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Research Paper

Reconceptualizing green infrastructure for climate change adaptation: Barriers to adoption and drivers for uptake by spatial planners

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HIGHLIGHTS

- The paper defines the concept of green infrastructure within the context of climate adaptation.
- Green infrastructure uptake is subject to biophysical and socio-political constraints.
- Interviews with planners indicate tendencies for institutional path dependence.
- We discuss this as an institutional barrier to the green infrastructure adoption.
- We propose a conceptual model that explicitly recognizes such institutional factors.

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ABSTRACT

Urban green infrastructure can help cities adapt to climate change. Spatial planning can play an important role in utilizing green infrastructure for adaptation. Yet climate change risks represent a different sort of challenge for planning institutions. This paper aims to address two issues arising from this challenge. First, it defines the concept of green infrastructure within the context of climate adaptation. Second, it identifies and puts into perspective institutional barriers to adopting green infrastructure for climate adaptation, including path dependence. We begin by arguing that there is growing confusion among planners and policy makers about what constitutes green infrastructure. Definitional ambiguity may contribute to inaction on climate change adaptation, because it muddies existing programs and initiatives that are to do with green-space more broadly, which in turn feeds path dependency. We then report empirical findings about how planners perceive the institutional challenge arising from climate change and the adoption of green infrastructure as an adaptive response. The paper concludes that spatial planners generally recognize multiple rationales associated with green infrastructure. However they are not particularly keen on institutional innovation and there is a tendency for path dependence. We propose a conceptual model that explicitly recognizes such institutional factors. This paper contributes to the literature by showing that agency and institutional dimensions are a limiting factor in advancing the concept of green infrastructure within the context of climate change adaptation.

1. Introduction

How to adapt cities to climate change is emerging as one of the greatest challenges that spatial planners will face in the 21st Century (Measham et al., 2011; Perry, 2015). Planning scholars have responded to this challenge by articulating a range of potential responses through both adaptation and mitigation. Adaptation responses include: fortifying coastal zones; devising interventions to bolster food and water security; developing strategies for coastal retreat; and better integrating emergency service responses into planning systems (Davoudi, Crawford, & Mehmood, 2009). Some of these responses are already being implemented by practitioners. Yet adaptation has been slow, mainly because some potential solutions are politically unpalatable (Byrne & Yang, 2009). Other solutions may be expensive, may impact the rights of private property owners, may require major changes to existing planning systems, or may constrain future property development options (Bulkeley, 2013). Green infrastructure however, appears to be relatively quick to implement, is comparatively inexpensive, has broad

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public appeal, and is politically benign (Bowler, Buyung-Ali, Knight, & Pullin, 2010; Byrne & Yang, 2009). Moreover, it could gain rapid acceptance in an age where planning is increasingly attentive to urban infrastructure (Dodson, 2009).

Green infrastructure has broad appeal, largely due to its multiple benefits (Emmanuel & Loconsole, 2015; Gill, Handley, Ennos, & Pauleit, 2007; Jim, 2015; Kambites & Owen, 2006). For example, climate change will likely magnify urban heat island effects and increase flood events for many cities (Field, Barros, Stocker, & Dahe, 2012; Lo, 2013). Such impacts will likely be exacerbated by increases in 'hard' surfaces associated with rapid urbanization (e.g. concrete, stone, tile, asphalt and tarmac) (Field et al., 2012; Gartland, 2011). In cities worldwide, hard surfaces can now comprise as much as 67% of land area, while 'green' areas can fall as low as 16% in some cities (Gartland, 2011). Green infrastructure can contribute to ameliorating these problems by regulating ambient temperatures and reducing storm-water runoff, as well as affording recreational opportunities – among other benefits, recognizing of course that benefits are dependent upon the scale, form and function of urban greening (Pataki, Carreiro, et al., 2011). Although there is considerable scope within various planning systems and institutional structures to advance green infrastructure initiatives, this is yet to be realized on a major scale.

The relatively slow uptake of green infrastructure is perplexing. It begs the question: 'What are the barriers to, and drivers for, adopting green infrastructure for climate adaptation?' Unfortunately, researchers have tended to privilege the biophysical dimensions of green infrastructure over socio-cultural and political-institutional concerns, so we know little about the latter. Byrne and Yang (2009, p. 38) have suggested that four classes of interrelated factors shape the efficacy of green-space as a climate change adaptive response: The biophysical character of the built environment; planning systems; institutional frameworks and governance structures; and the perceptions and values of urban residents. Although they did not undertake empirical research to test these assertions, their conceptual overview is instructive, and is worth briefly revisiting here.

According to Byrne and Yang (2009, p. 38), biophysical factors that potentially delimit the utility of green infrastructure include: The area available for greening, urban morphology, site contamination, engineering and geological issues, vegetation characteristics, and climate. They also highlighted socio-political factors, which include: Governance systems; fiscal constraints; and expectation for public involvement in decision-making. Together these factors describe the social and biophysical feasibility of green infrastructure as a climate adaptation measure. Byrne and Yang (2009) also suggest that these factors interact in multiple, sometimes paradoxical, ways to shape the efficacy of green infrastructure. For example, their conceptual model suggests that species characteristics and urban morphology will combine to determine the maximum scope and scale of ecosystem service benefits that can be derived from a specific green infrastructure intervention. Planning regimes, governance systems and resident's attitudes and perceptions may combine to thwart the deployment of green infrastructure, even when it is viable; conversely they may facilitate the use of green infrastructure, even if ecosystem service benefits are marginal. While insightful, these ideas have yet to be empirically validated.

