W3 | Work in a Warming World

Working Paper # 2015-01

Socio-Material Systems and Sustainability Transitions: Integrating Climate Change into Transport Infrastructure in Ontario, Canada

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Abstract

Our infrastructure threatens us with carbon lock-in, unless we do something about it now. This is because infrastructure lasts for such a long-time, meaning that anything we build or rebuild now will be with us until well past mid-century – even until the end of the century in some cases. If we do not integrate climate change, especially adaptation, into our infrastructure now we will be left with infrastructure designed around unsustainable socio-technical systems (e.g. combustion engines, suburbanization, etc.). In order to understand the sustainable infrastructure transitions we need, however, means that we have to adapt existing analytical perspectives in order to properly address infrastructural materialities (e.g. physical form, environmental context, etc.). In this paper I develop the concept of *socio-material systems* in order to do this. I apply the concept by examining three transport infrastructure projects in Ontario, Canada.

Acknowledgements

This study is part of the Work in a Warming World Project (W3), a SSHRC-CURA research programme

The author appreciates the financial support received for this project through a Social Sciences and Humanities Research Council of Canada, Community-University Research Alliance (SSHRC-CURA) research grant. W3 is a five-year research project to address the challenge of climate change for Canadian employment and work carried out under the direction of Carla Lipsig-Mummé at York University. The author would also like to thank Dalton Wudrich for his invaluable research assistance during the research project, and Bernard Ennis and Catherine Shearer-Kudel of OCEPP/PEO for their advice and suggestions at different points of the project. All errors remain my own.

Introduction

Extreme weather events have brought considerable attention to bear on the potential and actual impacts of climate change on our cities and communities. These range from the destruction caused to the eastern seaboard of the United States by Hurricane Sandy in 2012 through the devastating floods in Calgary in 2013 to the more recent snowstorms in eastern Canada and US in early 2015. Whether or not these are the result of climate change is beside the point; what they have shown the world are the significant effects that extreme weather events can have. Such weather events have been increasing in frequency and damage over the last few years, suggesting that worse is to come. While the human cost of these events is obviously appalling, the socio-economic costs have also started to attract the attention of publics, politicians, policy-makers, the insurance industry, professional groups, and others (Sturm and Oh 2010).

Extreme weather events and their consequences provide an important illustration of the drive behind the search for *sustainability transitions* to a low-carbon society – an area of increasing academic interest in the last decade or so (e.g. Geels 2002, 2004; Geels and Schot 2007; Shove and Walker 2007; Frantzeskaki et al. 2012; Lawhon and Murphy 2012; McCormick et al. 2013; Tyfield 2014). How these sustainability transitions are meant to happen is still contested, but one area where there is a definite and urgent need for debate – and, even more urgently, for action – is the adaptation of core infrastructure (e.g. roads, transit, energy, water, etc.) to changing weather and climate patterns (Monstadt 2009; Franyzeskaki and Loorbach 2010; Markard 2010; Bulkeley et al. 2013). As noted in a recent OECD report, countries like Canada, and many others around the world, face a growing infrastructure crisis as the need for both new infrastructure and the replacement of old infrastructure rises (Corfee-Morlot et al. 2012). Consequently, there is a major opportunity – and risk – now to integrate climate change into the planning, design, construction and maintenance of new and old infrastructure.

The key problem facing many countries is that infrastructure has a long lifespan, which means any developments now are likely to be with us for several decades to come; moreover, it is not clear whether or how climate change is being integrated into new or rebuilt infrastructure. Critically, such infrastructure has to be thought of as *socio-technical systems* in which physical components are bound up with societal components, meaning that any transition is complicated by interacting social and material opportunities and limitations. Without action now, for example, infrastructure developments are going to reinforce our societal 'carbon lock-in' (Unruh 2000), especially through the failure to integrate climate change mitigation and adaptation strategies in infrastructure planning, design and development (e.g. promoting public transit and discouraging automobile reliance). The threat of infrastructure lock-in could be profound, in that it could limit our capacity to develop or choose particular sustainability transition pathways. It is vital, in this context, that both mitigation *and* adaptation are integrated in infrastructure developments since there is a strong possibility that global mitigation efforts will be ineffective.

In light of these concerns, it is necessary to understand whether and how climate change is being integrated into infrastructure development, or what I conceptually define as *sustainable infrastructure transitions*. My aim in this paper is to ask three key questions: (1) How should we conceptualize sustainable infrastructure? (2) What are the examples and implications of sustainable infrastructure transitions? And (3) what are the barriers to these transitions? In order to answer these questions I first develop the analytical concepts of *socio-material systems* and *sustainable infrastructure transition* by drawing on the existing literature on sustainability transitions, infrastructure studies and socio-technical systems. I then use these concepts to analyze empirical material from a research project I carried out in Ontario, Canada in 2012 and 2013, by looking at the integration of climate change in three transport infrastructure projects at different stages of their life cycles.

Socio-material Systems and Sustainability Transitions

As Shove and Walker (2007) note, recent sustainability transitions literature owes a clear debt to earlier work on large-scale, technical systems pioneered by Hughes (1983, 1987), although the later literature has a greater emphasis on social aspects. In particular, work by Geels (2002, 2004), Geels and Schot (2007) and others on *multi-level* models of socio-technical regimes, innovation governance and sustainability transition are underpinned by a conceptual framework in which there is a co-evolutionary and inter-dependent dynamic between social and technical components. Here, scholars concerned of sustainability transitions as constituted by social and technical components changing in relation to each other, often in complex and uncertain ways.

