize. The eventual removal of mandatory targets by the government and austerity budget cuts to local government also left little incentive for local authorities to take further action or to coordinate city-region initiatives.

The preceding discussion leads to variability in the co-production of urban climate science and local climate change policy in the case study cities. Despite all the cities having an historical understanding and appreciation for urban climatology, not all have maintained it. In some cases, the link between the science and the policy is long standing and highly institutionalized, such as in Stuttgart where urban climatologists were integrated into city government policy-making, driven by a keen awareness of the impact of climate change on the city's local climate, the power to develop regulatory tools, a bottom-up concern for the environment driving national regulation, and a long-standing exchange of knowledge on urban climatology nationally and internationally. While Tokyo had similar levels of knowledge exchange and scientific expertize, the connection between scientist and city policy was far less developed than in Stuttgart. While scientists have long contributed to the examination of the urban heat island effect there was no formalized method by which that knowledge was explicitly linked to local climate change policy through an in-house department within the local government amid continued concern for the impact of urban climatology on the real estate market at a national scale.

New York City's engagement with scientists was extensive in the delivery of its *PlaNYC* climate change strategy. However, despite having a coordinating unit and institutionalized bureaucratic system for the setting of targets and implementation of the plan there was an overall lack of explicit use of urban climatology science within city policy. While regulatory tools were being used to adapt to and mitigate climate change, local-scale urban climatology concerns largely formed an implicit rather than explicit component of this strategy. In contrast, Manchester had few regulatory competences or financial capacity to allow it to institutionalize urban climatology into local policy. Rather, despite Manchester's historic academic innovations in the field, it was limited to piecemeal engagement with scientists and consultants on localized pilot studies with little urban climatology consideration rather than comprehensive institutionalization.

If science and social factors cannot be divorced from environmental policy-making as Corburn (2009) argues, then neither can history. While each case study city explored here has developed, to varying extents, different ways of understanding their climate and integrating that knowledge into local climate change strategies, the ways in which those processes are applied, stabilized, and institutionalized are a product of historical engagement with scientists, the long-term local socio-cultural contexts of the city, and past political and policy decisions made at all scales of governance. For coproduction to be successful, scientists and policy-makers should be acutely aware of the historical context in which they work and seek to mutually align their strategies to build on and adapt to past events and practices in order to advance the integration of climate science and policy, or else they may encounter significant resistance leading to a lack of policy action in the long term.

Note

1. Interviewees quoted have agreed their individual transcript to be an accurate record and provided permission for their names and positions to be made public.

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