Low carbon transitions and the reconfiguration of urban infrastructure

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Abstract

Over the past decade, a growing body of research has examined the role of cities in addressing climate change and the institutional and political challenges which they encounter. For the most part, in these accounts, the infrastructure networks, their material fabric, everyday practices and political economies, have remained unexamined. In this paper, we argue that this is a critical omission and develop an approach for understanding how urban responses to climate change both configure and are configured by infrastructure networks. Central to any such analysis is, we argue, the conception of how and why (urban) infrastructure networks undergo change. Focusing on urban energy networks and on the case of London, we argue for an analysis of the 'urban infrastructure regimes' and 'experiments' through which climate change is governed. We find that climate change experiments serve as a means through which dominant actors articulate and test new 'low carbon' logics for urban infrastructure development. We argue that experiments work by establishing new circuits, configuring actors in new sets of relations and through these means realizing the potential for addressing climate change in the city. At the same time, experiments become sites of conflict, a means through which new forms of urban circulation can be confined and marginalized, leaving dominant energy regimes (relatively) intact.

Keywords

Urban governance, climate change, infrastructure, socio-technical system, energy, experiment

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Introduction

Over the past two decades, climate change has shifted from being a minor policy issue in a handful of pioneering municipal authorities to a growing concern for many of the world's cities In this context, a growing body of research has documented the emergence of urban climate governance and the factors – primarily issues of institutional capacity and political economy – that have served to construct and limit its extent and effectiveness (Bulkeley 2010). Central to these analyses has been the investigation of the policies and measures that are being developed in key urban infrastructure networks – energy, transport, the built environment and increasingly water and sanitation. However, with some notable exceptions (Monstadt 2007; Rutland and Aylett 2008), for the most part these networks, their material fabric, everyday practices and political economies, have remained unexamined. Rather than providing a static backdrop against which the politics of governing climate change in the city might play out, an understanding of urban infrastructure networks as socio-technical – that is, as a seamless web of interrelated social and technical components – suggests that they form a critical means through which responding to climate change takes place.

In this paper, we develop an approach for understanding how urban responses to climate change both configure and are configured by infrastructure networks. In the first part of the paper, we draw on bodies of work that have explicitly sought to understand the dynamics of technological change and the city – socio-technical regimes, studies of urban political ecology and infrastructure networks. While we find the emphasis within the socio-technical regime literature on the possibilities of innovation in shaping urban transitions useful, we argue that such processes need to be understood through the political economies and ecologies of infrastructure provision. In the second half of the paper, we focus our analysis on energy systems and the case of London. The growing political saliency of the carbon intensity of energy systems, coupled with concerns for reliability and security of supply, is giving rise to a

politics of 'low-carbon energy transitions' amongst actors as diverse as BP, the Transition Towns movement, WWF and various nation-states Drawing on our analysis of the dynamics of urban infrastructure systems, we suggest that the governing of climate change in London is taking place through the reworking of energy systems through new 'low carbon' modalities within which particular 'climate change experiments' are central. Rather than heralding a decisive transition from one socio-technical system to another, a picture emerges of fragmented and plural energy regimes whose development in practice is both subject to structures of interest and to the open-ended nature of urban circulations. In this view, climate change experiments do not function as neatly bounded niches of innovation, but rather as critical junctures through which new socio-technical configurations take place, are maintained, contested and may be undone. In so doing, experiments serve both to contest and reproduce the dominant 'post-political' climate change frame which "evacuates dissent through the formation of a particular regime of environmental governance that revolves around consensus, agreement, participatory negotiation of different interests and technocratic expert management in the context of a non-disputed management of market-based socio-economic organization" (Swyngedouw, 2010; p.227). We find the political and environmental potential of such experiments is ambivalent, serving both as a means through which to orchestrate potentially progressive and effective socio-technical change and as a means through existing interests can contain the challenges of 'low carbon' urbanism.

Urban infrastructures in transition

Theories of socio-technical regimes have explicitly sought to understand how infrastructure systems undergo change and transition, focusing on the dynamics of innovation in the process of transition but

with limited engagement with the ways in which such dynamics are structured politically and spatially. In seeking to understand the ways in which the dynamics of infrastructure systems are configured by and through urban places, we find that accounts of urban political ecology and related work on the political economy of urban infrastructure systems provide powerful means for understanding the ways in which relations of power, society and nature in the city serve to embed particular regimes and configure the possibilities of change. In bringing these theories into dialogue, our objective is therefore to unravel how their insights can help us to comprehend the dynamics of urban infrastructure within the city in relation to the emerging urban politics of climate change.