As Geels (2002) outlines, this *multi-level perspective* (MLP), as it is known, entails different scales of interaction – defined as ‘landscape’, ‘regime’ and ‘niche’ – between different social and technical elements (e.g. science, technology, users, government). Moreover, in this framework existing and stable socio-technical regimes (e.g. petroleum-powered automobile) are dynamic in that emerging niche innovations (e.g. electric car) can enter, align with and then change existing regime (endogenous pressures), or the broader landscape (exogenous pressures) can put pressure on regimes to change (e.g. climate change policy) (ibid.; also Geels and Schot 2007). According to Tyfield (2014: 586), the strength of this MLP framework is that it avoids the tendency, especially in policy circles, to “focus on new technologies to the exclusion of both the irreducible social factors and the systemic nature of stabilised socio-technical settlements and their transition”. Thus one of the key intellectual insights provided by the sustainability transitions literature is that climate change, and other environmental issues, cannot be resolved by technology alone; societal change is also necessary.

This raises a series of issues with how to promote sustainability transitions in core infrastructure developments (e.g. roads, transit, utilities, etc.), the epitome of techno-material artefacts; as Monstadt (2009: 1926) argues, “Key socioecological problems like climate change, air and water pollution, resource shortages, etc. can thus only be tackled through the transition of existing infrastructure”. Within the sustainability transitions literature infrastructure is becoming an increasingly important topic for a number of reasons. While the work of Geels (2002) and others on the MLP has proved fruitful in some areas, it does have gaps. Some, like Shove and Walker (2007), highlight how notions of sustainability transition – themselves contested and contestable – are frequently aligned with resource and energy efficiencies in infrastructure development, rather than wholesale transformations of infrastructure and its social purpose. Others, like Tyfield (2014: 594), note the clear power dimensions to any socio-technical transition, emphasizing that infrastructure is but one part of the "*knowledge-power technologies* that specifically enable or constrain". Finally, the likes of Truffer and Coenen (2012) highlight the general point that some transitions involve long-term shifts and policy changes – an obvious case being infrastructure development – necessitating a different, more reflexive approach to transition. While literature on transition management (e.g. Kemp and Rotmans 2009) might represent one way to deal with such longevity issues, it has "been accused of adopting an overly linear and mechanistic view on the politics of transformation, power and discourse" (Truffer and Coenen 2012: 6). In contrast, there is need for a careful conceptualization of infrastructure in order to take account of its material particularities, such as its relatively stable, physical longevity.

Infrastructure has been conceptualized in a number of ways: (a) as a network (Graham and Marvin 2001); (b) as a system (Frantzeskaki and Loorbach 2010); and (c) as an embedded and hidden set of processes (Star 1999). First, geographers and planners like Graham and Marvin (2001) have argued that infrastructure is best thought of as a network bringing together the production and consumption of resources with (particular) geographical settlements (e.g. cities). For example, at the urban scale networked infrastructure plays an important role in "shaping resource use and urban development" according to Bulkeley et al. (2011). Second, scholars in innovation studies, broadly conceived, like Johnsson (2000, 2005) and Frantzeskaki and Loorbach (2010) argue that infrastructure is better thought of as a bounded system, each infrastructure separate from the others and representing individual 'infra-systems' – that is, the physical artefact *and* institutional arrangements in which it sits. While this might involve networks, it also necessitates the incorporation of flows, links and other connections into the conceptual framework. Finally, science and technology studies (STS) scholars like Susan Leigh Star (1999) stress the embeddedness, transparency, scope, invisibility, and so on, of infrastructure. Moreover, Star highlights the problems of incompatibility, recalcitrance and bottlenecks in this infrastructure.

What this discussion of infrastructure should illustrate is that it can be thought of in a dual sense when it comes to the sustainability transitions literature (e.g. Geels 2002, 2004). According to Frank Geels, socio-technical systems are characterized as a diverse array of elements "including technology, regulations, user practices and markets, cultural meanings, infrastructure, maintenance networks and supply networks" (quoted in Lawhon and Murphy 2012: 357). Of these, infrastructure stands out as the one element with particular *materiality* characteristics (Monstadt 2009). On the one hand, it is positioned as one element in a socio-technical regime; on the other hand, it can be thought of as part of the (physical) landscape in which regimes operate, evolve and change. Infrastructure is, then, both part of a socio-technical system *and* a constitutive part of that systems' environmental context (i.e. landscape). However, as Furlong (2010: 465) highlights, current debates about socio-technical systems rarely discuss this latter aspect, or what she calls the "production of space and nature" – in other terms, the fact that infrastructure is the "central interface between nature and society" (Monstadt 2009: 1935).

While people like Geels (2002) position infrastructure inside the socio-technical regime, it is critical – analytically-speaking – to examine the *materialities* of this infrastructure (see Mitchell 2011; Birch and Calvert 2015); that is, its constitutive role as part of the landscape. I follow the work of Mitchell (2011) and others in conceptualizing materiality – or, the physical characteristics of an artefact – as both shaping and being shaped by socio-technical relations (Monstadt 2009; Markard 2010). Two examples will have to suffice to illustrate what I mean here. First, infrastructure's physical lifespan means that it changes at a very different pace to other regime elements (e.g. buildings last several decades if not whole centuries), if we accept Geels' (2002) characterization. This makes it difficult to analyze the sustainability transitions relating to infrastructure from the MLP lens without focusing on long-term, historical change; while this might be conceptually possible, it is not adequate for analyzing current, urgent and future policy issues (e.g. future responses to climate change). Second, infrastructure has a materiality to it that differs from the other regime elements highlighted by Geels (2002); for example, Star (1999) and others stress the embeddedness, scope and invisibility of infrastructure. It represents an assumed background and environment in which social actors operate. Consequently, it is more apt to talk of *socio-material systems* rather than socio-technical ones – see Birch (2013) – when discussing sustainability transitions. This conceptualization helps to identify and understand the *socio-material* limitations inherent to infrastructure when it comes to sustainability transitions; for example, bio-physical limits (e.g. size, weight), environmental limits (e.g. precipitation, flooding), life-span limits (e.g. adaptability, resilience, redundancy), life cycle limits (e.g. decay, renewal, maintenance), etc.

