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Cities, Climate Change and Urban Heat Island Mitigation: Localising Global Environmental Science

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Abstract

This paper explores how city planners engaged with global climate scientists to devise contextually relevant strategies to address the urban heat island effect—a potentially dangerous heat event expected to increase along with global warming. Drawing original data from the New York City Regional Heat Island Initiative, a collaborative effort between scientists and urban planners, the paper highlights how global climate science is 'localised' as researchers and policy-makers struggle to make technically legitimate and politically accountable decisions. The paper argues that the localisation of global science often involves a process of co-production, where technical issues are not divorced from their social setting and a diverse set of stakeholders engage in analytical reviews and the crafting of policy solutions. The paper argues that the co-production framework can contribute to more scientifically legitimate and publicly accountable decision-making related to urban climate change.

Introduction

Urban environmental planners are increasingly faced with two seemingly divergent policy trends: the globalisation of environmental policy issues and the decentralisation of policy responsibilities to local, often municipal, governments. Local governments are commissioning expert scientific advice, formulating policy goals, setting standards and developing new institutions for environmental governance and sustainability. These trends have placed new demands on scientists to communicate their findings effectively in new settings and scales, and on local policy-makers who are faced with combining global science with contextual knowledge and local governance practices. One policy arena where global science is increasingly interacting with local politics is climate change, where cities have emerged as key players in policy discussions once limited to national and

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international institutions (Bulkeley and Betsill, 2005; Kousky and Schneider, 2003; Lindseth, 2004). This paper explores how global climate science—often model-making abstracted from local context and politics—is being 'localised' and legitimised by municipal planners in collaboration with global scientists and how the credibility of science policy is crafted in the 'localisation' process through collaborative review processes that are every bit as significant for policy legitimacy as the reliability and credibility of the scientific information under review. More specifically, this paper explores how scientists and planners interested in devising strategies to mitigate the adverse ecological and human dimensions of urban heat island (UHI) events in New York City (NYC) negotiated the localisation process and simultaneously grappled with issues of technical legitimacy and political accountability in municipal environmental decision-making.

Climate change is expected to increase the occurrence of urban heat island events—where air temperatures in cities rise disproportionately to surrounding areas and result in locally acute adverse human health, economic and environmental impacts. This paper examines the localisation discourse among planners and scientists involved in the New York City Regional Heat Island Initiative (NYCRHII), a collaborative effort that modelled anticipated climate-change-induced temperature changes across NYC's diverse built environment and evaluated a range of UHI mitigation strategies ranging from increased tree planting and surface lightening to the construction of living roofs (Rosenzweig *et al.*, 2006). Using detailed qualitative data documenting over two years of interactions between scientists and policy-makers who were members of the NYCRHII Advisory Committee[1]—including meeting minutes, presentations, e-mail correspondence, report drafts, reviewer comments, internal research notes and interviews with participants—we highlight the challenges scientists and urban planners faced when considering highly contextual information with global change models.[2] The cases highlight that negotiations among the participants reveals tensions and uncertainties within the 'localisation' process not resolvable by either science or politics alone. We argue that the frame of co-production—where technical issues are not divorced from their social setting and a plurality of participants engage in everything from problem-setting to decision-making—can contribute to more scientifically legitimate and publicly accountable urban climate change policy-making (Betsill and Bulkeley 2006; Jasanoff 2004).

Localising Science and the Co-production of Knowledge

While environmental issues from climate change to desertification to biodiversity are increasingly understood as global, planetary scientific assessments of these issues are encountering resistance from the reassertion of local knowledge claims and local identities (Jasanoff and Martello, 2004). For example, national governments and non-governmental organisations participating in the Intergovernmental Panel on Climate Change (IPCC) assessments have made the local impacts of climate change, such as sea level rise on small island states and crop yields in the Great Plains of the US, a priority issue (Miller, 2004). This paper aims to build on recent work emphasising how municipal governments often integrate technical and policy issues at multiple scales when addressing global climate change (Bai, 2007; Bailey, 2007). Yet, as local, often place-based, knowledge is increasingly considered in global environmental assessments, a new set of analytical and political challenges have taken hold, such as how to design processes that incorporate a range of diverse actors, how to adjudicate conflicts over analytical methodologies and different interpretations of evidence, and whether context-specific or universal intervention strategies ought to be pursued (Mitchell *et al.*, 2006).

This paper argues that the notion of the 'co-production of knowledge' offers a framework both for understanding the conflicts involved in localising global science and for structuring analytical processes that can tap into the multiple kinds of expertise necessary for making prudent urban climate-change-related policy decisions. Sheila Jasanoff (2004) suggests that co-production should be considered an emerging science policy framework that aims to question institutionalised notions of expertise from the outset and hard demarcations between nature and society. The co-production idea suggests that science and technology are not 'contaminated' by input from social and political institutions and actors, but rather that science and technology should be understood as embedded in

> social practices, identities, norms, conventions, discourses, instruments, and institutions — in short, in all the building blocks of what we term the social (Jasanoff, 2004, p. 3).

Co-production not only aims to bring the social back into science policy-making, but also to explore how this knowledge is applied, stabilised and institutionalised over time, and thus is a critique of the realist ideology that persistently separates the domains of nature, facts, objectivity and reason from those of culture, values, subjectivity and emotion in policy and politics more generally.