Socio-technical regimes and urban transitions

Within the broad field of science and technology studies, (urban) infrastructure networks can be regarded as socio-technical systems, co-produced through both technical and social components including, for example "physical artefacts, mines, manufacturing firms, utility companies, academic research and development laboratories, and investment banks" (Hughes 1987: 207). Such systems tend towards stability or obduracy, held in place through socio-technical regimes, the "relatively stable configurations of institutions, techniques and artefacts, as well as rules, practices and networks that determine the 'normal' development and use of technologies" (Smith et al. 2005: 1493).. Given this tendency to stability, scholars have sought to understand how 'transitions' in such socio-technical systems have occurred historically (e.g. ;) and how they might be managed in order to achieve sustainable outcomes e.g. (;) through the interaction across three levels of the system – landscape, niche and regime (Geels 2004; Foxon and Pearson 2008;; Smith et al. 2010). In this multi-level model, socio-technical regimes are located within a landscape that is largely inert and external to actors' scope for action, to the degree that processes may be congealed into physical artefacts, such as power stations

and electricity grids. Within regimes, at the micro-level, are 'niches', protected or exceptional spaces where innovations originate and system constraints are thought to be weakest. For a transition to occur, there must be 'alignments' at the three levels – for example, outsider niches may 'break through' when incumbent regime actors fail to re-orient their efforts in response to landscape pressures (Geels and Kemp 2007). Such processes of innovation and alignment may result in intra-systemic adaptation ('reproductions' or 'transformations') (Geels and Kemp 2007), or in 'transitions', which are defined as "major technological transformations in the way societal functions such as transportation, communication, housing, feeding are fulfilled", such as the transition from a transport system based on horse-drawn carriages to a system based on automobiles (Geels 2002: 1257).

Despite an emphasis on the social networks surrounding processes of innovation, in the main "the emphasis is … on *technological* experimentation" rather than on "the *co-evolution* of technology and society" (Hegger, Van Vliet et al. 2007: 731). In response to this technological focus, other authors have begun to draw attention to the importance of *social niches* in the dynamics of socio-technical systems, analysing "bottom up experiments with environmental technology by citizen groups and/or NGOs, operating outside the institutional structures of firms and governments" (Hegger, Van Vliet et al. 2007), also termed "grassroots innovations" (Seyfang and Smith 2007), in which novel forms of social organisation co-evolve with technological artefacts and practices to create alternative forms of service provision,. Rather than developing in response to the creation of strategic opportunities within the dominant regime, social niches are conceived as emerging organically, operating in the margins of mainstream regimes and may gain much of their momentum precisely because of their opposition to dominant values and practices.

The critical role assigned to both social and technical niches in the process of socio-technical transition is potentially highly significant for understanding the process of urban responses to climate change, given that the development of demonstration projects, best practices, novel policy instruments, new forms of public-private partnership, community-based initiatives and so on is seen as a core characteristic of this domain (Bulkeley 2010Rutland and Aylett 2008). Considering such initiatives as 'niches' within a socio-technical regime opens up the possibility that they may have an important influence on how infrastructure networks are responding to climate change. However, we find that several critiques of the conception of socio-technical regimes and niches in the multi-level framework limit its current utility in this domain. First, socio-technical regimes are more or less explicitly considered as operating at the national scale, while, 'niches' are regarded as local (and often urban) phenomenon so that "little is known about the place-specific formation of sociotechnical regimes and the contestation, negotiation and management of urban transition strategies" (Monstadt 2009: 7; see Bulkeley et al. 2011). A secondproblem is that the conceptual separation of niches and regimes is not straightforward, not least because they are regarded as in continuous interaction (Smith 2007). The distinguishing features seeming to lie in both the scale and stability of regimes (Geels 2004; Geels and Schot 2007), but delimiting these boundaries may be difficult in practice, calling into question whether multiple 'levels' of the socio-technical system can be easily separated. Third, in describing the process of niche formation primarily in terms of innovation, analysts have tended to stress individual agency over the material or structural factors that shape niches. Finally, in conceiving of niches as bounded and 'protected' spaces within regimes, this approach underplays the extent to which such processes are subject to contestation and conflict. As Smith (2007: 436) argues, "green niches", most notably grassroots innovations, are "constructed in *opposition* to incumbent regimes. They are informed, initiated and designed in response to sustainability problems perceived in the regime." Overall, the approach tends to neglect the

fundamentally *political* nature of the processes through which they are maintained and challenged (Walker and Shove 2007; Monstadt 2009).