In light of this theoretical discussion, I conceptualize sustainable infrastructure and their transitions as follows. It is systemic, involving social, technical and material components; as a result *sustainable infrastructure transitions* are constituted by the interaction of these components, which includes, but is not limited to, decisions about the location and distribution of infrastructure – for example, questions about who benefits from the physical artefact (e.g. road), who is impacted by flows (e.g. traffic, congestion, commuting times), who is included and excluded by new linkages (e.g. employment access, resource access) – and broader decisions and choices about lifestyles, population flows and densities, and urban and regional planning – for example, suburbanization versus densification of urban developments. Moreover, sustainable infrastructure transitions are constituted by interacting technical elements, including: codes and standards, technical and legal specifications, cost efficiencies, and so on. For example, infrastructure has to be delivered to certain specifications (e.g. building codes, development standards), which are implicitly tied to specific socio-economic options (e.g. public spending versus public-private partnerships) and materialities (e.g. risks of collapse, deterioration, resilience, etc.). These system components are not only inter-dependent – and constitute one another – they also necessitate understanding a diverse array of knowledges (e.g. engineering), practices (e.g. design, construction), discourses (e.g. sustainability) and, critically, materialities (e.g. deterioration, precipitation) in the operations and interactions of the overall system. Consequently, in order to analyze sustainable infrastructure transitions we have to include the materiality of the infrastructure itself as a part of any analytical perspective; for example, where is infrastructure sited, what is it made of, how its physical components interact with the environmental context, and so on.

Research Design and Methods

This paper draws on empirical findings from a research project carried out in 2012 and 2013 on sustainable infrastructure in Ontario, Canada. The project was specifically concerned with identifying whether and how climate change was integrated in the planning, design, construction and renewal of transport infrastructure in Ontario, and what implications this had for the engineering profession. It involved working with the Ontario Centre for Public Policy and Engineering (OCEPP), and the policy wing of Professional Engineers Ontario (PEO) which is the licensing and regulatory body of the engineering profession in Ontario.

The project had four main research objectives: first, to identify the impacts of climate change on infrastructure planning, design, construction and renewal; second, to identify how climate change is being integrated into infrastructure planning, design, construction and renewal; third, to identify the barriers to this integration; and, fourth, to identify the implications of this integration for the engineering profession. In this paper I focus on the first three research objectives since I have reported the findings on the implications for engineers elsewhere (Birch and Wudrich 2013, 2015).

In order to address these three objectives, the project involved a two-stage methodological approach. First, using secondary policy literature I sought to map out the main policy strategies and activities of the municipal, provincial and federal governments in Ontario and Canada. Second, using in-depth interviews with key informants I sought to identify how climate change was being integrated in infrastructure projects and the barriers to this integration. My research assistant and I interviewed a total of 30 people, mostly engineers but also ancillary professionals (e.g. architects) and policy-makers (e.g. city officials, standards developers).

Methodologically, the unit of analysis was the engineering profession associated with transport infrastructure. I made this decision for three reasons: first, the research was concerned with the implications of climate change and sustainable infrastructure needs for the engineering profession (Birch and Wudrich 2015); second, the conceptual framing of sustainable infrastructure as a socio-material system (see above) meant I was interested in more than just the technical or physical artefact (e.g. road, bridge, railway), I also wanted to be able to identify the knowledges, practices and discourses that inform its development; and, third, infrastructure has a life-cycle (e.g. planning, construction, use, renewal) that necessitates taking a multi-project approach in order to understand the varied ways that climate change is integrated in the present (e.g. in planning, in design, in construction, in use), rather than look historically at infrastructure when climate change was a lesser concern. Consequently, I chose three transport projects at different points in the life-cycle: planning and design; construction; and renewal/repair. This enabled me to analyze how climate change is integrated (or not) at different points in the life-cycle through the work of engineers. I chose transport infrastructure because it is implicated in both climate change mitigation (e.g. emissions reductions) and adaptation (e.g. flood risks).

Sustainable Infrastructure Transitions in Ontario: Integrating Climate Change in Transport Infrastructure

4.1 Background: Climate Change Policy in Canada and Ontario

Neither Canada nor the Province of Ontario are leaders in climate change policy, whether mitigation or adaptation policy (Mees and Driessen 2011). That being said, there has been and still is policy interest in this area at both the federal and provincial level. The evolution of policy, however, reveals some of the distinct cleavages in Canada's broader political environment. Focusing on the concept of sustainable infrastructure – that is, the integration of climate change in core infrastructure – helped to identify a range of policy strategies and their implementation (e.g. in standards, regulations, etc.) in these jurisdictions since (at least) the mid-2000s. Here I am using the term “policy” in its broadest sense to refer to an array of social actors who influence policy-making (e.g. business, trade associations, NGOs, professional associations, community groups, etc.); thus I mean more than government or the state.

Policy strategies focusing on climate change and infrastructure are relatively new in Canada (Birch and Wudrich 2015). Two early examples at the federal level are Infrastructure Canada's 2006 literature review, *Adapting Infrastructure to Climate Change in Canada's Cities and Communities*, and Natural Resources Canada's 2007 report, *From Impacts to Adaptation: Canada in a Changing Climate* (Infrastructure Canada 2006; NRC 2007). Both policy strategies emphasized the need for the federal government to integrate climate change into infrastructure planning and decision-making. Other national-scale and non- or quasi-governmental organizations have produced similarly-framed policy strategies since: for example, Engineers Canada produced a report in 2008 called *Adapting to Climate Change*; the now-defunct National Roundtable on the Environment and Economy (NRTEE) produced a report in 2009 called *True North: Adapting Infrastructure to Climate Change in Northern Canada* (NRTEE 2009); and the Federation of Canadian Municipalities (FCM) produced reports in 2011 and 2012 called *Building Canada's Green Economy* and *The Road to Jobs and Growth* (FCM 2011, 2012).