The frame of co-production aims to open up how authoritative technical knowledge is produced in society and gets stabilised and institutionalised over time, so that it becomes a 'given' or 'taken-for-granted truth'. Co-production also extends Habermas' (1975) critical discussion of 'decisionism', or a model where policy processes are conceptualised as a series of completely unrelated decisions over issue meaning, authority and legitimacy, each one of which has no interaction with any other. Instead, co-production aims to problematise the origins and substance of the meanings of policy issues, who was included or left out of generating these meanings and builds on constructivist work in the social sciences highlighting that scientific legitimacy is simultaneously a social, political and material phenomenon, none of which can be disentangled from the others (Hacking, 1999). The notion of co-production also aims to extend analyses within the interpretive turn in the social sciences, particularly post-structuralist frameworks, by highlighting the often-invisible role of knowledge, expertise, technical practices and material objects in shaping, sustaining, subverting or transforming relations of authority, particularly those of the state (Scott, 1998).

Co-production as used here should not be viewed as a fully fledged theory—claiming law-like consistency and predictive power—but rather as an *idiom*, or a way of interpreting and accounting for complex phenomena to avoid the strategic deletions and omissions of most other approaches to understanding the role of the public and non-disciplinary actors in science policy (Jasanoff 2004, p. 3). For example, Hacking (1999) describes how the American legal and policy processes created new 'social kinds' of child abuse and 'recovery memory' in response to specific cultural anxieties of the 1980s and, in the process, generated 'objective' evidence of these phenomena. In another example of co-production, Evelyn Fox Keller (1985, p. 131) showed how concepts central to the practice of science, such as objectivity and disinterestedness, came to be gendered as masculine through centuries of rhetorical usage and that the construction of the 'laws of nature' has political origins. Thus, a central aim of the co-productionist framework is to help clarify how power originates, where it gets lodged, who wields it, by what means and with what effect within the complex network of science policy-making (Wynne, 2003).

Co-production also provides a framework for understanding assessment processes when the science under question is what Funtowicz and Ravetz (1993) have called 'post-normal'. When science is 'normal', or paradigmatic in the sense described by the philosopher of science Thomas Kuhn, independent review can help to ensure that researchers are applying the standards of their field rigorously, consistently and without bias or deception. In these circumstances, there is ordinarily little doubt who counts as a peer; peers are the recognised members of the scientific specialty or sub-specialty within which normal science is conducted. Such peers share a common culture of scientific practice and a shared commitment to the goals and methods of inquiry in their field.

However, as the following case studies highlight, the science of climate change is inherently political, as facts are uncertain, values in dispute, stakes high and decisions urgent—all characteristics of post-normal science. Under post normal science conditions, Funtowicz and Ravetz have called for an extension of the peer-review community, noting that

> When problems lack neat solutions, when environmental and ethical aspects of the issues are prominent, when the phenomena themselves are ambiguous, and when all research techniques are open to methodological criticism, then the debates on quality are not enhanced by the exclusion of all but the specialist researchers and official experts. The extension of the peer community is then not merely an ethical or political act; it can possibly *enrich the process of scientific investigation* (Funtowicz and Ravetz, 1993, pp. 752–753; emphasis added).

The following cases explore how an extended peer review process struggled with issues of scientific credibility, local relevance and political legitimacy while attempting to co-produce an assessment of urban climate change and heat island mitigation strategies.

Urban Heat Islands and Climate Change

Temperature increases resulting from climate change are expected to disproportionately impact cities, exacerbating the phenomenon known as the urban heat island (UHI) effect. The UHI effect refers to elevated air temperatures in urbanised areas relative to surrounding rural areas. The UHI effect is suspected of warming urban areas 3.5–4.5°C more than surrounding rural areas and is expected to increase by approximately 1°C per decade (Voogt, 2002). The built environment, including buildings and roadways that absorb sunlight and re-radiate heat, combined with less vegetative cover to provide shade and hold cooling moisture, all contribute to cities being warmer and susceptible to dangerous heat events.

Global climate change may intensify urban heat islands with implications for local air quality, heat stress, morbidity, mortality and energy demand (Arnfield, 2003; Kalkstein and Green, 1997). Exposure to excessive heat kills more people each year in the US than deaths from all other weather-related events combined (*MMWR*, 2006). The 2003 European heat wave is estimated to have resulted in 22 000–35 000 premature deaths that were concentrated among already socially vulnerable populations, such as the poor and elderly (Schar and Jendritzky, 2004). Excessive heat events have emerged as a serious public health issue across Europe (Kovats and Ebi, 2006). In addition to mortality, hospital admissions due to serious illnesses, such as heat stroke, heat exhaustion, cardiovascular and respiratory problems, are a serious public health concern related to heat events (Semenza *et al.*, 1999). Extreme heat events tend to impact disproportionately the urban poor, elderly and infirm—all populations that tend to lack the economic means and social support systems necessary to avoid the adverse health impacts associated with extreme heat (Klinenberg, 2002). In the New York City region, Knowlton *et al.* (2004) estimate that climate-change-related heat events and air pollution will disproportionately increase mortality among the poor.

Modelling Urban Climate Change in New York City

The New York City Regional Heat Island Initiative (NYCRHII) is a partnership between federal government scientists, academic researchers, state and local governments. The New York State Energy Research and Development Authority (NYSERDA), a public benefit corporation that funds research into energy supply and efficiency, as well as energy-related environmental issues in New York State, sponsored an effort in 2004 that aimed to combine modelling of urban climate in NYC with an evaluation of cost-effective UHI mitigation strategies (Rosenzweig *et al.*, 2006). A research team consisting of the Columbia University Center for Climate Systems Research, the federal National Aeronautics and Space Administration (NASA)/Goddard Institute for Space Studies, the Hunter College—City University of New York (CUNY) Geography Department and SAIC, a scientific consulting firm based in Albany, New York, was formed along with an Advisory Committee consisting primarily of local, state and federal agencies.[3] The research team was charged with modelling microclimate variation across the city and working with the Advisory Committee to generate heat island mitigation strategies that would provide the greatest cooling at the lowest economic cost city-wide and within six neighbourhood study areas (See Figure 1; also Rosenzweig *et al.*, 2006, pp. s-1–s-2).[4]