This paper contributes to an important contemporary spatial planning debate by showing that agency and institutional dimensions are limiting factors to the implementation of green infrastructure through spatial planning activity. Scholarly examination of this issue in literature and debates concerning the role of green infrastructure for climate adaptation is currently lacking. The idea of green infrastructure as a climate adaptation measure warrants a more focused scope and a modified definition in terms of climate *risks* and *systemic complexities*. These unique aspects of climate change differ from common urban issues, such as recreational needs and landscaping, in terms of scale and implications, and challenge some of the current planning practices and existing institutional arrangements.

The key aim of this paper is to begin to test assumptions about the role of biophysical, socio-cultural and institutional factors as potential drivers or barriers in using green infrastructure for climate adaptation, by examining some of these factors within the planning systems of England and Ireland. We begin by defining what we mean by green infrastructure and identifying problems with broad definitions in existing studies. We then discuss empirical research that we conducted, in the form of interviews with seven planners, all of whom have significant experience of planning processes in England and Ireland. From this research, we identify additional potential barriers and drivers to green infrastructure adoption, including path dependence, within the institutional context of planning. We synthesize our findings with those of other studies to produce a revised conceptual framework that can inform future research on this important topic. To advance the debate, we elaborate two important concerns that Byrne and Yang (2009) overlooked, which limit the utility of their conceptual model. First, they did not give sufficient attention to the institutional environment in which decision-making occurs. Second, they overlooked the 'agency' of climate and vegetation as a factor shaping the efficacy of green infrastructure (Pelling, High, Dearing, & Smith, 2008). We offer a revised conceptual framework, which seeks to redress these limitations. We conclude by discussing policy implications and sketch out an agenda to address some of the important knowledge gaps.

2. Background

2.1. Definition

One of the earliest uses of the term infrastructure, as applied to parks and green-spaces, sought to redefine the public park as an extension of urban infrastructure (Rosenberg, 1996). This use of the term infrastructure sets parks apart from amenity functions, and was intended to invoke an integrated set of large-scale, city-wide public works; functioning as investments and/or assets, and deployed primarily for human benefits–like transport, wastewater, storm-water or energy infrastructure. Green infrastructure has since become an important object of scholarly inquiry.

Green infrastructure typically refers to an interconnected network of multifunctional green-spaces that are strategically planned and managed to provide a range of ecological, social, and economic benefits (Bendict & McMahon, 2006; Kambites & Owen, 2006; Tzoulas et al., 2007; Wright, 2011). Examples of green infrastructure include green roofs, permeable vegetated surfaces, green alleys and streets, urban forests, public parks, community gardens and urban wetlands (Byrne & Yang, 2009; Douglas, 2011; Foster, Lowe, & Winkelman, 2011; Gill et al., 2007; Klemm, Heusinkveld, Lenzholzer, & Van Hove, 2015). Scholars recognize that green infrastructure can potentially improve residents' health and wellbeing, provide food, lower wind speeds, reduce storm-water run-off, modulate ambient temperatures, reduce energy use and sequester carbon, among other 'ecosystem service benefits' (Mell, 2013; Mell, Henneberry, Hehl-Lange, & Keskin, 2013; Roy, Byrne, & Pickering, 2012), although the extent of these benefits remains somewhat contested (Pataki, Carreiro, et al., 2011). Green infrastructure thus holds the potential to cushion cities against many expected climate change impacts (Byrne & Yang, 2009; Brown, Vanos, Kenny, & Lenzholzer, 2015).

However, there are difficulties with how spatial planners and built environment researchers have defined and operationalized the term green infrastructure. For example, the term has tended to

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be conflated with 'green-space' generally, weakening its conceptual strength. There are four key reasons for this identified in recent literature (Bendict & McMahon, 2006; Wright, 2011). While limited space prevents an extended discussion, they reasons cited are: (i) a desire among preservationists to link green-space preservation to the growing political legitimacy of green infrastructure; (ii) a desire by green-space preservationists to bolster their claims about the importance of green-space generally by 'hitching their wagon' to growing status of green infrastructure; (iii) a tendency by some planning scholars to use the term green-space and green infrastructure inter-changeably and uncritically, and (iv) a tendency by some planning practitioners to 're-brand' existing green-space initiatives to comply with their institutional agendas (Bendict & McMahon, 2006; Wright, 2011).

Until now, definitional ambiguity has not created substantial problems, perhaps because it has allowed an inclusive dialog about the benefits of urban greening generally (Wright, 2011). But growing confusion among planners and policy makers about what constitutes green infrastructure could stymie future action on climate change adaptation, because it: (i) muddies existing programs and initiatives that pertain to green-space more broadly; (ii) feeds path dependency – because it can simply bolster existing programs; and (iii) potentially stifles innovation. For this reason, taking a cue from Mell et al. (2013, p. 297), we advance a more focused definition of green infrastructure as: 'the biological resources in urban areas that are human-modified and primarily serve an overt ecological function' and which are 'intentionally designed and deployed primarily for widespread public use and benefit'. Our intent is not to perpetuate a schism between nature and culture; rather we seek clarity around the ways that biological interventions are being deployed for climate change adaptation.