There are, therefore, good grounds to be cautious about the use of the multi-level perspective for understanding socio-technical systems and their transformation. If, however, we return to the core principle that regimes, as relatively stable ways of organising and providing for societies needs, are socially and technically constituted we can reconsider how this achieved in both political and spatial terms. Rather than conceiving of the urban (or indeed the national) as a discrete, natural, scale of affairs, work on the social construction of scale points to the ways in which spatiality is constituted through and with social-material relations (Swyngedouw and Heynen, 2003). Equally, rather than conceiving of discrete national and urban regimes, in this manner, the urban becomes a means through which infrastructure regimes are constructed, stabilised and contested, while these regimes, in turn, serve to create distinctive forms of urbanism. Understanding how such regimes are constituted requires therefore an understanding of the ways in which urban infrastructure networks are structured and assembled, and the political economies and ecologies of such processes.

Political economies and ecologies of urban infrastructure

Attending to the political and spatial constitution of socio-technical regimes enables us to consider how contemporary re-workings of the circulation of global capital are conducted through the simultaneous fragmentation and rebundling of urban network infrastructure.. This 'splintering urbanism' involves processes whereby existing and integrated infrastructure networks are unbundled and segmented while simultaneously there is a 'rebundling' of the city through the creation of 'premium networked spaces'

that actively separate the economic lives of the rich from those of the poor (Graham and Marvin 2001). The simultaneous fragmentation and re-bundling of infrastructure is interpreted as emerging from a shift in dominant logics of infrastructure provision in cities, from a universalist centralist 'modern infrastructure ideal' to a model of service liberalization and privatization illuminating how "urban-nature relationships have been rescaled and newly defined in the global age" (Keil 2005; 723-724). In locating the dynamics of system change within the logics of capital accumulation, the splintering urbanism approach seeks to attend to the historical and structural processes at work in the (re)production of urban infrastructure networks. However, critics have suggested that such analyses have placed too much emphasis on the integrity of the 'modern urban ideal' and its global applicability, failing to pay sufficient attention to the contingency of urbanization and infrastructure development, and have neglected the progressive potential of 'splintered' urban systems, not least in regard to the development of environmentally sustainable urban futures (e.g. Bénit-Gbaffou 2008; McFarlane 2008; ; Coutard and Rutherford 2010). Viewing cities as

"dense networks of interwoven sociospatial processes that are simultaneously local and global, human and physical, cultural and organic" (Swyngedouw and Heynen 2003: 899), urban political ecology provides one means through which to open up the multiplicity of potential urban infrastructural relations at work. Here, infrastructures are conceptualised as "metabolic vehicles" which facilitate the securitisation and circulation of resources through the city, embedded in and co-evolving with capitalist and economic institutions (Cooke and Lewis 2010; Moss 2009). Because of their central role in "the modernist quest to sanitize and rationalise urban space" infrastructure networks are "integral parts of the urban fabric and the process of transformation of nature into the city and vice versa" (Kaika 2006; 28).

In turn, through these processes of circulation and flow, the apparent permanence and fixity of urban forms and governance is conferred (Harvey 1996) and networks are rendered invisible (Star 1999). Work in this field draws attention to the dynamic and contested processes through which apparently obdurate urban socio-technical systems are established and maintained. Such processes are both strategic, reflecting the dominant interests of the state and capital, and mundane, accomplished through routine practices by a myriad of actors in a variety of settings and with dependency relations between actors, resources and urban infrastructures. Despite a tendency to stress the structural dynamics of the urban, the routine and multiple dynamics processes of flow and fixity suggest that contingency is also critical in configuring urban infrastructure networks. This perspective allows for an analytical move away from normative views on low carbon cities inspired in fixed views of idealised nature, towards an examination of the socio-environmental processes, mediated by infrastructure, which seek to conform the urban, and in particular, the work that goes into its maintenance and contestation and how urban power relations are reconstituted.

Rather than conceiving of urban infrastructure change as a move from one (more or less) stable regime to another, as suggested by socio-technical systems accounts of infrastructure, urban political ecology perspectives suggest that what is at stake is the reconfiguration of processes of metabolic circulation, a process conducted through multiple sites and human/non-human agents across different scales. Particular forms of metabolic circulation are regarded as historically produced in relation to different logics of capital (Gandy 2004), and while one regime may be dominant at any one time, urban metabolisms co-exist, compete and conflict in shaping particular urban conditions. While sharing a concern for identifying the social and technical structures that hold particular networks in place, these approaches depart from the rather homogenous accounts of socio-technical regimes and provides a more dynamic, plural, and fragmented account of the regimes within and through which urban