The Penn State/NCAR Mesoscale Model (MM5), a regional climate model, was used to evaluate a range of potential mitigation strategies selected collaboratively by researchers and advisors. The MM5 was selected because it is one of the few regional climate models that allow for complex topography inputs and outputs at fine geographical resolutions, both important features for urban climate modelling (Rosenzweig *et al.*, 2006, p. 35). The analysis used observed meteorological data and remotely sensed satellite data from three heat waves[5] during August 2002—the hottest month on record in NYC—and these data were used to evaluate three mitigation scenarios selected by the research team and based on a review of the UHI literature: planting trees in open spaces or along streets; blanketing rooftops with vegetation (living roofs/green roofs); and, increasing the reflectivity of built surfaces (Rosenzweig *et al.*, 2006, p. 23; Akbari *et al.*, 1992). Tree planting was selected for heat mitigation because tree canopies shade built surfaces and also cool the air through evapotranspiration (Taha, 1997). Living or green roofs were selected because they can cool the roof surface of a building through evaporation from soil media and transpiration from plants, reducing air temperatures above the roof which then mix with adjacent air to cool the entire surrounding area (Davis *et al.*, 1992). A living roof can also reduce building energy demand by decreasing the amount of solar energy that is conducted into a building and improve the quality of stormwater runoff. In cities like New York that have limited space for street-level planting, the NYCRHII team suspected that living roofs could provide additional area for introducing cooling vegetation into the urban environment (personal communication, C. Rosenzweig, NYCRHII principal investigator, 2006). Surface lightening includes mixing lighter-coloured aggregate into asphalt, typically on streets and rooftops. While urban areas typically have large areas available for surface lightening, light-coloured surfaces are difficult to keep clean and may lose up to one-third of their reflectivity in a few years due to staining, weathering and soot deposition (Bretz and Pon, 1994).

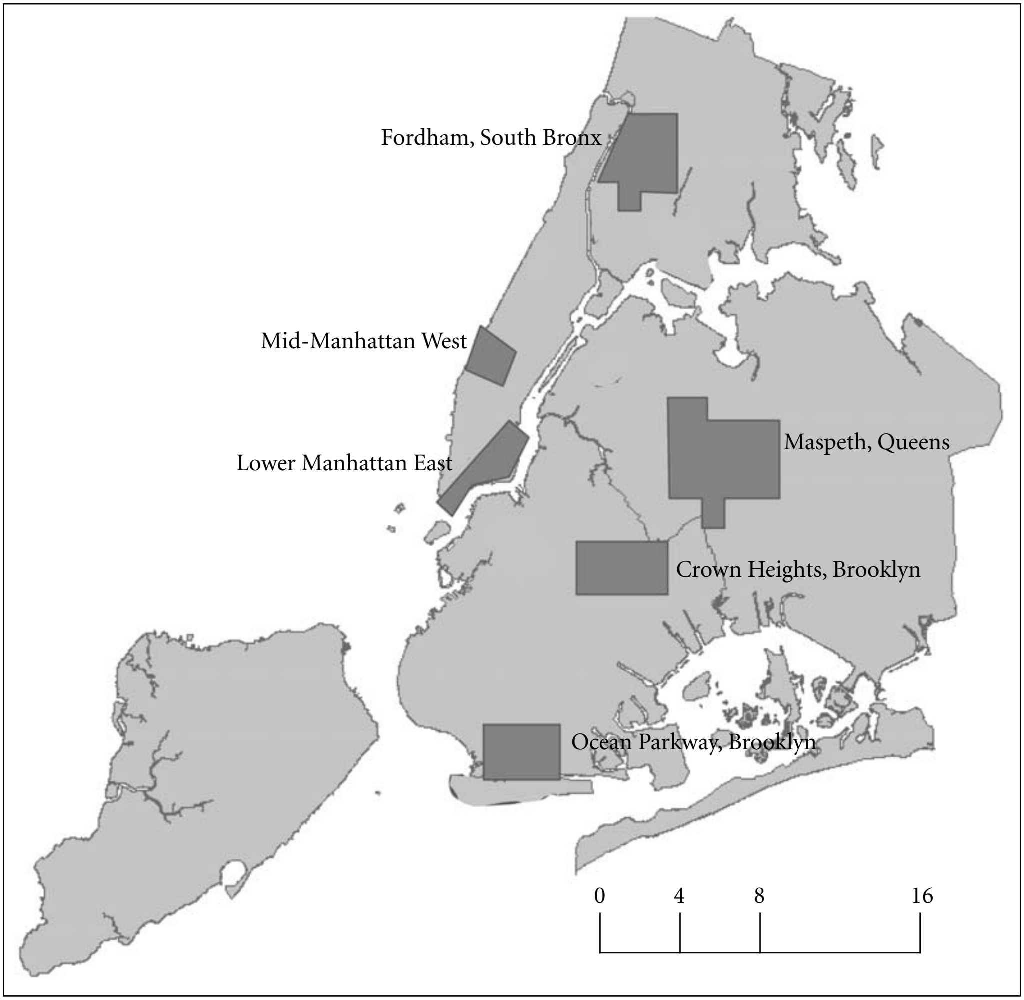

Figure 1. New York City Regional Heat Island Initiative, neighbourhood study areas (Scale: in km)

Modelling Micro-scale Temperature in New York City

Scientists with the NYCRHII combined temperature readings derived from weather stations across the metropolitan region and those remotely sensed with land use data known to alter temperature, including reflectivity of surfaces (albedo) and vegetation density. The climate modelling required the team to understand and predict the behaviour of the Earth's climate system while incorporating local land use data. One of the first challenges the NYCRHII research team encountered was how to downscale the MM5 regional climate model to the urban neighbourhood, specifically the census block, and generate a near-surface air temperature that adequately reflected the contribution of local surface heating, not just regional meteorology. This required specifying variables at a modelling resolution of 1.3 km, rather than the 4 km or greater resolution at which MM5 is normally calculated, and incorporating high-resolution land use data (personal communication, L. Parshall, NYCRHII project director, 2006).