3. Challenges for spatial planners

Three key challenges facing spatial planners regarding green infrastructure are identified from literature: (i) difficulties in conceptualizing green infrastructure, (ii) problems with enshrining green infrastructure within planning tools and processes, and (iii) challenges in employing green infrastructure for climate change adaptation. We address these in turn.

3.1. Problems in conceptualizing green infrastructure

Different disciplines have attached different environmental, political, social and economic meanings to the concept of green infrastructure, with little agreement as to how it should be defined and interpreted (Wright, 2011). The search for a shared understanding is further complicated by the view that green infrastructure can alleviate a wide array of problems confronting society (i.e. combating the obesity epidemic, lessening civil unrest and mitigating carbon pollution). As we noted above, definitional ambiguity is leading to issues with how planners conceptualize green infrastructure, potentially frustrating its adoption as a climate change response. A way out of this conundrum is to make a distinction between green infrastructure as a *form of capital* and as a *risk buffer*. We have developed Table 1 to illustrate this distinction.

For Bendict and McMahon (2006), green infrastructure connotes a shift in how we understand managed networks of natural sites and open spaces that serve multiple environmental and social ends. They explicitly distinguish between green-space and green infrastructure:

> *While green-space is often viewed as something that is nice to have, green infrastructure implies something that we must have. Protecting and restoring our natural life-support system is a necessity, not an amenity*. (Bendict & McMahon, 2006, p. 2)

Table 1
Capital and risk-based concepts of green infrastructure.

	Capital concept	Risk-based concept
Problem framing and role	Well-being – promotion of public health, recreational and social uses Deliver discrete benefits and fulfill social and economic needs (public goods)	Impeding threats – heat stress alleviation and hazard mitigation Cope with irreducible uncertainties and minimize adverse impacts (public 'bads')
Embedded policy discourse	Sustainability, sustainable development and progressive growth	Resilience, risk society and prudent development
Planning approach	Pragmatic, rationalist and instrumental	Creative, incremental and cooperative

Defining green infrastructure as a necessity accentuates the strategic benefits of urban green elements and insulates these planning interventions from the sometimes-fraught political status of green-space planning generally. The infrastructure approach elevates urban greening to a higher level of importance, linking it to key socio-economic imperatives, such as local economic development and reduction of health care expenditure (Tzoulas et al., 2007). In this sense, the green infrastructure movement is essentially an economic case for greening (Horwood, 2011). For planners, the attraction of green infrastructure is its great potential to move beyond conflicting debates about continuing growth and land conservation (Horwood, 2011; Wright, 2011).

As Bendict and McMahon (2006, p. 58) argue, "communities that want more housing, more jobs, *and* more open space can use green infrastructure to achieve all of these goals" (emphasis in the original). The green infrastructure approach thus provides a comprehensive framework to accommodate competing interests and, in practice, to engage environmental objectives and dominant economic imperatives. Such an approach is integrative as well as pragmatic, involving attempts to ecologically modernize the concept of urban green-space in economic terms in an effort to win political support in the growth-oriented planning processes – hence its attraction for spatial planners (Byrne, Gleeson, Howes, & Steele, 2009; Lo, 2012).

This economic conceptualization of green infrastructure underscores its character as a form of critical *natural capital*, able to generate a flow of material *benefits*, rather than being an ecological or social ideal. The shift in focus is categorical – from an ecological to an economic rationality (Horwood, 2011), from amenity to necessity (Bendict and McMahon, 2006), and from a peripheral concept to one that is central to almost all policy debates (e.g. economic benefits). In a working environment dominated by fiscal constraint, this conceptual shift potentially enables planners to invoke the multiple benefits of green infrastructure, improving policy traction.

3.2. Issues with enshrining green infrastructure within planning

Like other forms of built infrastructure, the planning and management of green infrastructure is often seen as a rationalist exercise. There is some certainty about the scope and scale of the practical issues to address, such as recreational needs and conservation requirements. This has given rise to a preference for technocratic management approaches, which "engage with the identifiable and quantifiable instrumental characteristics [of green-space] rather than the more nebulous intrinsic values" (Horwood, 2011, p. 971; see also MacCallum, Byrne, & Steele, 2014). The expertise and knowledge base required are currently available and have for a long time been used for managing 'grey' infrastructures, such as roads and buildings.

For example, a key rationalistic-technocratic instrument advocated by the infrastructure approach is monetary valuation

techniques, which put a dollar value on otherwise un-priced natural resources, such as urban trees (Horwood, 2011). Putting a price on trees and other natural elements is a pragmatic act – providing a common currency by which they can be represented and compared with other forms of infrastructure in planning and management processes (Lo, 2012). This allows what many perceive to be an 'objective' evaluation, using scientifically derived assessments of economic benefits and costs, and thus presents a rational basis for green-space planning and management.

The capital concept of green infrastructure, therefore, does not identify a new or transformative problem to address. Rather, it seeks to re-frame the scarcity or poor maintenance of green-space in terms of existing problems, notably the lack of growth-supporting (and not merely life-supporting) resources. Nor does it seek to advance a new policy program or planning practice. Advocates of this concept often pursue precisely the opposite end (i.e. promoting a new approach on par with existing planning priorities and practices). The shift in concept does not involve a paradigm shift in environmental planning and management, making the idea potentially more politically palatable. This is especially important where green infrastructure is deployed as a climate adaptation strategy. Rather than preventing economic development, the green infrastructure idea complements neoliberal agendas and may thereby offer a way forward in countries like Australia where climate mitigation and adaptation are deadlocked by 'rancorous' political contests (MacCallum et al., 2014, p. 70). A key challenge for planners though, is how to utilize green infrastructure as a new and innovative form of planning, not just re-branding existing initiatives as somehow being 'green'. Innovating is necessary if planners are to help stave off the worst impacts of climate change in cities. Overcoming path dependence is likely to become a central tenet of this process of innovation.