At the national-scale, climate change policy strategies are increasingly produced by non- or quasi-governmental organizations as a consequence of the political position of the Conservative federal government which first came to power in 2006. This Conservative government has taken a strong anti-climate change stance (Winfield 2012), leaving other policy-makers to champion specific strategies.

The federal political situation has resulted in a rescaling of climate change policy downwards, evident in the Province of Ontario. The Provincial Government has made several policy statements designed to promote a series of climate change strategies and policies. Examples include: the establishment of an Expert Panel on Climate Change Adaptation in 2007; this Expert Panel's 2009 report called *Adapting to Climate Change in Ontario*; the creation of a climate change action plan in 2011; and the more recent 2015 climate change consultation (MOECC 2015). Similar initiatives have been taken at the municipal level as well, with Toronto representing a key Canadian example. The City of Toronto produced a Climate Change, Clean Air and Sustainable Energy Action Plan in 2007 and a Climate Change Adaptation Strategy in 2008 (MacLeod 2011).

What is evident from these activities is that as the federal government has retreated from climate change policy, provincial and municipal governments have sought to develop their own strategies and implement them despite federal indifference. Examples of the latter include: the 2010 introduction by Toronto of the Toronto Green Standard, which is a list of development performance measures to promote sustainability; Ontario's 2011 capital infrastructure plan that incorporates climate change into infrastructure development and asset management; and Ontario's 2014 Provincial Policy Statement setting out the requirement to consider the implications of changing climates (Birch and Wudrich 2015).

4.2 Sustainable Infrastructure as Socio-material System

The policy discussion above is meant to provide some context for the qualitative analysis next. In the following analysis I focus on three key issues around sustainable infrastructure transitions: first, the relationship between social and material components, which lead me to theorize it as a socio-material systems and not simply a socio-technical one; second, the forms of sustainable infrastructure transition happening in Ontario; and, third, the barriers to this transition.

The research findings show that the informants I interviewed conceived of sustainable infrastructure as more than a large, technical system (Hughes 1983, 1987). Engineers, for example, undertook development activities (e.g. planning, design, construction, etc.) from the perspective that infrastructure is both a social *and* material phenomena. This entailed a range of considerations from operational efficiencies and inter-dependencies – on the social side – to passive design and smart systems – on the material side. I discuss each of these in turn.

First, when it comes to the social-side, a number of informants highlighted the importance of the operational costs and efficiencies inherent in infrastructure use, especially in relation to buildings (e.g. subway stations). The representative of a concrete companies' trade association claimed that:

> "The cost of operating a building over the life of the structure uses so much more energy than the energy that we'd use to construct it, it dwarfs it ten to one" (Concrete 1, 2013).

As outlined in the theoretical discussion above, this point reflects the importance of considering the inter-dependence of the various components in infrastructure systems –

i.e. physical, social, technical, etc. (e.g. Frantzeskaki and Loorbach 2010). As the same informant commented:

> "...as soon as they [other informants] start talking about embodied energy, you can rest assured that they've missed the point. Because it's not really about embodied energy, it's about a system and how its overall objectives are achieved" (Concrete 1, 2013).

Similarly, a member of the Canadian Standards Association (CSA) pointed out that 80 percent of energy use happens during the operations phase of an infrastructure project, and not its planning, design or construction phases (CSA 1, 2013). With regards to the concept of sustainable infrastructure, these comments illustrate how the integration of climate change necessarily entails more than a simple change to physical form and function (e.g. resource efficiencies in construction). As much of the sustainability transitions and socio-technical systems literature stresses (e.g. Monstadt 2009; Bulkeley et al. 2014), the physical artefact is one element in a complex system – much of which is only evident in use. Infrastructure is an inter-dependent system not only in terms of the delivery of public services (e.g. social care, health care, emergency services, etc.). As a City of Toronto official explained:

> "...we've recognized the interdependency of infrastructure and we've done a whole study on identifying basic core functions that are necessary for maintaining the city of Toronto. And these core functions, they're not infrastructure, but they're actually services to people" (City of Toronto 1, 2013).

That being said, however, the materiality of infrastructure is important, both in terms of the physical state of infrastructure and its implications for supporting sustainability transitions.

Second, in relation to the material-side of infrastructure systems there was an emphasis on the importance of passive design or smart systems when integrating climate change into infrastructure. By this the informants meant engineering that incorporates 'natural' systems into planning, design and construction. Examples included: planning that is focused on "low impact development techniques, and this is all about managing storm water" (Ministry of Municipal Affairs and Housing 1, 2013); design that is "very cognisant of sun, wind, other elements in the locating of buildings" (Planning 1 and Planning 2, 2013); and construction that introduces air-conditioning "through airflow and the piston effect essentially from the subways" (Construction 6, 2013). As one engineer put it:

> "...how do we design the stations to integrate sustainability, how do we design the stations so that we can use natural processes for heating and for cooling; so, all that went into the design" (Construction 7, 2013).

And another put it in a similar fashion:

> "[In a subway station] you don't need air conditioning and you know we don't air condition our stations, so that will be something naturally, you know, that [uses]

> less power consumption and yet you give a better environment to the public or the passengers or the commuters” (Construction 9, 2013).

Similar comments were made about things like ‘natural lighting’, ‘natural heating’, ‘permeable paving’, and so on (e.g. Construction 2, 2013). All of these comments reflect the materiality of the physical artefact itself and not necessarily its social or technical components; critically, these materialities are very much implicated in the operation of the infrastructure as an inter-dependent or networked system (Graham and Marvin 2001; Bulkeley et al. 2011). As a result, this raises the question of how to incorporate these materialities into existing theoretical discussions about sustainability transitions; e.g. where do they sit in the MLP framework? Are they part of the landscape or regime, or even niche? It is not possible to answer these questions fully here, but I want to stress that another analytical layer is required in this literature, as I outline next.