The climate modellers saw this 'localisation challenge' not as a constraint, but "as an opportunity to innovate with new modeling techniques and data inputs" (personal communication, C. Rosenzweig, 2006). The modellers used vegetation and albedo (surface reflectivity) calculations in their model derived from satellite imagery. Yet, controversy arose after initial model predictions suggested that the UHI mitigation scenarios—including tree planting, lightening surfaces and green or living roofs—would not significantly reduce local temperatures during an urban heat wave. For example, the initial MM5 model calculations predicted potential temperature reductions of approximately 0.1°C for each individual mitigation strategy if implemented in half the available area for these interventions and twice that if implemented in 100 per cent of the available area (6 July 2005 draft report).

The initial temperature estimates predicted by the modelling team were presented to the Advisory Committee in August 2005 for their review. One committee member questioned why the NYCRHII results contrasted so radically with a 2002 report by the North East State Foresters' Association that found near-surface air temperature reductions of up to 1°C when trees were added to all available open space in NYC (Luley and Bond, 2002). The NYCRHII research team had not reviewed this study and agreed with the sentiment of the local policy-makers that the MM5 model results might need to be re-evaluated (18 August 2005, e-mail). According to one municipal planner, the low results suggested that the project needed a better strategy for communicating

> that this is a climate modeling effort on a regional basis complicated by enormously complex urban land use, building and street geometry, as well as dynamic drivers like wind, rivers, and ocean effects [and] as a modeling effort includes considerable uncertainties (22 August 2005, e-mail).

More specifically, local city and environmental planners questioned whether the modelling team had properly represented New York City's built environment.

Locating Global Science

A key debate between the modelling team and the Advisory Committee was how best to capture the near-surface temperature, or the temperature at 2 metres above the ground in the human breathing zone, rather than just the surface temperature. In the MM5 model, features such as buildings, grass and trees that vary in height are 'flattened' onto the surface layer and a surface temperature is calculated. The near-surface temperature is estimated as the difference between the modelled surface temperature and temperatures estimated at higher elevations using infrared satellite imagery (Rosenzweig *et al.*, 2006).

The city planners on the Advisory Committee suggested that readily available land use data might act as additional, perhaps more accurate, inputs than the satellite imagery and might help to ensure that temperature estimates captured the city's complex built environment (August 2005, meeting minutes). The planners emphasised that an additional set of physical and demographic data might help the model more accurately to predict near-surface temperatures. These data included roadway density, building age and size, population density, housing density and locations of electrical generators. According to one urban planner at the August 2005 Advisory Committee meeting

> There has to be a better way to capture micro-scale temperature variation than satellite data. Our department maps over twenty land use categories by every tax parcel in the city. We might differentiate each of these by the intensity of energy used. This could be factored using population and worker density, so that the greater the density of people, the more energy used and heat generated. We also know the size and pollution outputs of boilers in

> large buildings. Why not add all this to the micro-temperature model estimates?

The city planners and the climate modellers debated whether and how such micro-scale data could be used in a regional climate model, but agreed to work together to assign energy use constants (in units of KBtu/ft2) to each of New York City's 24 land use categories, using values published by the US Department of Energy's Energy Information Administration (US DOE, 1999). The modellers agreed to rescale the model for a second time and recalculate temperatures across a 10-metre-square grid, rather than the 1.6-km grid used in the first model calculations. According to one member of the climate modelling team

> As we reduced the scale of the temperature model, we felt like we were losing accuracy because the major meteorological conditions that influence temperature do not generally change from one city block to another. However, including very localized land use and population data made sense to planners who perform land use analyses and make related decisions at that scale everyday. I doubt the methodology we all agreed to would be accepted in the climate modeling community, but it seemed to make sense in New York City.

While the new collaborative effort between urban planners and scientists eventually produced a new set of land use inputs that altered the climate modellers' original assumptions, some members of the research team were reluctant to work with "policy people" who, in the modeller's view, "needed to be taught some science" (personal communication, L. Parshall, 2006). However, other members of the NYCRHII research team were more open to the non-scientist's input, especially after the initial modelling results showed very little temperature variations. One of the directors of the research team, Cynthia Rosenzweig suggested that the researchers

> could have given more attention to how local land use conditions might impact the 2-meter air temperature and that our initial assumptions likely missed very localized, perhaps acute, effects of the built and social environments (personal communication, C. Rosenzweig, 2006).

By October 2005, only three months after the 6 July report first suggested limited temperature variations, the NYCRHII team issued a second draft report that stated

> Because the 2-meter air temperatures calculated with MM5 do not capture the full effect of New York City's highly heterogeneous surfaces on the city's heat island, a weighted average of MM5 calculated surface and 2-meter air temperatures, along with heat contributions estimated from land use features, was calculated to better represent New York City's near-surface air temperature.

This localisation of global science occurred largely because planners did not view the original NYCRHII model outputs as consistent with their understanding of the likely impact of the local built environment on micro-scale temperatures. Using the new land use inputs to estimate the near-surface temperature, the UHI mitigation scenarios were recalculated for their temperature reduction potential (Table 1). The new results suggested that surface lightening had the greatest potential to reduce urban temperatures during a heat island event. This finding stimulated more controversy between the climate modellers and local planners.