The concept of path dependence is used to describe situations where institutions become adapted to certain issues and activities over time, and consequently become reluctant to respond to the emergence of new imperatives (Low & Astle, 2009; Matthews, 2013). Path dependence can produce benefits by perpetuating past successes, engaging with dominant institutions and keeping development on the intended track (Sydow, Lerch, & Staber, 2010). Such perceived benefits are the driving force for adopting the hybrid idea of green infrastructure. On the other hand, however, path dependence may act as a barrier to institutional change by locking institutions into specific patterns of thinking and decision making and reducing their ability to adequately or meaningfully respond to new problems, such as climate change. As such, path dependence is fundamentally ambivalent (Sydow et al., 2010), allowing engagement with existing imperatives and reducing costs of negotiation, but discouraging institutional innovation and reducing the capacity for pursuing new imperatives.

Spatial planning regimes are vulnerable to path dependence and may resist change imperatives, including the need to respond to climate change through adaptation (Matthews, 2013). A key challenge for planners though, is how to utilize green infrastructure as a new and innovative form of planning, not just re-branding existing initiatives as somehow being 'green'. And innovating is necessary as planners are to help stave off the worst impacts of climate change in cities that have created a new policy and planning discourse (Heazle et al., 2013).

3.3. Challenges for adopting green infrastructure for climate change adaptation

Climate change presents new challenges for green-space planners and policymakers (Byrne & Yang, 2009; Foo, McCarthy, & Bebbington, 2015; Pearson, MacKenzsie, & Pearson, 2015). Anthropogenic climate change involves possibilities for unpredictable alterations to the climate system and unknown probabilities of future catastrophic impacts (e.g. intense storms, heat-waves and floods). Unlike natural weather variations, climate change risks arise as the unintended consequences of modernity, are displaced over time and space, are mostly invisible, and are typically only amenable to scientific knowledge (Beck, 1992; Bulkeley, 2001). The cultural meanings of climatic change are variable and at times compete with each other, and perception of climate risks is highly dependent upon power relations and the socio-economic aspirations of individuals (Hulme, 2009).

Managing green infrastructure for climate adaptation is primarily about managing risks or uncertainties created by anthropogenic activities. The risk-based approach to climate change has three defining aspects: problem framing and role; embedded policy discourse; and planning approaches. First, problems associated with adverse weather conditions, including rainstorms, floods, heat waves and cyclones, tend to be understood in probabilistic terms. The 'thing' that matters is not discrete material benefits that can fulfill the needs of the public, but non-linear, irreducible uncertainties associated with changes in the climate. Functioning as a risk buffer, green infrastructure actually helps minimize the impacts of public 'bads' (i.e. natural perils) and, by doing this, indirectly provides public 'goods'. There is limited precision as to where and when these impacts will eventuate and in what manner. The 'necessity' for green infrastructure is thus reduced to a matter of probabilities that are influenced by global climatic dynamic and humanity's collective actions. It is driven by problems that we seek to avoid and are unable to predict with high level of precision.

Second, the concept of green infrastructure is embedded into a policy discourse that is cautious toward mainstream policy imperatives. Traditional progressive growth models have ultimately contributed to human-induced climate change, which is an outcome of uncontrolled industrial activities producing excessive quantities of greenhouse gases. The role of green infrastructure then is to cope with the adverse side-effects of unchecked economic growth, rather than to promote it. Moreover, adaptation to climate change emphasizes system resilience, which refers to 'the amount of change a system can undergo and still retain the same function and structure' (Nelson, Adger, & Brown, 2007, p. 398). Green infrastructure can moderate the adverse impacts of climate change and may enhance our ability to deal with larger-scale extreme weather events. These contributions are usually articulated in terms of resilience, which describes the ability of communities to recover from shocks and return to a functional state within a reasonable timeframe (Pelling, 2011; Renn, 2008).

The third defining aspect of a risk-based approach to climate change relates to planning approaches. In this regard, Dryzek arues that rationalist approaches are ill-suited for managing systemic uncertainties (Dryzek, 1987). A lack of precision is inherent in the prediction of extreme weather events. This allows cultural and political reinterpretations of scientific information, leading to conflicts between various kinds of reproduced knowledge (Hulme, 2009). Moreover, the impacts of climate change are displaced across scales and do not adhere to conventional governance boundaries (Steele et al., 2013). The benefits and costs of climate change actions are subject to probabilistic calculations over an extended period. These factors create considerable difficulties for a rational spatial planning approach, which assumes an objective, politically neutral, and analytical process and is typically confined to a specific jurisdiction and defined time scale. The inherent, reinterpretable uncertainties and the cross-scale nature of climate change fall short of the rationalistic assumptions of conventional institutions.

What this means is that planning regimes are confronted with a 'wicked' policy problem with respect to climate change and the need for associated responses, including the adoption of green infrastructure. 'Wicked' problems can create challenging

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Table 2
Information on interview respondents.