Finally, sustainable infrastructure *transitions* are bound up with both these social and material elements of infrastructure as a socio-material system. It is important to stress the analytical, and practical, importance of materialities to sustainable infrastructure transitions because they are little covered in the literature at present (e.g. Geels 2002; cf. Furlong 2010). As Mitchell (2011) argues, these materialities are deeply political, in that they both enable and constrain particular forms of social, political and economic action (see Birch and Calvert 2015). For example, planning can encourage or discourage physical density (e.g. suburbs versus high rises); this density has direct implications for the political viability of certain transit systems (e.g. ridership numbers); which then reinforces the former planning decisions (e.g. lack of public transit is likely to reinforce the mobility needs for cars, which then reinforces social preferences for suburban living, and so on). As such, these materialities could be ascribed to the landscape in the MLP model (e.g. Geels 2004), but they represent more than the conditions under which sustainability transitions happen. They are an integral part of those transitions, shaping their very possibility and the parameters in which they can happen. Moreover, they involve contestable decisions and choices; for example, a shift from planning, designing and constructing road infrastructure to public transit infrastructure is a major and contested societal challenge.

4.3 Sustainable Infrastructure Transitions in Ontario, Canada

Having outlined why it is important to analyze infrastructure – sustainable or otherwise – as a socio-material system, I want to show how climate change is being integrated – and how it is not – in transport infrastructure in the Province of Ontario. I start with examples of this integration before discussing some of the key barriers to its integration. These examples are drawn from the interviews I carried out with engineers and other professionals involved in the planning, design, construction and renewal of three transport infrastructure projects.

4.3.1 Planning, Construction and Maintenance of Sustainable Infrastructure

In order to undertake this analysis, I take a life cycle view of infrastructure (Frantzeskaki and Loorbach 2010); that is, I start by focusing on *planning and design*, then consider *construction*, and finally *maintenance and renewal*. I do this for two main reasons: (a) in order to reflect better the social, technical and material characteristics of infrastructure (e.g. financing, codes and standards, lifespans, etc.); and (b), because it enables me to consider a range of contemporary issues without relying on historical analysis, which is not attuned to current concerns and issues (e.g. future climate change).

First, climate change is increasingly – and most obviously in many ways – integrated at the planning and design stages in infrastructure projects; for example, we include environmental impact assessment in this phase. These are inherently political processes (e.g. planning, assessment, etc.) and do not fit neatly into the MLP framework as outlined by Geels (2002) and others, being too broad to reflect *specific* socio-technical regimes. Indeed, they reflect the need to incorporate more fully the political (or power) processes in the analysis of sustainability transitions, as highlighted by several academics (e.g. Walker and Shove 2007; Monstadt 2009; Bulkeley et al. 2013; Tyfield 2014). Critically, the environmental – i.e. material – impacts of climate change (e.g. flooding) are used to politically legitimate new forms of assessment, planning and design (City of Toronto official 1, 2013); in this sense, the materialities at play provide the opening for the introduction of new social and technical components into the regime itself. For example, an Engineers Canada representative pointed out that there are a number of new or emerging assessment and planning tools created by diverse stakeholders across Canada:

> “We've had lots of flooding of course...So sewer backups causing huge issues there and the insurance industry has developed a tool. A municipal risk assessment tool that assesses the risks of sewer backup...most provinces have a climate change action plan at the provincial level and then that goes down into the municipal, local action plans” (Engineers Canada 1, 2013).

Other informants, however, highlight the fact that assessment, planning and design are still largely the preserve of more specific technical processes, including established building code requirements and environmental impact assessments. For example, one engineer suggested that:

> “...the preliminary design or ultimate design has to be by legislation, acknowledge those and incorporate or address them or mitigate those concerns within the design. So inasmuch as that process has been set up, it's a way in which to try to influence the design in accordance to what implications on climate change it could have” (Design 3, 2013).

Consequently, it is important to keep the specific technical processes within sight in any analysis, as highlighted in the MLP literature (e.g. Geels 2004). That being said and as Tyfield (2014) argues, these processes are still sometimes better thought of, analytically-speaking at least, as part of the landscape; that is, the broader social, political and economic pressures that condition a specific socio-technical regime. The reason for this is that legislation, codes, standards and so on are often barriers to integrating climate change in infrastructure, which is happening *despite* and not because of these conditions – I return to this issue below.

Second, while climate change is more obvious at the planning and design stages, there are numerous examples of how it is being integrated in the construction stage too. Here, it is possible to identify what Geels (2002, 2004) and others conceptualize as specific socio-technical regimes. Informants offered a number of specific examples during their interviews, including: larger runoff, culvert and sewer systems to cope with increased or extreme precipitation; traffic signalling with electronic-cooling controller boxes to avoid over-heating; new asphalt mixes designed to tolerate heat and cold; material recycling (e.g. asphalt, steel, wood, etc.); permeable surfaces; 'green infrastructure' like tree planting, green roofs, bioswales, etc. to reduce heat island effects, increase water absorption, avoid dangerous water runoff, etc.; and natural ventilation, lighting, heating, etc. in buildings.

Informants also stressed more systemic examples like "adaptive" and "resilient" infrastructure and planning (City of Toronto 2, 2013). By adaptability and resilience, informants meant a number of things. On the one hand, some stressed the importance of connecting and integrating future planning needs and infrastructure construction:

> "One of the other things that goes along with that is they're also designed to support future development around them. So there's been that connection between design and planning...the design of sort of the plazas or the access to the station or they're suited to a future development road network or development plan" (Construction 5, 2013).

There is an obvious inter-dependence along the infrastructure life cycle, in this sense, as stressed in the literature on infra-systems (e.g. Frantzeskaki and Loorbach 2010). That is, infrastructure is meant to fit life cycle needs of users. However, on the other hand, several informants were also more reflexive, highlighting the important interplay between social and material components in future planning, suggesting that such planning, and the design that follows, is largely guesswork – in that no-one *knows* (i.e. discovers) where future demand for public transit will be – and that construction decisions and choices actually help to shape that future demand through the 'retrofitting' of cities (Construction 5, 2013). As one design engineer put it:

> "So on these sorts of projects you get not just into an element of, you know, pure...shall we say transit design in just the pure sense; as you come to larger projects which are more about city building, right, and so then therefore we start looking a bit more strategically" (Design 4, 2013).