Making Global Science Accountable to local practice

When the October 2005 results were reviewed, members of the Advisory Committee again questioned whether the scientists had used locally accurate information. During the Advisory Committee meeting in November 2005, a representative from the NYC Department of Design and Construction (DDC), a city agency that permits and oversees most large construction projects, did not believe that roadway and sidewalk surfaces could be lightened to raise their albedo to 0.5—the assumption the modelling team had used to generate their new temperature reduction estimates of the three heat island mitigation scenarios. An albedo of 0.5 suggests that 50 per cent of incident solar radiation is reflected and surfaces with a higher albedo tend to be cooler than those with a lower albedo. According to the DDC, most surfaces in New York City had an albedo of approximately 0.15, meaning that only 15 per cent of incident solar radiation is reflected, and the agency estimated that using commercially available light-coloured paving materials could raise city-wide albedo to approximately 0.2 (meeting minutes, November 2005).

The NYC Department of Transportation (DOT) also questioned whether the modelling team had an accurate sense of local roadway paving practices and costs. According to a representative of the DOT

> Supplies of the proven and accepted choice (quartz) for light colored aggregate (LCA) are locally available from LI [Long Island] sources and there are also some NJ sources eager to supply new or scaled up demands as needed … as far as White binders, we found costs, durability, logistics and maintenance issues make the product unsatisfactory at this point. We have tried it in particular locations to identify turning lanes etc. Costs were in the hundreds of dollars per ton as opposed to the tens of dollars per ton for standard practice.Premature wear, potholes and logistics of spot maintenance—meaning that this material requires different equipment than our normal operations—will all increase the costs of light pavement (30 November 2005, e-mail message).

Advisory Committee members raised issues of construction practice and costs that modellers did not consider. While the initial controversies over temperature modelling focused on whether scientists had adequately captured the local built environment, this challenge focused on whether researchers had seriously considered whether and how agency practices and economic decisions might alter model assumptions (personal communication, L. Parshall, 2006). Since these internal agency decisions are often tacit and invisible to the outsider, climate modellers would not be expected to know these details and, without an institutionalised forum like the Advisory Committee, these practice details would never have surfaced.

Table 1. Modelled temperature reductions from mitigation scenarios before (July 2005) and after (October 2005) local planner input

	Urban heat island mitigation scenarios					
	Street trees (°F)		*Green (living) roofs (°F)*		*Lightening surfaces (°F)*	
Case study area	*July 2005*	*October 2005*	*July 2005*	*October 2005*	*July 2005*	*October 2005*
New York City	–0.2	–0.6	–0.2	–0.4	–0.5	–1.3
Mid-Manhattan West	–0.4	–0.9	–0.3	–1.1	–0.5	–1.7
Lower Manhattan East	–0.4	–1.0	–0.3	–0.9	–0.6	–1.6
Fordham, Bronx	–0.2	–0.7	–0.2	–0.5	–0.5	–1.3
Maspeth, Queens	–0.2	–0.6	–0.2	–0.5	–0.5	–1.1
Crown Heights, Brooklyn	–0.2	–0.9	–0.3	–0.7	–0.5	–1.4
Ocean Parkway, Brooklyn	–0.2	–0.8	–0.2	–0.7	–0.5	–1.5

However, this type of information can have a significant influence on whether a particular policy strategy will be viewed as legitimate and politically accountable for street-level bureaucrats (Lipsky, 1976)—or those local actors and institutions that are charged with implementing policy directives.

Advisory Committee members also raised concerns that the modelling effort ought to be consistent with emerging policy objectives of New York City's Mayor, Michael Bloomberg, who was positioning the city to be a global leader in addressing climate change and sustainability planning. The mayor's advisors had begun formulating a set of possible strategies to address climate change through readily available technologies independent of administrative agencies (New York City Mayor's Office, 2006). One member of the Advisory Committee noted that the UHI mitigation project could be deemed irrelevant by the mayor if the NYCRHII team failed to take the executive policy developments into account

> The City Council is considering a cool roofing bill, which, if passed, will need to be approved by the Mayor. There is also a Mayor's Task Force on Sustainability that is looking at Heat Island reduction strategies such as more trees and lighter pavements. The decision-makers in these processes are very interested in demonstrable cost-effectiveness of all sustainable strategies, and they are likely to come across this report. So we need to be careful that we don't present something that can be misconstrued in the context of the City's decision-making process (10 November 2005 e-mail).

Concerns over the policy relevance of the research effort combined with the specific albedo suggestions offered by the DDC and DOT to revise the model for a third time. In the third iteration, new parameters for albedo and surface lightening were used. The revised results now suggested that surface lightening was less attractive than street tree planting as a UHI mitigation strategy.

Policy Commitments and the Distribution of Benefits

As the optimal UHI mitigation scenario shifted to tree planting, the NYC Department of Parks and Recreation (Parks Department) began to contribute more strongly during peer review meetings. The Parks Department expressed concern that the modellers had overestimated the available area for planting street trees and thus the cooling potential of the intervention. The Parks Department representative to the Advisory Committee wrote to the group

> Folks, I am not yet comfortable with the analytical method used to calculate the maximum growing area for street trees … I would hate for the street tree numbers to not reflect the actual maximum area they are physically able to occupy (which is far less than described above [in the report]); this would throw the whole model off, as well as the recommendations derived from it (28 November 2005, e-mail message).

The Parks Department was reacting to the process the modelling team used to estimate the available area for street tree planting. The NYCRHII team constructed an estimate of the available tree planting area using a GIS to create a 30-metre buffer around street segments and then estimated the number of trees that could be planted within this buffer based on standard tree canopy sizes (Rosenzweig *et al.*, 2006). The modellers relied on their own method and did not use the Parks Department's Street Tree Inventory database, which was generated annually using field visits and direct observation to identify existing trees and available areas for planting. The Parks Department suggested that the modellers, using their satellite imagery data and general assumptions about street tree canopy size, had greatly overestimated the available area for tree planting, possibly by as much as 100 per cent (November 2005, meeting minutes).