infrastructure systems are maintained and contested In addition, debates concerning 'splintering urbanism' point to the ways in which contemporary, neoliberal, logics of capital accumulation produce urban spaces with the simultaneous fragmentation and rebundling of infrastructures in cities, leading to multiple urban modalities and new logics of nature transformation. These processes point to the specific ways in which power relations choreograph specific socio-technical practices. However, in regarding changes in such systems as being orchestrated through these structural dynamics, accounts of splintering urbanism can underplay the work involved in establishing these modes of infrastructure and their contingent and unruly nature (Kaika, 2006). Here, we find the emphasis on the critical role of niches within the literatures on socio-technical systems in transition useful. Rather than reading niches as contained, bounded entities, separate from the regime and from the dominant interests it represents, reading innovative initiatives and projects in the city through the lens of urban political ecology points to their open-ended, 'experimental' nature (cf. Hoffmann 2011)[1], a means through which climate change comes to be learnt and experienced within the urban context, as well as to their central role in the metabolic circulations that serve to (re)configure urban infrastructure networks.

As we have argued above, understanding the socio-technical nature of urban responses to climate change is fundamental to gaining insights into the potential and limitations of such efforts. Drawing on the insights generated from our reading of the literatures on socio-technical systems and urban political ecology, we suggest that this analysis can be approached in two, related, ways. First, there is a need to understand how particular urban infrastructure regimes, as configurations of discourses, agents

[1] In conceiving of these interventions as 'experimental' we draw on Hoffmann's conception of climate governance experiments. Hoffmann suggests that twin processes of the fragmentation of global authority and increasing dissatisfaction with the outcomes of 'mega multi-lateralism' in the climate governance domain are giving rise to a novel set of 'rule-based' interventions outside of formal political structures. However, our analysis departs from his work in two important respects. First, Hoffmann explicitly rules out initiatives emerging in individual cities from his analysis. Second, Hoffmann's concern is not with the socio-technical character of such experiments.

"institutions, techniques and artifacts" (Monstadt 2009: 14), are established, maintained and challenged, and their implications in relation to climate goals. In so doing, we draw on the notion of a socio-technical regime, but rather than locating it within a multi-level perspective, we seek to understand the ways in which such regimes are configured socio-spatially and structured through processes of political economy and political ecologies. Engaging theories of urban political ecology points to the multiplicity of urban infrastructure regimes that may co-exist, each configured through distinct forms of relation between power, nature and urban life. Second, we argue that such an analysis needs to focus on the emergence of climate change 'experiments', as sites within and through which new forms of circulation are configured and challenged. Here, we suggest, the task for analysis is one of understanding how, why and with what implications climate change 'experiments' take place and, in particular, their role in maintaining or challenging dominant regimes and in the governing of climate change in the city. Rather than regarding such experiments as heralding the development of particular niches, we draw on the urban political ecology literature to suggest that they provide distinct sites and moments through which regimes are both formed and sustained. In the next section of the paper, we turn to explore these issues – of the development of low carbon regimes of urban infrastructure and climate change 'experiments' – through an analysis of the case-study of London.

Urban infrastructure regimes, climate change experiments and energy transitions in London

With a population of some 7.7 million and recognized as a 'global' city, London is a significant source of greenhouse gas emissions estimated at 44Mt or 8% of the UK's total in 2006 (GLA 2008). In the early 2000s, following changes to the structure of government in London in the form of the Greater London Authority, its Assembly (GLA) and directly elected mayor, an explicit policy for addressing climate change

in London emerged. Central to this have been attempts to govern the urban energy system in London towards a 'low carbon' transition. Drawing on two separate accounts of the emergence of the 'low carbon' transition in London[2], our analysis uses the insights developed above to argue that this process has been accompanied by attempts to configure a 'low carbon' urban energy regime. We suggest that this configuration is neither contiguous nor coherent, but rather composed through and of experiments which provide the means for making, demonstrating and practicing the new 'low carbon' logic and assembling a new socio-technical network. Climate change experiments, and the mode of low carbon urbanism which they constitute, are in a constant state of flux as different discourses, interests, institutions, techniques, and artefacts are enrolled and excluded. Rather than producing a 'transition' from one socio-technical system to another, we suggest that the governing of climate change in London involves the emergence of a new urban infrastructure regime, configured alongside and in-between existing socio-technical systems.