Interview respondent (IR) number	Occupation	Location	Professional experience (years)
IR1	Professor of Urban Management; Director of a University Research Centre	Australia (formerly Ireland)	20+
IR2	National Government Climate Change Risk & Policy Advisor	UK	4
IR3	Consultant Private Sector Planner	Ireland	6
IR4	Senior Planner; Head of Local Council Planning Policy Unit	Ireland	20+
IR5	Senior Executive Local Government Policy Planner & Urban Designer	Ireland	15+
IR6	National Government Sustainable Communities Policy Advisor	UK	10+
IR7	Executive Local Government Planner (Development Management)	Ireland	10+

socio-political contexts in which environmental and urban planning decisions are made (Rittel & Webber, 1973). Institutional responses may entail new forms of management and governance, which should be incremental, sequential and reflexive (Heazle et al., 2013; Howes et al., 2012). The institutional capacity and scope of planning regimes may span multiple scales. Consequently, planning regimes may need to engage with a wide range of sectors and groups and be prepared to promptly and continually update their risk assessments and action plans as circumstances change. Climate change, which underlies the risk-based concept of green infrastructure, will almost certainly cause circumstances to change. The changing climate has agency; it not only forms but also alters the socio-political context in which green infrastructure is rationalized and institutionalized (Nash, 2005). New institutional and socio-economic considerations emerge in the planning and management of green infrastructure. These agency and institutional issues associated with climate change have not been adequately discussed in the green infrastructure literature, a point we return to shortly. In Section 5 we examine how spatial planners think about green infrastructure, in order to identify potential barriers and drivers to its widespread adoption in England and Ireland. Prior to that, in the next section, we discuss the methods underpinning our research and its findings.

4. Methods

A qualitative research program informed this paper. Two interlinked methodological approaches were employed: A review of scholarly literature with thematic analysis; and semi-structured interviewing. The literature review, concentrated principally on planning literature related to green infrastructure adoption, was undertaken to allow thematic mapping (Sproule, 2006). The process was fundamental in directing and orientating the interview schedules for the subsequent program of semi-structured interviewing (Travers, 2006). The literature review facilitated a general understanding of important issues, whereas semi-structured interviewing tested practitioner knowledge of and understanding of these issues by canvassing the views of practicing planners.

Seven semi-structured interviews were conducted. Respondents included public and private sector planners and urban designers, planning scholars, and policy-makers working in the policy space between climate change, spatial planning and green infrastructure as a form of urban climate adaptation. Three interviews were conducted face to face, with the other four conducted over the telephone due to geographic distance. Each interview was digitally recorded and lasted approximately 1 h. The interviews were then transcribed and analyzed using text-analysis techniques (Hay, 2005; Sproule, 2006; Walter, 2009). Each participant was given an interview respondent (IR) number to ensure their anonymity. Table 2, below, identifies each respondent by their IR number and provides information on their specific occupations, geographic locations and extent of professional experience.

5. Results

Sections 2 and 3 of this paper have highlighted the importance of institutions in shaping planners' capacity to use green infrastructure for climate adaptation. We now present the results of the research undertaken for this paper, where the primary aim was to identify the barriers and drivers to a more widespread adoption of green infrastructure by planners in England and Ireland.

5.1. Multiple rationales – the more the better

Interview respondents were widely aware of and keen to promote the multiple rationales supporting an institutional advancement of green infrastructure through spatial planning. For example, conscious engagement in the capital concept of green infrastructure was clearly expressed by respondent IR3, a private sector planner from Ireland:

> *Design elements like green roofs and permeable paving systems. . .are things that would be good things to do even if you didn't have a climate change agenda. Things like that are not just pure environmental tools, they are also visual tools. So, they're good for other reasons other than purely delivering on the climate change agenda. That's the trick–every intervention should have multiple benefits. My experience is that every planning intervention should have multiple uses and benefits. If you can show that something has say, five advantages, it will be better accepted by developers and the public.*

The multiple rationales argument was also advanced by respondent IR5, a senior executive local government policy planner and urban designer:

> *Changes in design philosophy can be hard to sell. If planning can demonstrate that it [green infrastructure] has practical and visual benefits, you can build support for it. Then planning will find it easier to insist on certain technical standards.*

When questioned on how "practical and visual benefits" of green infrastructure may be framed, the same respondent suggested that:

> *There would be two main drivers for change. One is you could demonstrate that you could make it [development] far more attractive; the other is you can demonstrate the benefits from say, a hydrology perspective. If you can bring the two together it would be fantastic and may be taken more seriously.* [IR5]

The task for planners and planning regimes is then to demonstrate the multiple benefits, preferably physically. As respondent IR4, the director of a planning policy unit with more than twenty years professional experience, argued:

> *When it comes to detailed implementation, you might well have to have a separate adaptation plan that would cross over from planning and take in a number of other disciplines too. You'd need to bring in engineering colleagues, the environment side and*

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transport. You'd need input from architects. Some kind of emergency planning. You'd need to look at some aspects of that. You'd need some input from businesses too.

We can see form these comments that there is a need for reorganizing planning institutions to accommodate a wider range of professions and stakeholders, such as emergency managers, traditionally not a key part of urban green-space planning. Yet, involving more people in the planning process invariably requires considerable efforts to moderate conflicting views and interests. Progress might be limited if parties retreat to demonstrated, feasible, viable and widely acceptable options, which will not necessarily be the most innovative or effective in the longer term.