After a series of meetings between the Parks Department and the spatial analysis team of the NYCRHII, agreement was reached to recalculate the available area for street trees using the Parks Department data as the primary input. The modellers agreed, after detailed presentations from the Parks Department about their street tree data and method for estimating available tree planting area, that the local data had validity (12 December 2005 e-mail message). According to one member of the spatial analysis team

> We had confidence in our methods since they had been validated for estimating street tree planting area in other cities, but Parks [Department] made a convincing case that local knowledge mattered more than a model validated somewhere else. I mean, it was hard to argue with someone that had actually walked the streets, took measurements and tracked this information over time. In the absence of this level of local specificity, I think we would have been more adamant about the efficacy of our model.

Having a readily available dataset in a quantitative format that the spatial analysts could interpret clearly helped the local planners to make their case that local knowledge should be preferred to modelled estimates in this example. Yet, the scientists also trusted *the process* of local data collection—namely, field surveys and measurements—and this trust contributed to the credibility of the Parks Department data in the eyes of the scientists. Using the new data, the NYCRHII scientists recalculated the available area for street tree planting and the result was that the potential planting area was reduced by as much as 75 per cent. Since a reduction in the number of trees would result in less cooling potential from street tree planting, the mitigation strategy became less attractive to the Advisory Committee.

By the time the final NYCRHII report was issued in the summer of 2006, the wording of the conclusions referencing the three different mitigation scenarios reflected the scientific uncertainty and political indeterminacy that had been raised during the analytical process. The NYCRHII final report noted that "curbside planting, living roofs, and light roofs and surfaces have comparable cooling effects" but that "light surfaces required an area many times greater than the area for street trees needed to achieve comparable cooling" making this intervention less cost-effective than street tree planting (Rosenzweig *et al.*, 2006, p. S-8). Despite the ambiguity of the analyses, a street tree planting pilot project was initiated in the Fordham/South Bronx sub-study area and the NYCRHII was charged with monitoring the temperature impacts from this pilot intervention.

The tree planting project, called the 'Greening the Bronx Initiative', included participants from the NYCRHII modelling team and Advisory Committee as well as community-based organisations from the Bronx concerned with environmental health and justice (personal communication, L. Parshall, 2006). In this new collaborative effort, researchers and community activists were to survey neighbourhoods for available tree planting areas, gather regular temperature data and track the health of newly planted trees. The partners were also charged with evaluating the impacts of the project on energy demand and local temperature and reporting back to NYSERDA with 'lessons learned' for a city-wide UHI mitigation strategy (personal communication, C. Rosenzweig, 2006).

City Planning and Climate Change: Co-producing Science Policy

As these cases suggest, both local planners and global scientists have important expertise to offer the process of localising global climate science for urban policy and neither the local nor the global ought to be an *a priori* privileged form of knowledge. In other words, the localisation process demands that scientific 'facts' are things whose status needs to be explained rather than taken for granted. When climate modelling encounters the complex and contentious built and political environments of cities, disagreements over the legitimacy of technical analyses, the appropriate kinds of 'expertise' for making regulatory science and the extent and breadth of political accountability are all likely to be the norm, rather than the exception. The co-production framework can offer city planners and climate scientists a way to move forward in such contentious policy situations.

The examples presented here highlight that the localisation of climate science for UHI mitigation is 'post-normal' regulatory science—or science that demands timely answers to pressing but uncertain policy questions. Research science, on the other hand, generally operates under no comparable time pressures; in principle, it can wait indefinitely to produce results. Accordingly, the meanings of reliability and legitimacy are different for regulatory and research science. The reliability of regulatory science cannot and should not necessarily be measured according to the same criteria as the reliability of research science.

The NYCRHII process also revealed details about the substance and methods of 'extended peer review'. Differently situated participants on the Advisory Committee not only highlighted data relevant to modelling the urban context that 'outside' researchers missed, they also suggested that co-producing legitimate regulatory science required attention to the social and political landscape for making recommendations. In contentious policy environments, early and on-going 'extended peer review'—using multiple modes of interaction from face-to-face deliberations to e-mail exchanges to comments on draft documents—rather than a single, end-of-pipe review process that is more typical of scientific review processes, can help to adjudicate conflicts. Adversarial science and policy disputes might be avoided, or at least minimised, if more agreement between scientists and urban planners can be negotiated before and during the research process, rather than waiting until conclusive reports are issued.

More fundamentally, the cases offered here suggest that *trust* is essential for legitimate and accountable regulatory science and that it is often generated through deliberation and collaborative problem-solving—it is not something based solely on the cognitive content under consideration or the institutional affiliation of scientists. As Wynne notes, in a discussion of scientific understandings

> Trust and credibility are themselves analytically derivative of social relations and identity-negotiation … they too should not be treated as if they have an objective existence which can be unambiguously measured and manipulated (Wynne, 1996, p. 42).

Thus, building trust between different stakeholders is a central feature of credible regulatory science, particularly when the uncertain science of climate change modelling is applied to contentious, and often ill-defined, urban environmental governance processes.

While the NYCRHII did not devise a comprehensive city-wide UHI mitigation strategy, the Bronx pilot project extended the peer review community even further by including public stakeholders in the intervention and evaluation process. This pilot project reflects the kind of contingent policy outcomes that may become the norm, rather than the exception, in post-normal science. Contingent interventions are common under adaptive ecosystem management regimes—such as those used for watershed and habitat conservation planning—where public, collaborative processes engage a range of stakeholders to make timely decisions that are open to revision as new learning occurs (Weber, 2003). Instead of one-size-fits-all rules, adaptive management regimes are designed to adjust regularly interventions over time as new technologies emerge and continuous monitoring reveals how actual conditions are changing (Fung, 2004).