They went on to note that:

> "And cities are dynamic and they're always evolving so again a lot of the decisions relate around to the maturity of a city because that sort of dictates somewhat the issues of serving versus shaping".

The point I want to emphasize here is that integrating climate change at the construction stage is not simply a response to planning knowledge, practices and standards – e.g. ridership needs and existing demand in the case of transit infrastructure. Rather, construction, which entails a set of socio-material choices and decisions, involves the shaping and reshaping of socio-technical regimes *and* landscapes, whether intended or not. In relation to this point, other informants talked about things like: 'transit oriented development' (Construction 5, 2013); 'building higher densities' (Construction 8, 2013); 'intensification' (Design 2, 2013); and so on. Hence, why it is a number of scholars who think it critical to include geography in any discussion of sustainability transitions (e.g. Coenen et al. 2012; Lawhon and Murphy 2012; Truffer and Coenen 2012).

Finally, the renewal stage is an increasingly important phase at which to integrate climate change, especially since so much infrastructure is in need of renewal or rebuilding in Canada and the world (Corfee-Morlot et al. 2012). As one engineer put it:

> "Replacing like-for-like has future cost implications. Under-designing infrastructure can result in the accelerated deterioration or failure of the infrastructure; much higher future costs. We are setting up future generations with better assets that are more resilient to the impacts of climate change" (Renewal 2, 2013).

The emphasis here, notably, has been on adaptation and not mitigation. The drivers of this renewal in Ontario, and presumably elsewhere, are: (a) the shift from mitigation to adaptation strategies as responsibility has shifted downwards from national to provincial and municipal scales of government (i.e. state-led); and (b) rising insurance costs (i.e. market-led). First, the increasing importance of adaptation strategies was evident in new policy concerns and strategies undertaken at the local government level by public or quasi-public sector actors. An Engineers Canada official pointed out that adaptation is "very much a local community based thing, it's not like mitigation" (Engineers Canada 1, 2013). Similarly, a Federation of Canadian Municipalities official noted that adaptation was important in "the communities particularly that keep getting hit by similar events repeatedly", including "extreme storm events, extreme rainfall events, the basement flooding" (FCM 2, 2013). These sorts of events have become a major focus of the City of Toronto, for example, according to one official:

> "Now there's a thing called the basement flooding program and the wet weather flow master plan. Those were undertaken because engineers and staff at Toronto Water perceived more frequent extreme weather and complaints from the public" (City of Toronto official 1, 2013).

As a result, renewal and maintenance are increasingly important issues, especially when it comes to cost (FCM 1, 2013). This is evident in the fact that municipal policy-makers and others are focusing on developing risk assessment tools and asset management mechanisms to extend the lifespan of infrastructure rather than simply knocking it down and building again (City of Toronto 1, 2013; Engineers Canada 1, 2013; FCM 2, 2013). As Monstadt (2009: 1932) highlights, however, there is a risk that local governments have or will lose control over infrastructure development as the result of cost *and* market pressures; that is, declining budgets and increasing privatization of infrastructure development.

Consequently, it is vital to consider how sustainable infrastructure transitions are being shaped and led by market pressures, or private sector actors. As Geels and Schot (2007) note, there are a range of social actors in socio-technical landscapes, regimes and niches, including government and business. One important private sector actor driving sustainable infrastructure transitions is the insurance industry, whether directly or indirectly (e.g. Sturm and Oh 2010). For example, a City of Toronto official speculated that "insurance becomes so expensive that they [people] decide, 'well, I'm not going to have anything expensive in my basement anymore'" (City of Toronto 1, 2013). More specifically, an informant from the Insurance Board of Canada explained that climate change adaptation has become an important issue within the insurance industry due to significantly rising insurance claims resulting from flooding, weather events, and so on. What this informant also highlighted, however, is that sustainable infrastructure transitions are hampered by certain factors:

> "The issue [of lack of response to climate change] is mostly related, is mostly systemic and financial; systemic in the lowest bidder process, which is quite frankly, in my perspective, is moronic. And the second component of it is financial; there's, you know, municipalities are strapped for funding and because of that they don't necessarily have as much money as they would like in order to perform the maintenance of their infrastructure and let alone the upgrades. So those are the two drivers that essentially stops significant integration of adaptation into the urban planning" (IBC 1, 2013).

As a result of constraints on government, market-led pressures – like rising insurance premiums – may end up proving to be the key drivers behind sustainable infrastructure transitions. However, this does not explain, analytically-speaking at least, how these social actors fit within socio-material systems. On the one hand, Geels and Schot (2007) theorize 'regime actors' as key players in the MLP approach; on the other hand, the importance of both state and market actors highlighted in our research suggests that it is 'landscape actors' who provide a clearer driving or derailing force in transitions; that is, social actors not directly implicated in particular socio-technical regimes. I now turn to the barriers to integrating climate change in infrastructure.

4.3.2 Barriers to Sustainable Infrastructure Transitions

While there are numerous specific and generic examples of how climate change is being integrated in transport infrastructure in Ontario (see above), this should not obscure the fact that sustainable infrastructure transitions – or the societal-level change needed to shift from fossil fuel dependence – remain contested, controversial and uneven. This is reflected in the continuing barriers to the integration of climate change in infrastructure development, which I cover in this section. For what of space, I focus on three specific, yet inter-related, issues: (a) cost, financing and contracting issues; (b) infrastructure life cycle issues; and (c) implications for engineers as a professional group.