There is thus an institutional tension as existing agencies are still regarded as the proper actors to develop green infrastructure strategies for climate adaptation. This is because planning regimes appear to have sought to merely articulate the benefits – as many as possible – of green infrastructure in terms that are acceptable to existing institutions. Doing so does not require the creation of new institutional arrangements, since existing ones appear to be sufficient for dealing with multiple stressors, including climate risks, as well as other social and environmental needs. Accordingly, a possible outcome is a reluctance to pursue institutional innovation, leading to the problem of *path dependence*, to which we now turn.

5.2. Path dependence as a key institutional barrier

Path dependence describes situations where institutions become used responding to specific issues and are consequently reluctant to respond to new imperatives when they manifest (Low & Astle, 2009; Matthews, 2013). Path dependence can lock institutions into fixed patterns of thinking and decision-making and can reduce their ability to adequately or meaningfully respond to new problems. As such, path dependence can act as a barrier to institutional change. The planners we interviewed identified path dependence as a key barrier to the planning-led provision of green infrastructure.

While respondents recognized the multiple rationales associated green infrastructure, many suggested that there is a weak sense of urgency and motivation to act among some planners and decision-makers. For example:

There is a need for engagement [with the idea of planning-led climate adaption], but there's no great response yet. It [planning] should be taking it seriously. People – as the need becomes demonstrative – will have to react and get more serious, but are not at the moment. [IR5, a senior executive policy planner and urban designer from Ireland]

Awareness does not necessarily translate into action. Planners do not appear to be actively engaged with the concept of climate *risk*. Respondent IR7, an executive local government planner with more than ten years of experience, spoke to this point:

The realisation of the climate change risk hasn't really hit home [for planning]. A lot of people are aware of it but the vast majority haven't really bought into the whole concept yet.

A potential problem with existing planning responses to climate change, especially with regard to the adoption of green infrastructure, is that planners do not appear to be pursuing a clear and distinctive policy agenda. Instead, they appear to be loading the 'new', multiple adaptive functions of green-space into existing planning frameworks. This is partly caused by defining the concept of green infrastructure in more ambiguous and malleable terms, a point we noted earlier.

In a climate of fiscal austerity, there is an imperative that planners prioritize policy agendas that can be clearly defined and readily justified (especially in economic terms). A local government planner highlighted the tendency for spatial planning regimes to focus on 'traditional planning issues', rather than emerging imperatives. This could be a factor leading to institutional path dependence:

There are so many competing interests within planning. It's a matter of balancing the likelihood of potential risk with the resources it would take and trying to find a balance between the two. We wouldn't want to go over the top, considering all the other competing interests. Planning for the effects of climate change is important but not extremely important and not above other interests. Planning is always about balance, so to say that adapting to climate change is the key thing – I wouldn't say that. We always have other things to balance that against. [IR5]

Another possible reason is that planning agendas may be 'hijacked' by external interests. Respondent IR1, now a professor of urban management in Australia, noted the potential for stakeholder lobbies to perpetuate path dependence within spatial planning, thereby reducing the potential for developing adaptive responses to climate change:

I get concerned with the language of stakeholders because it's too often used as a cover for the lobbies that have taken control of the planning process and in a sense re-situated [sic] it away from a more participatory or democratic process. Too much of planning at the stakeholder level is a problem – it ends up being about business as usual.

Path dependence is in part a regrettable outcome of the broad but ambiguous definition of green infrastructure. The interviews with practitioners confirm that adhering to existing systems without creating new ones is intentional. For instance, respondent IR3, a private sector planner from Ireland, suggested that:

Climate change will impact on plan-making and we have to take it very seriously. The starting point is to build that [climate adaptation] into the existing statutory plan-making process. The last thing that the plan-making system needs is another level in the hierarchy of plans.

More importantly, this respondent also indicated that using a multiple rationales approach to encourage spatial planning would not constitute a significant re-orientation of planning practice:

Planning should promote planting and the use of green areas because it is probably the most important environmental aspect of design. You're not changing the planning agenda, only its priorities.

This shows how the framing of urban green-space as multifunctional infrastructure can potentially stifle institutional innovation, thus perpetuating a 'business-as usual' model, which is ill-equipped to deal with the 'wicked' problem of climate change.

Based on these findings, we now offer a conceptual model that may help to focus future research efforts on better understanding path-dependence and institutional inertia in green infrastructure planning.

6. Discussion: toward a revised conceptual model of green infrastructure for climate adaptation

Our earlier review shows that much of the green infrastructure literature to date has focused on the biophysical aspects of how parks, street trees, green pavements and vegetative interventions might be used to bolster the resilience of built environments to climate change over longer timeframes. As we noted in our review, the scholarly literature points to a broad set of factors that delimit the utility of green infrastructure for improving cities generally, and for climate change adaptation specifically. Although several