Configuring a low carbon urban regime

During the 2000s, as concerns over climate change and energy rose on the political agenda in the UK, a convergence between these previously separate policy arenas took place around the discourse of the

[2] The research that underpins this analysis was conducted in two separate projects, each of which included extensive empirical investigation of the low carbon transition in London but which focused on different aspects of this process. The first undertaken by Harriet Bulkeley under the auspices of Tyndall Phase II's work on the role of non-nation-state actors in post-2012 climate politics took place during 2008 – 2009 and focused on the development of climate change policy within the city and involved the analysis of a range of policy documents and grey literatures, as well as semi-structured interviews with policy-makers and stakeholders involved in the creation of London's climate change strategy and its implementation. The second *Solar Cities in Europe: embedding photovoltaics* was a PhD project supported by Sanyo and County Durham Development Corporation and took place from 2007 – 2011 and focused on the emergence and development of photovoltaic technologies within the city, and involved analysis of a policy documents, grey literature and technical specifications, semi-structured interviews with policy-makers, businesses and third-sector organisations, as well as site visits and observation of PV installations.

need for a 'low-carbon' economy (DECC 2009; Lovell et al. 2009). In London, this was manifest in the development of the 2004 Energy Strategy and its 'Vision' for London's energy future, where by 2050:

> "London has a radically different energy system from the one that characterised the 20th century - it is a high performance system powered by renewable energy and a reduced fossil fuel input which has delivered carbon dioxide (CO2) emission reductions of more than 60 per cent relative to those of 2000." (GLA 2004 p. 37)

The 2004 Energy Strategy, one of number of discretionary strategies published by Mayor Livingstone during his first term of office, demonstrated his aspirations to place London at the forefront of the development of new energy technologies and in the response to climate change (Hodson and Marvin 2007). Constrained by dependence on national government resources and limited direct powers, the 'low carbon' discourse was taken forward in Livingstone's second term of office in two ways. First, by developing the 'global' profile of London as a city addressing climate change (see also Hodson and Marvin 2007, 2009). Central here was the formation of the C40 Cities Climate Leadership Group, which enabled Livingstone to promote London as a progressive site for addressing climate change and, importantly, as the centre of the new carbon economy. Second, through the further development of strategies and targets for addressing climate change which effectively sought to configure a new 'low carbon' regime of energy infrastructure within the city. To this end, the 2007 London Climate Change Action Plan established a more ambitious policy goal with the aim "to stabilise CO_2 emissions in 2025 at 60 per cent below 1990 levels, with steady progress towards this over the next 20 years" (GLA 2008: 19). Central to achieving this ambition was the decentralization of energy generation:

> "The Mayor's top priority for reducing carbon emissions is to move as much of London as possible away from reliance on the national grid and on to local, lower-carbon energy supply (decentralised energy, including combined cooling heat and power networks, energy from waste, and onsite renewable energy - such as solar panels) … The Mayor's goal is to enable a quarter of London's energy supply to be moved off the grid and on to local, decentralised systems by 2025, with more than half of London's energy being supplied in this way by 2050." (GLA 2008: 105)

Reflecting the diverse interests and influence of various environmental groups, including Greenpeace who conducted a study on micro-generation for the GLA, the experience of the Director of the London Climate Change Agency[3] Allan Jones of developing off-grid energy systems in Woking, the interests of energy companies and the corporate sector in issues of energy security and corporate social responsibility, and the political ambitions of Mayor Livingstone and his advisors to create a distinct profile for London in the climate change arena, decentralizing energy generation became central to the promulgation of the 'low carbon' logic. As Monstadt (2009: 14) suggests, the configuration of this regime of energy infrastructure s takes place through the alignment of "institutions, techniques and artifacts" through which various logics underpinning the low carbon regime can be advanced. In institutional terms, the establishment of new partnerships, including the London Energy Partnership, set up in 2004 to address the key issues of the London Energy Strategy and to "achieve a sea change in

[3] The London Climate Change Agency was established in 2005 as "a municipal company wholly owned and controlled by the London Development Agency (LDA) and chaired by the Mayor" with extensive private sector and charitable support. Following the election of Boris Johnson as Mayor of London in 2008, the LCCA was integrated into the London Development Agency in 2009, demonstrating the continual reconfigurations taking place across the emerging low carbon energy mode.

thinking about sustainable energy by key stakeholders" (LEP website 2010),[4] the London Climate Change Agency, the London Hydrogen Partnership, the Better Buildings Partnership and the C40 network, have provided critical means through which to gather diverse actors, capacities and projects around the low carbon energy logic. As one policy-maker in London explained, the impetus behind the Energy Partnership was the need to create a means through which 'sustainable energy' could be delivered in London:

> "it's hard to see how in London you can deliver action on sustainable energy. ... having statutory requirements to do the strategy [is one thing] ... in terms of implementation, it's quite clear ... there has to be action elsewhere. So the idea was then well if you look at all the stuff that needs doing you know anything from fuel poverty to CHP to what have you, we do need to have a different approach ... so that was really the idea behind establishing the Partnerships so that you pull together anyone from the boroughs which obviously are important to the private developers to the health sector to you know higher, further education and try and work out [the] strategy [and] how it's delivered" (Interviewee, London, 2009)

In terms of techniques, assembling a new regime of 'low carbon' energy infrastructure has taken place primarily through three means: the use of the Mayor's planning powers to require that 20% of the energy required for new developments over a threshold size is generated from low carbon sources on site; the development of demonstration technologies, projects and area-based schemes, including four Energy Action Areas and, under the new Mayor Boris Johnson, the development of ten Low Carbon Zones; and a suite of voluntary programmes for businesses and residents, primarily focused on

[4] See: http://www.lep.org.uk/about-us.htm; members include government bodies, corporate sector organisations and environmental groups.

improving energy efficiency in the built environment. Various artefacts have also proven crucial to the emergence and development of the low carbon regime, including, for example, technical reports and feasibility studies undertaken by a range of state and non-state actors, micro-generation technologies, Combined Heat and Power (CHP) plants, biomass boilers, 'private wire' networks which have the potential to distribute locally generated energy, flagship buildings, insulation materials, and so on (Bulkeley and Schroeder 2008; Coutard and Rutherford 2010).

Through the alignment of these institutions, techniques and artefacts around the 'low carbon' and decentralised logic of energy provision a new configuration of urban energy infrastructures in London is taking place. This in turn entails a shift from attempts to integrate urban circulations within wider energy socio-technical networks in order to provide secure and efficient supplies, towards a reordering of processes of urban metabolism around particular places (for example, those with significant demands for cooling and or heating, amenable to CCHP and district heating schemes), new urban developments (including the Olympic Park and social housing schemes such as those at Elephant and Castle), as well as individual commercial buildings, schools and households (to be fitted with micro-generation technologies and with ambitions to be energy self-sufficient). Such a potentially radical reconfiguration might be expected to attract widespread opposition. However, the logic of a low carbon, decentralised energy regime has attracted support from across a diverse range of interests, from business interests, prominently in the shape of London First the representative body for big business and development interests in the city, to a range of community action groups whose primary concerns are with issues of social justice and local sustainability support which has been critical to its realisation. Further, this political support together with the effects of assembling a low carbon energy regime in London has meant that the ambitions for decentralising energy in London have survived the change in political leadership which occurred in 2008 with the election of Mayor Boris Johnson. As one interviewee pointed

out, the central place which climate change occupied in London's political imaginary during the late 2000s served to create a rather uneasy consensus around the issue, where overtly different political ideologies were dissipated:

> "climate change is now the centre of political debate in London. In a way even more so than it is in national discussion … when Boris Johnson announced [his] canditure for Mayor, even though he's got a record of opposing Kyoto, he's pro nuclear anti wind farms, he still felt he had to say he was going to be the greenest candidate. Because he couldn't let go that territory and expect to win the election." (Interviewee, London, 2008)

Once in office, Mayor Johnson has continued to promote the vision of a low carbon, 'green' energy future for London, for example, extending schemes for home energy retrofitting, electric vehicles and decentralized energy. The 2009 *Powering Ahead: delivering low carbon energy for London* reiterates the need for decentralized energy and promises support and funding from a range of public and private actors in the city. As Imrie et al (2009) argue: "Mayor Johnson (and Mayor Livingstone before him) and the coterie of politicians and policy officials in the Department of Communities and Local Government (DCLG), Greater London Authority (GLA) and the London Development Agency (LDA) subscribe to a particular narrative about London's global development." (p. 6)

After the numerous experimental interventions since the early 2000s, low carbon logics are an integral component of such global development narratives. While the ideological visions at play may differ between Livingstone and Johnson, both have sought to develop a low carbon regime at the intersection of market and political logics, albeit the means to achieve such low carbon regime may have been adapted following the evolution of these alliances. With its focus on the creation of additional energy

supply, new technologies and new developments within the city, the nascent regime of low carbon energy infrastructure has in effect been forged through and in-between existing urban energy regimes. Rather than heralding a 'transition' from one urban infrastructure regime to another, or indeed their mutation or adaptation, this suggests a more multiple process, creating a splintered landscape of urban energy regimes which co-exist, compete and conflict, driven by the new possibilities of (green) capital accumulation, as well as concerns for carbon control (While et al. 2009) and the securitization of urban resources (Hodson and Marvin 2009).