First, a number of informants highlighted cost, financing and contracting as key barriers to the integration of climate change in infrastructure (e.g. Design 1, Design 2, Construction 1, IBC 1, etc.). I put these three things together because they overlap, and were often characterized as related issues by informants. The main example of this relationship arose in relation to contracting, and how it informs costs and financing. As Geels (2004) emphasizes, these are integral components in the socio-technical regime; however, it might also be better to think of them as forms of landscape pressure that cut across regimes when it comes to infrastructure. For example, government budgeting and contracting rules usually cover a range of operations – not just infrastructure development – meaning that they are not particular to one regime or another. What is important to consider, as Shove and Walker (2007) and Tyfield (2014) highlight, is the conflict between parties in any regime, or between regime actors and landscape actors; they frequently have very different objectives, resources and competencies. As a construction engineer put it:

> "However, one of the most significant components of cost in a project is risk and the delineation of risk between parties on a contractual basis, and the delineation and separation of contracts where one person is responsible up to a certain line and then the next person's responsibility takes place past that, right. And often what it also does is it crosses borders of competencies" (Construction 3, 2013).

Another engineer confirmed this point by saying:

> "If it's built into a contract, people will do it, such as recycling programs that I was referring to earlier...[From earlier] But until it's legislated, you won't see the private sector lead that, because it adds cost to a competitive marketplace and nobody will that risk to do that" (Renewal 3, 2013).

As a result, costs, financing and contracting are bound up with broader societal issues like the public's willingness to pay higher taxes, or societal narratives about climate change, etc. There is a real danger that the integration of climate change is diluted as tasks and roles are subcontracted down the chain of responsibility. For example, subcontractors were frequently unable to integrate climate change in their activities because they needed to save costs *now*, as opposed to thinking about cost savings over the life span or cycle of the infrastructure project (Construction 2, 2013; Construction 8, 2013). Consequently, climate change has to be built into contractual arrangements throughout the various development stages, or it ends up being sidelined. Obviously, this is all largely driven by budgets, as one engineer explained:

> "...you're automatically setting yourself up for budgetary constraints, because you can't do everything you'd love to do and we've had some very ambitious designs initially, so the challenge is to work within the budget you've got available" (Construction 7, 2013).

Second, as suggested by the constraints imposed by costs, financing and contracting, infrastructure life spans and life cycles – a central aspect of their materiality – present a number of barriers to the integration of climate change. These range from the political – e.g. the turnover of politicians and their political mandates (Ontario Centre for Climate Impacts and Adaptation Resources 1, 2013) – to the technical – e.g. how to construct to specific codes and standards in light of data uncertainty (Engineers Canada 2, 2013).

Thinking about the life span and cycle of infrastructure – that is, as a physical artefact – means paying analytical attention to its materiality; to how its physical characteristics shape and are shaped by specific socio-economic relations, as Mitchell (2011) conceptualizes it. One example of this materiality relates back to the financing of infrastructure projects. Since they last for such a long time – several decades, if not a century – their costs can be capitalized, thereby spreading them out over their lifetime. While this is critical in budgetary terms (i.e. we do not need to pay enormous sums upfront), it entails certain knowledges and practices. For example, assessment and management tools to ensure proper maintenance and life cycle costing (Construction 2, 2013), which raises a series of political issues as a result. As one engineer put it:

> "And of course taxpayers want to pay as little and get a big return right and so if you don't have electricity priced properly and you don't have storm water drainage priced properly and you don't have all these other impacts priced properly based on carbon footprint, it's going to get the wrong answer because they're priced in dollars" (Construction 3, 2013).

Here is a prime example of how the political materialities of infrastructure represent a potential barrier to sustainable infrastructure transitions; its physical characteristics shape social and economic considerations (e.g. capitalized costs), which, in turn, shape its physical form (e.g. life span). It is not, in this scenario, the people who build the infrastructure who necessarily benefit from its integration of climate change; these are, moreover, hard to define since the avoidance of impacts (i.e. benefit) is the goal sought.

Finally, the integration of climate change has serious and ongoing implications for engineers as a professional group, especially when it comes to adaptation. Although we have discussed this in depth elsewhere (Birch and Wudrich 2015), it is still important to highlight the implications facing engineers as a significant barrier. To start with, it is clear that a majority of Canadian engineers feel their activities are already being affected by climate change (CSA Group 2012). However, as an Engineers Canada official noted:

> "And it looks like we've got quite a lot of work to do still in raising awareness. In fact, it's not really even raising awareness; they [engineers] seem to be aware, they just don't have the tools at this stage of the game" (Engineers Canada 2, 2013).

Despite a range of new assessment tools, engineers lack the 'tools' needed to alter workplace practices because of inertia from codes and standards; for example, these can take a significant length of time to change (CSA 1, 2013) and are frequently contested by private developers who want to keep minimum standards to exactly that. As a construction engineer put it:

> "Building codes, you know, they always up the ante in terms of energy consumption and insulation values and so on. But in my opinion it's not enough, and I think there's a huge lobby group out there of developers who want to deliver cheap buildings to the public and then what gets built is code minimum and that puts money in the developers' pockets" (Construction 8, 2013).

Here, it is obvious that there are significant conflicts between different social interests, and professional groups like engineers are often caught between different pressures. While Geels and Schot (2007) characterize professional associations as landscape actors, this misses the fact that engineers are themselves subject to certain (exogenous) limits, currently and in the future. For example, engineers in Ontario are, legally and professionally, required to work to specific codes and standards – which are often based on historical data that is increasingly useless in light of uncertain, future climate change (see CSA 2010) – but potentially face future liability claims if they ignore climate change now (IBC 1, 2013).

It is evident, from this brief discussion, that barriers to integrating climate change are inherent in the materialities of engineering practice; that is, future environmental changes represent a material barrier to establishing clear codes and standards, to which engineers can be held to account. Engineers are left with a serious dilemma; over-design to address every possibility, or design to existing code in order to avoid present liability. The former, however, is simply too expensive, while the latter could result in significant future costs as infrastructure has to be adapted, rebuilt, etc.