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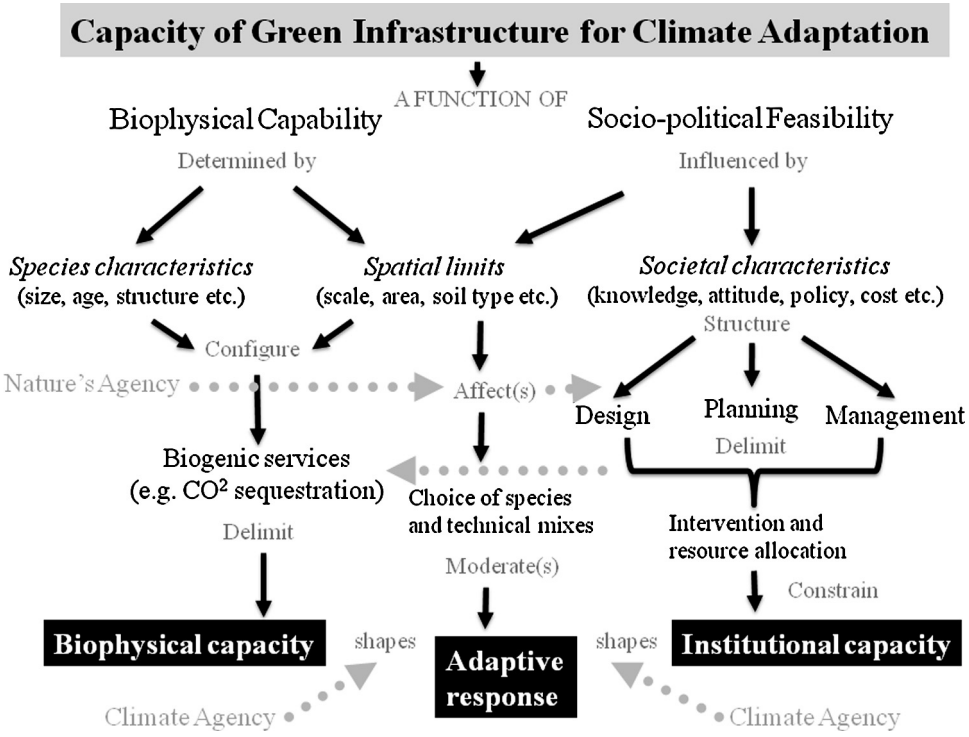

Fig. 1. Capacity of green infrastructure for climate adaptation.

of these factors were conceptualized by Byrne and Yang (2009), their model misses some important considerations. It is useful to concisely review these factors in the context of an alternative model that we propose here.

In our conceptual model (Fig. 1), we account for the biophysical capacity of green infrastructure for adapting cities to climate change. Since Byrne and Yang (2009) published their paper, a body of literature has emerged that empirically investigates many of these factors. They include: Scale of the area available for greening (e.g. a rooftop vs. a city block) (Andersson et al., 2014); history of site contamination (e.g. brownfield), soil compaction, drainage problems or other issues that might impede vegetation growth (Howard, Dubay, & Daniels, 2013); structural engineering and geological concerns (e.g. roof strength or slope stability) (Mell, 2013); and the climatic zone in which a city is located (i.e. temperature, precipitation, wind effects) (Pataki, Carreiro, et al., 2011). The choice of vegetation to be used is important too, including its structure, growth form and tolerance limits. For instance, groundcovers will have different water, light, nutrient, temperature and root-mass needs compared to broad-leaf, large woody canopy species (Pataki, Carreiro, et al., 2011; Pataki, McCarthy, Litvak, & Pincetl, 2011). Different types of vegetation will grow at different rates, will have varying levels of disease resistance, and different capacities to provide biogenic services (e.g. sequestering carbon, filtering water, lowering ambient temperatures) (Farrugia, Hudson, & McCulloch, 2013). Some species will also be more tolerant than others to the modified soil types found in cities, including soil porosity, oxygen levels, organic matter, compaction, pH, moisture, depth (Jim, 2011; Tian & Jim, 2011). And some species will interfere less with underground electricity, sewerage and telecommunication infrastructure, making them better suited for urban greening (Jim, 2003).

Much of the green infrastructure literature has been attentive to these functional aspects, which are largely technical issues that can be overcome through careful site selection and management and wise species selection; though much work remains to be done on refining our knowledge about these matters (Bendict & McMahon, 2006; Hostetler, Allen, & Meurk, 2011; Pataki, Carreiro, et al., 2011).

Socio-political factors on the other hand, are somewhat more complex and have direct institutional implications. These factors are less readily resolved through technical planning and management approaches, and are less understood. Fewer studies have addressed such considerations. Socio-political factors include: governance concerns (e.g. the political context in which planning decisions are made and the planning system that constrains development options) (Young & McPherson, 2013); management issues (i.e. the budget available for citywide greening and maintenance of green assets) (Netusil, Levin, Shandas, & Hart, 2014); urban morphology restrictions (past decisions will have already constrained areas available for greening) (Cameron et al., 2012); and public involvement challenges (people will value greening depending on how they perceive and use these spaces or are affected by them) (Davison & Kirkpatrick, 2014). As we show in our model, these concerns combine to describe the socio-political feasibility of green infrastructure as a climate adaptation measure.

The role of institutions is also vitally important. One of the key challenges for the uptake of green infrastructure, as we have seen from the interviews with planning practitioners, is overcoming the path-dependence of existing planning institutions. Multiple rationales exist for urban greening, and some of these are in competition with each other. As we show in our revised model, there can be difficulties in coordinating the interactions of different government agencies operating across different scales with a stake in green infrastructure decision-making. Indeed, Pincetl (2010, p. 43) has argued, the widespread adoption of green infrastructure as part of an everyday land use planning activity is dependent upon: "the organization of existing departments and agencies, urban morphology and land use, public interest, acceptance and participation, and potential unanticipated consequences".