Experimenting with climate change: the London ESCO and municipal photovoltaic projects

Configuring spaces for the new low carbon energy mode in London is a process, we suggest, that is critically dependent on the development of 'climate change experiments'. That 'experiments' have been central to the governing of climate change in London is evident from the energy and climate change strategies published in the period 2000-2010, the texts of which are replete with calls for new, demonstration, or best practice projects, technical innovation, and the formation of new organizations, social practices and community or area-based initiatives. Here, we examine two such experiments – the London Energy Services Company (ESCO) and municipal photovoltaic projects, demonstrating how they have been constituted through the new regime of urban infrastructure but are at the same time central to its realization. The London ESCO was established in 2006 as a private limited company jointly owned by the LCCA (with a 19% shareholding) and EDF Energy (with an 81% shareholding) (LCCA 2007: 5-6) with the explicit aim of developing decentralised energy systems to achieve CO_2 emission reductions. Critical to the formation of the London ESCO was the alignment of institutions, techniques and artifacts realised within low carbon energy regimes. This included the Mayor and his advisors, Allan Jones, then Director of the LCCA and formerly of Woking Borough where such an approach had previously been successful,

EDF Energy, a French multi-national company (which incorporates the former London Electricity Board, and hence the existing energy supply network in London), particular technologies (especially Combined Cooling Heat and Power plants) and the potential of large urban development projects as arenas within which to implement the ESCO model:

> These big projects … are multi-utility projects … not just electricity, heat, also cooling and air conditioning, water supply, data and telecoms it was very much this multi-approach to a new development. When you've got a new development you can afford to do that. You can lay the pipes in the ground for potable and non-potable water you can lay the data cables you can lay the heating pipes, chilling pipes and everything else, so it's your opportunity to do things on brownfield sites from the ground up. Big projects, of 8MW, 10MW, 20MW some really quite big ones in terms of capacity. Still small in the scheme of things in terms of what the market out there is doing, on the grid-scale of things, but quite significant within a London or city context. (Interviewee, London, Autumn 2008)

Developing urban PV capacity in London has similarly been central to the emerging low carbon energy regime. In 2004, the Energy Strategy acknowledged the role of small scale renewables in London's overall policy, stating that "there is massive scope for employing PV in London" (GLA, 2004), while The London Plan sets an indicative target of installed PV capacity of over 25 MW by 2010 and over 80 MW by 2020 across the commercial and residential sectors. The emerging low carbon energy regime in London provided the GLA with a means through which to align the fortuitous conjunction of solar entrepreneurs, particularly Solar Century, the UK's leading manufacturer of PV, national government funding programmes (e.g. for schools, communities and individuals to install PV), and leading corporate

actors seeking to become involved in addressing climate change in the city towards the development of micro-generation capacity in the city.

At the same time, climate change experiments have been critical to mobilising and sustaining the momentum of the low carbon energy regime. First, they have provided a means through which to signify the presence of this new modality within urban networks, whilst also circumventing the obduracy of existing infrastructures by focusing on new technologies and the development of new urban spaces. PV projects have become an important – and often highly (politically) visible - means through which the GLA have sought to demonstrate their commitment to addressing climate change and decentralising energy generation, though for example PV powered urban infrastructure from Transport for London, as well as the installations at City Hall, the Palestra building and the London Transport Museum. Being seen to be taking action has been especially important for advancing London's claims to be an 'exemplar' city (see Hodson and Marvin 2007): "whether it's India or China or Africa, you know, once you've done it yourself, then at least you have the right to stand up and say, we know what we're doing" (GLA Interviewee, London 2008). Equally, the London ESCO has sought to promote alternative technologies and infrastructure networks, whilst also challenging conventional business and organisation models for the provision of energy, seeking to recover "a relationship with the infrastructure" network and move away from the remote generation of power to "actually integrate energy generation and waste processing into the same urban environment" (ESCO Interviewee, London, March 2008) in a way that makes it visible. Second, such experiments have provided a means through which the 'low carbon' logic can be put into practice. Making PV 'real' was seen to be a critical:

> And yet, […] there's no substitute for projects that you can go and see. People can ask questions about, what did you do and how did you do it. And there's lots of lessons to be learnt, not just

> from the technology ... you start to reveal problems with regulations and legislations, that they don't work in your favour. … There's a lot of barriers that get exposed from doing a project for real. And that's the idea of doing them. (Interviewee, London, Autumn 2008)

At stake here was not only the realisation of how different technical, social, political and economic factors structured the possibilities for PV, but also that they could be overcome. The London ESCO was also regarded as central in proving that a key policy – the requirement to provide energy generation on-site for large developments – was practical and would stand up to policy challenge (London, GLA Interviewee, December 2008).