As these cases have shown, localising global climate science for urban policy-making demands an extended peer review process that can co-produce policy-relevant information. More generally, co-production offers a framework for regulatory science, or science policy that: crosses disciplinary lines; enters into previously unknown investigative territories; requires the deployment of new methods, instruments, protocols and experimental systems; and, involves politically sensitive processes and results.

These characteristics make the science of localisation 'post-normal' and the identification of independent, objective peers both difficult and controversial. This call for 'democratising' the science policy review process is not new, as the US National Research Council determined in a landmark 1996 report that the quality of risk information disseminated by federal regulators will be improved if the risk analytical process develops through coupled procedures of analysis and deliberation and recommended wide stakeholder participation in the development and critique of regulatory science (Stern and Fineberg, 1996). Thus, urban planners grappling with the new challenge of localising global science ought to draw from over a decade of lessons and policy experiments in the democratisation of science policy-making, including participatory processes such as 'science shops' and 'consensus conferences' used in Europe and the US (Fischer *et al.*, 2004; Wachelder, 2003).

As an emerging analytical and policy domain, urban climate change policy represents a series of challenges for both scientists and city planners. Uncertain science coupled with heterogeneous policy contexts demands a new conceptual approach and normative process that can account for the challenges of localising the global while retaining technical legitimacy and building political accountability. The co-production frame offers one such analytical and normative approach. As urban policy-makers are increasingly asked to generate policy responses to mitigate climate change, decision-makers must learn simultaneously to ascertain emerging facts about the natural world and to confront issues of social authority and credibility, so that 'doing science' merges with 'doing politics.'

Notes

1. The advisory committee consisted of the following agencies and organisations: United States Department of Agriculture Forest Service; New York Energy Consumers Council, Inc.; New York City Mayor's Office of Environmental Co-ordination; Sustainable Energy Partnerships; New York City Department of Design and Construction; United States Environmental Protection Agency—Region II; New York City Department of Parks and Recreation; Consolidated Edison Company of New York; Environmental Energy Alliance of New York; New York City Department of City Planning; New York State Department of Environmental Conservation.
2. Throughout the cases, we note where information was gleaned but protect confidentiality of participants by not attributing comments, e-mails or internal notes to any specific people since we used internal confidential interviews, e-mails and notes to help reconstruct the cases examined here.
3. Advisory Committee members included: Matthew Hudson Arnn, United States Department of Agriculture Forest Service; David F. Bomke, New York Energy Consumers Council, Inc.; John Dickinson, New York City Mayor's Office of Environmental Co-ordination; Adam W. Hinge, Sustainable Energy Partnerships; Laurie Kerr, New York City Department of Design and Construction; Edward J. Linky, United States Environmental Protection Agency—Region II; Jacqueline Lu, New York City Department of Parks and Recreation;

Joseph Madia, Consolidated Edison Company of New York; Sandra Meier, Environmental Energy Alliance of New York; Stephen A. Pertusiello, Consolidated Edison Company of New York; Nicole Rodriguez, New York City Department of City Planning; Gopal Sistla, New York State Department of Environmental Conservation; Megan Sheremata, New York State Department of Environmental Conservation; Fiona Watt, New York City Department of Parks and Recreation; Michael Weil, City of New York Department of City Planning; Eva Wong, United States Environmental Protection Agency.

4. The six neighbourhood study areas (Figure 1) were selected for their geographical and demographic variability and comprised: Mid-Manhattan West; Lower Manhattan East; Fordham in the Bronx; Maspeth, Queens; Crown Heights, Brooklyn; and, Ocean Parkway, Brooklyn.
5. A heat wave period is defined as at least three consecutive days with maximum temperatures above 90°F (32.2°C).

References

Akbari, H. S., Davis, S., Dorsano, S. *et al.* (1992) *Cooling Our Communities: A Guide-book on Tree Planting and Light-colored Surfacing*. US Environmental Protection Agency Guidebook. Washington, DC: US Government Printing Offices.

Arnfield, A. J. (2003) Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island, *International Journal of Climatology*, 23, pp. 1–26.

Bai, X. (2007) Integrating global environmental concerns into urban management: the scale and readiness arguments, *Journal of Industrial Ecology*, 11, pp. 15–29.

Bailey, J. (2007) *Lessons from the pioneers: tackling global warming at the local level*. Institute for Local Self-Reliance Minneapolis, MN.

Bernard, S. M. and McGeehin, M. A. (2004) Municipal heat wave response plans, *American Journal of Public Health*, 94(9), pp. 1520–1522.

Betsill, M. M. and Bulkeley, H. (2006) Cities and the multilevel governance of global climate change, *Global Governance*, 12, pp. 141–159.

Bretz, S. and Pon, B. (1994) *Durability of high albedo roof coatings*. Issue No. 5, Recent Research in the Building and Energy Analysis Group, Lawrence Berkeley Laboratory (http://eetd.lbl.gov/Buildings/RResearch/Albedo.html; accessed June 2006).

Bulkeley, H. and Betsill, M. M. (2005) Rethinking sustainable cities: multilevel governance and the 'urban' politics of climate change, *Environmental Politics*, 14(1), pp. 42–63.

Bulkeley, H. and Kern, K. (2006) Local government and the governing of climate change in Germany and the UK, *Urban Studies*, 43(12), pp. 2237–2259.

Davis, S., Martien, P. and Sampson, N. (1992) Planting and light-colored surfacing for energy conservation, in: H. S. Akbari, S. Davis, S. Dorsano *et al.* (Eds) *Cooling Our Communities: A Guidebook on Tree Planting and Light-colored Surfacing*. US Environmental Protection Agency Guidebook. Washington, DC: US Government Printing Offices.