For example, a decision to use a road easement for urban greening may entail a multitude of meetings with representatives from

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city government, power utilities, transport departments, telecommunication agencies and planning departments (Gill et al., 2007). Moreover, there will also need to be coordination and meetings within these agencies. And the sharing of revenue for such activities and effective accounting for money saved is a tricky process that has yet to be resolved (Pincetl, 2010). The uptake of best practice may also depend upon the dissemination of new ideas, clear communication strategies, effective demonstration projects and the ability to creatively overcome the inertia that may be present in planning systems. But we currently lack research into these important potential barriers and enablers to green infrastructure.

A second area that has thus far been neglected in green infrastructure research, and which was omitted from Byrne and Yang's (2009) conceptual model, is what might be called 'the agency of nature' (Hulme, 2010). Agency here refers the way that the non-human bio-physical environment is not an inert backdrop for human activities; rather it has the ability to act upon humans in profound ways – through disease, natural disasters, severe weather events, and the like. The failure to account for nature's agency is an important oversight for two reasons. First, it means that green infrastructure research to date has tended to neglect the actions of climate on human settlements in an explicit way, and to factor that into deliberations about effective greening strategies. In more specific terms, if the climate in a city is going to shift – becoming hotter and drier or cooler and wetter for example, then the species chosen in an urban greening project will need to be suitable for the future conditions, not just those prevailing today. Climate thus becomes an *active agent* in shaping decision-making – and deserves a place at the decision-making table.

The second failure to account for nature's agency centers on the fact that green infrastructure itself, as Pincetl (2010) cogently observes, is alive. This means green infrastructure also has agency – thriving or dying, potentially uplifting pavements, overshadowing buildings, damaging water pipes and even killing people through the shedding of large limbs during storms or through the inhalation of pollen and subsequent asthma attacks (Byrne, Lo, & Yang, 2015; Roy et al., 2012). Yet much of the green infrastructure literature reduces decision-making about greening to simply implementing 'a good idea' or evaluating a set of cost-benefit parameters that can be readily aggregated on a ledger. In reality the situation is a lot more complex and messy. As we show in our model, decision-making must account for prevailing political sentiments, fiscal pressures, the attitudes, values and training of bureaucracies and the perceptions, needs and concerns of local residents (Davison & Kirkpatrick, 2014). These socio-political factors have to be taken into account in assessing the (institutional) capacity for using green infrastructure for adapting cities to climate change. Understanding the capacity of green infrastructure as a climate adaptive response requires a recognitions of the interplay between biophysical, socio-cultural and institutional factors, as we have done here, thus illuminating potential policy deadlocks, offering fertile terrain for future research.

7. Conclusions and future research directions

In this paper, we have argued that green infrastructure could play a potentially important role in adapting to some anticipated impacts of climate change. Such impacts represent a different sort of challenge for green-space planning, acting as a new agent driving institutional change. Our research has provided four key findings. (i) The green infrastructure literature has largely overlooked the existence of path dependence as a barrier to institutional change. (ii) Our research indicates that planners and policy makers may be confused about what constitutes green infrastructure. This may contribute to inaction on climate change adaptation because it muddies existing green-space programs and initiatives. More broadly, it may feed institutional path-dependency and could potentially stifle institutional innovation. Our seven interviewees, who all have extensive professional experience of urban planning in England and Ireland, confirmed path dependency is a key institutional barrier.

(iii) Conceptually, the idea of green infrastructure can be understood as a source of a wide range of benefits, including the climate-related biophysical ones. The emphasis on multiple benefits is a core element of the 'capital' concept of green infrastructure. This concept, however, does not recognize the agency of climate change, nor does it indicate explicit content about new institutional arrangements. Agency must be factored into decision-making if green infrastructure interventions are to be effective (iv) Agency and institutional dimensions should be key foci of efforts to better understand the role of green infrastructure in adapting cities to climate change. For instance, socio-political factors, which ultimately define institutional environments and are central to risk governance, are often missing from the discussion of green infrastructure. Insights from our interviews with urban planners suggest that socio-political factors may constitute key barriers to the provision of green infrastructure. Tendencies for path dependence may consequently persist, and affect the institutional capacity for adopting green infrastructure for climate adaptation.

This paper has given particular attention to the institutional dimensions of green infrastructure for climate change adaptation. Recognizing the limitations of existing research, we have devised a conceptual model that departs from earlier conceptualizations by emphasizing the importance of the institutional environment in which green infrastructure is planned and managed for adapting cities to climate change, and the agency of both climate change and greenery. We regard our conceptual model as a starting point and call for further research into the role of agency and institutions in precluding or mainstreaming climate adaptation imperatives in the provision of green infrastructure. We are not calling for a paradigm shift – at least not yet. Rather we intend that this paper opens a broader discussion, and we recognize that much more work needs to be done.

Our findings suggest that there are some potentially fruitful directions for future research, across national borders, transcending built environment scales (from a street verge to a conurbation) and across disciplinary boundaries. For instance, future research enquiries may answer questions such as: "Do green-space and green infrastructure play different roles in climate change adaptation, and if so, what are the conceptual differences?"; "How do urban planners and green-space managers respond to climate change risks and the opportunities it offers for urban greening?"; and "How do they deal with the institutional issues (e.g. cross-departmental coordination) arising from using green infrastructure as a climate change adaptation strategy?". Answering these questions may help move us toward a future where using green infrastructure is a commonplace climate adaptation strategy.

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