Through making space for the low carbon logic, rendering it both visible and practical, climate change experiments serve to constitute a new energy regime. In so doing, they occupy a fragile and often contested political space. Despite the consensus between political elites, global energy companies, social interests and capital that a 'low carbon' future is one that London should pursue, significant differences have arisen as to how this might be achieved in practice, in part as a result of the metabolic circulations that such experiments have been able to enable. For example, the results from PV projects have served to demonstrate that it has limited potential as a technology for delivering the GHG reductions required by GLA targets, resulting in a gradual downplaying of the significance of micro-generation as a means of meeting the policy goals for addressing climate change and decentralising energy supply. More explicitly, business groups, predominantly those with interests in property development, have challenged an approach to decentralised energy generation focused on on-site generation and new development. A scoping study by Buro Happold for London First suggests that meeting the 25% target is equivalent "to 31,250GWh of energy" and that "initial assessments show this equates to 170 schemes of the scale proposed for Olympic Park (a 15MW electrical output), assuming

no further growth in energy demand" (Buro Happold 2008 p.11). However, rather than questioning the low carbon logic underpinning the policy of decentralised energy generation, these arguments have been used as a means of advancing an alternative approach, one based on fewer, larger (but still decentralised) power plants. The mobilisation of different forms of technology and interests through different experiments therefore serves as a means through which what it means to be 'low carbon' is continually being produced and challenged. In this manner, experiments provide a means through which "alignment of multiple actors (and artefacts)" into the low carbon regime takes place through processes of "mutual translation" (Smith 2007: 448). This is a set of practices that requires continual and mundane work (Rutland and Aylett 2008), but it is also a strategic process, reflecting the power relations that shape the sorts of socio-technical practices that will be deemed to fit within new found orthodoxies (Smith 2007: 447), and those that will not.While

Conclusions

In seeking to engage with the very 'stuff' of urban climate governance, there is much to be gleaned from an engagement with studies of socio-technical systems, urban political ecologies and urban infrastructure networks. In developing and critiquing these bodies of work, we argue for a an approach that seeks to understand how, why and with what implications particular urban infrastructure regimes are established and maintained, and which recognizes the role of 'experiments' as sites through which such regimes are configured and challenged. Rather than being separate 'niches' within a regime, this reading locates experiments as central to the working and maintenance of particular modes of socio-technical organization.

In examining the case of London in this way, we find that the development of a new mode of 'low carbon' energy has been critical to the governing of climate change in the city. This 'low carbon' regime has emerged and been stabilized through the (re)alignment of discourses, actors, institutions, techniques and artifacts, a process which has involved many of the most powerful actors in London's energy system. Emphasis on technological and institutional solutions has tended to create alignments of actors with different political orientations, moving action away from fundamental debates around political positions and values about the specific processes of socio-nature production in London. This draws attention to the ways in which "the particular staging of the environmental problem and its modes of management signals and helps to consolidate a postpolitical condition, one that evacuates the properly political from the plane of immanence that underpins any political intervention" (Swyngedouw, 2009, p.604). However, while a degree of consensus pervades the logic of low carbon energy systems emerging in London this apparent unity belies the diverse rationales at work, conflicts over how and by whom new forms of urban energy should be generated, and the practical and material ways in which low carbon is enacted and disrupted. Central to these processes have been a series of climate change 'experiments'. Examining two such processes – the London ESCO and municipal PV projects – we find that these experiments have been created by dominant actors as a means of articulating and testing a new logic for urban infrastructure development, and have served as a means through which to circumvent the obduracy of existing energy regimes, creating (political) space and visibility for the low carbon logic, while at the same time serving to demonstrate that new forms of energy generation (and use) can be realized in practice. A post-political consensus centered on the need of both address the collective challenge of climate change and project London as a global exemplar in terms of responding to the global environmental crisis has been mobilized to transform the existing urban infrastructure regimes and adapt them to new logics. The question here is whether, together with specific global development logics, different technological, natural and social elements embedded in urban circulation

can be mobilized in the same direction, towards the imposition of a new regime, or whether multiple urban infrastructure regimes may emerge out of the need for reconfiguration which do not respond but challenge hegemonic urban development discourses. The process of the adjustment of incumbent regimes to newly hegemonic logics generates moments in which those very logics are laid bare for contestation and thus, constitute opportunities for the construction of more progressive outcomes. Through these means, experiments work by establishing new circuits, configuring actors in new sets of relations and through these means realizing a different potential. At the same time, experiments become sites of conflict, a means through which new forms of urban circulation can be confined and marginalized, leaving dominant energy regimes (relatively) intact.

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