Fischer, C., Leydesdorff, L. and Schophaus, M. (2004) Science shops in Europe: the public as stakeholder, *Science & Public Policy*, 31(3), pp. 199–211.

Fung, A. (2004) *Empowered Participation: Reinventing Urban Democracy*. Princeton, NJ: Princeton University Press.

Funtowicz, S. O. and Rawetz, J. (1993) Science for the post-normal age, *Futures*, 25, pp. 739–755.

Gedzelman, S. D., Austin, S., Cermak, R. *et al.* (2003) Mesoscale aspects of the urban heat island around New York City, *Theoretical Applied Climatology*, 75(1/2), pp. 29–42.

Habermas, J. (1975) *Legitimation Crisis*. Boston, MA: Beacon Press.

Hacking, I. (1999) *The Social Construction of What?* Cambridge, MA: Harvard University Press.

Jasanoff, S. (2004) The idiom of co-production, in: S. Jasanoff (Ed.) *States of Knowledge: The Co-production of Science and Social Order*, pp. 1–45. London: Routledge.

Jasanoff, S. and Martello, M. B. (Eds) (2004) *Earthly Politics: Local and Global in Environmental Governance*. Cambridge, MA: The MIT Press.

Kalkstein, L. S. and Green, J. (1997) An evaluation of climate/mortality relationships in large U.S. cities and the possible impact of a climate change, *Environmental Health Perspectives*, 105(1), pp. 84–93.

Keller, E. F. (1985) *Reflections on Gender and Science.* New Haven, CT: Yale University Press.

Klinenberg, E. (2002) *Heat Wave: A Social Autopsy of a Disaster*. Chicago, IL: University of Chicago Press.

Knowlton, K., Hogrefe, C., Lynn, B. *et al.* (2004) Climate-related changes in ozone mortality over the next 50 years in the New York City metropolitan region, *Environmental Health Perspectives*, 112(15), pp.1557–1563.

Kousky, C. and Schneider, S. (2003) Global climate policy: will cities lead the way?, *Climate Policy*, 3, pp. 359–372.

Kovats, R. S. and Ebi, K. L. (2006) Heatwaves and public health in Europe, *European Journal of Public Health*, 16(6), pp. 592–559.

Lindseth, G. (2004) The cities for climate protection campaign and the framing of local climate policy, *Local Environment*, 9, pp. 325–336.

Lipsky, M. (1976) *Street-level Bureaucracy: Dilemmas of the Individual in Public Services.* New York: Russell Sage Foundation.

Luley, C. J. and Bond, J. (2002) *A plan to integrate management of urban trees into air quality planning*. A report to the North East State Foresters Association (www.fs.fed.us/ne/syracuse/Pubs/Downloads/Final_report_March2002_Davey.pdf; accessed November 2006).

Miller, C. (2004) Resisting empire; globalism, relocalization, and the politics of knowledge, in: S. Jasanoff and M. Martello (Eds) *Earthly Politics: Local and Global in Environmental Governance*, pp. 81–102. Cambridge, MA: MIT Press.

Mitchell, R. B., Clark, W. C., Cash, D. and Dickson, N. M. (Eds) (2006) *Global Environmental Assessments: Information and Influence*. Cambridge, MA: MIT Press.

MMWR (*Morbidity and Mortality Weekly Report*) (2006) Heat-related deaths—United States, 1999–2003, *MMWR*, 55(29), pp. 796–798 (http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5529a2.htm).

New York City Mayor's Office (2006) *PlaNYC 2030* (http://www.nyc.gov/html/planyc2030; accessed May 2007).

Rosenzweig, C., Solecki, W. D. and Slosberg, R. (2006) *Mitigating New York City's heat island with urban forestry, living roofs, and light surfaces*. A report to the New York State Energy Research and Development Authority (www.nyserda.org; accessed November 2006).

Schar, C. and Jendritzky, G. (2004) Climate change: hot news from summer 2003, *Nature*, 432, pp. 559–560.

Scott, J. (1998) *Seeing Like a State.* New Haven, CT: Yale University Press.

Semenza, J. C., McCullough, J. E., Flanders, W. D. *et al.* (1999). Excess hospital admissions during the July 1995 heat wave in Chicago, *American Journal of Preventive Medicine*, 16(4), pp. 269–277.

Stern, P. and Fineberg, H. (Eds) (1996) *Understanding Risk*. Washington, DC: National Academy Press.

Taha, H. (1997) Urban climates and heat islands: albedo, evapotranspiration and anthropogenic heat, *Energy and Buildings*, 25, pp. 99–103.

US DOE (US Department of Energy) (1999) *1999 Commercial building energy consumption survey for buildings in the northeast* (www.eia.doe.gov/emeu/consumption/reports.html; accessed May 2007).

US EPA (US Environmental Protection Agency) (2006) *Urban heat island pilot project* (www.epa.gov/heatisland/pilot/index.html; accessed February 2007).

Voogt, J. A. (2002) Urban heat island, in: I. Douglas (Ed.) *Encyclopedia of Global Environmental Change*, pp. 660–666. New York: John Wiley & Sons.

Wachelder, J. (2003) Democratizing science: various routes and visions of Dutch science shops, *Science, Technology & Human Values*, 28(2), pp. 244–273.

Weber, E. P. (2003) *Bringing Society Back In: Grassroots Ecosystem Management, Accountability, and Sustainable Communities*. Cambridge, MA: MIT Press.

Wynne, B. (1996) Misunderstood misunderstandings: social identities and public uptake of science, in: B. Wynne and A. Irwin (Eds) *Misunderstanding Science? The Public Reconstruction of Science and Technology*, p. 19–46. Cambridge, MA: Oxford University Press.

Wynne, B. (2003) Seasick on the third wave? Subverting the hegemony of propositionalism, *Social Studies of Science*, 33, pp. 401–417.