Conclusion

In this paper I started out by discussing a range of literature on socio-technical systems, sustainability transitions and infrastructure studies in order to theorize the relevance of materialities, as theorized by the likes of Mitchell (2011), to sustainable infrastructure development. In doing so I highlighted a number of political and analytical issues.

First, sustainability transitions, as political projects, are premised on finding ways to transition to low-carbon societies and economies; however, this necessitates avoiding carbon lock-in (Unruh 2000), which happens through the embedding of fossil fuel dependence in infrastructure developments. What makes this so urgent is that societies must undertake this action now or end up with infrastructure that is unsuitable for the next century.

Second, there is a real risk that new and rebuilt infrastructure developments will not integrate climate change, which means that any examination of these processes necessitates an analytical and methodological approach that can examine current changes as they are happening now. The sustainability transitions literature, however, has an analytical gap here at present. Consequently, in focusing on a particular professional group – engineers – and their role in three Ontario infrastructure projects at different points in the infrastructure life cycle, I hope to have partially addressed this gap. What it enabled me to do was look at how climate change is or is not being integrated in new developments.

Finally, the sustainability transitions literature, as an analytical project, builds on a long conceptual tradition stretching back to the work of scholars on large, technological systems (e.g. Hughes 1983). The subsequent incorporation of social components by the likes of Geels (2002) and others, while important, has left an analytical blind-spot. This concerns the over-emphasis on transitions as socio-technical phenomena, concentrating on changes in specific regimes, to the exclusion of a range of materialities (Mitchell 2011). Consequently, I sought to theorize sustainable infrastructure transitions, my specific empirical focus, as socio-material systems, thereby incorporating the materialities of the artefact itself (e.g. infrastructure) and the environmental context in which it is developed. This provided the means to study how the sustainable infrastructure transitions are shaped by and also shape the physical characteristics of infrastructure (e.g. life span, deterioration, materials, etc.).

References

APEGBC (2014) *A Changing Climate in British Columbia,* Vancouver: Professional Engineers and Geoscientists of BC.

Birch, K. (2013) "The political economy of technoscience: An emerging research agenda", *Spontaneous Generations: A Journal for the History and Philosophy of Science,* 7(1): 49-61.

Birch, K. and Calvert, K. (2015) "Rethinking 'drop-in' biofuels: On the political materialities of bioenergy", *Science and Technology Studies,* 28(1): 52-72.

Birch, K. and Wudrich, D. (2013) "Climate change, sustainable infrastructure and the challenge facing engineers", *Engineering Dimensions,* Sept/Oct: 46-48.

Birch, K. and Wudrich, D. (2015) "(Re)building sustainable infrastructure: The implications for engineers", in C. Lipsig-Mummé and S. McBride (eds.), *Work in a Warming World,* Montreal: McGill-Queen's University Press, pp. 125-141.

Bulkeley, H., Castan Broto, V. and Maassen, A. (2013) "Low-carbon transitions and the reconfiguration of urban infrastructure", *Urban Studies,* 51(7): 1471-1486.

Bulkeley, H., Castan Broto, V., Hodson, M. and Marvin, G. (2011) "Cities and low carbon transition", *The European Financial Review,* 14 August.

Coenen, L., Benneworth, P. and Truffer, B. (2012) "Towards a spatial perspective on sustainability transitions", *Research Policy,* 41(6): 968-979.

CSA (2010) *Climatic Information Requirements of Built Infrastructure Codes and Standards and their Users,* Toronto: Canadian Standards Association.

CSA Group (2012) National Survey of Canada's Infrastructure Engineers about Climate Change, Ottawa: Engineers Canada and CSA Group.

Engineers Canada (2008) *Adapting to Climate Change: Canada's First National Engineering Vulnerability Assessment of Public Infrastructure,* Ottawa: Engineers Canada.

FCM (2011) *Building Canada's Green Economy: The Municipal Role*, Ottawa: Federation of Canadian Municipalities.

FCM (2012) *The Road to Jobs and Growth: Solving Canada's Municipal Infrastructure Challenge,* Ottawa: Federation of Canadian Municipalities.

Frantzeskaki, N. and Loorbach, D. (2010) "Towards governing infrasystem transitions", *Technological Forecasting and Social Change,* 77(8): 1292-1301.

Frantzeskaki, N. and Loorbach, D. (2012) "Concluding editorial: Sustainability transitions and their governance: lessons and next-step challenges", *International Journal of Sustainable Development*, 15(1/2): 173-186.

Furlong, K. (2010) "Small technologies, big change: Rethinking infrastructure through STS and geography", *Progress in Human Geography,* 35(4): 460-482.

Geels, F. (2002) "Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and case study", *Research Policy,* 31: 1257-1274.

Geels, F. (2004) "Understanding system innovations: A critical literature review and a conceptual synthesis'", in B. Elzen, F. Geels and K. Green (eds.), *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy*, Cheltenham: Edward Elgar, pp. 19-47.

Geels, F. and Schot, J. (2007) "Typology of sociotechnical transition pathways", *Research Policy,* 36(3): 399-417.

Graham, S. and Marvin, S. (2001) *Splintering Urbanism*, London: Routledge.

Hughes, T. (1983) *Networks of Power*, Baltimore: John Hopkins University Press.

Hughes, T. (1987) "The evolution of large technological systems", in W. Bijker, T. Hughes and T. Pinch (eds), *The Social Construction of Technological Systems,* Cambridge MA: MIT Press, pp. 51-82.

Infrastructure Canada (2006) *Adapting Infrastructure to Climate Change in Canada's Cities and Communities*, Ottawa: Infrastructure Canada.

Johnsson, D. (2000) "Sustainable infrasystem synergies: A conceptual framework", *Journal of Urban Technology,* 7(3): 81-104.

Johnsson, D. (2005) "The nature of infrasystem services", *Journal of Infrastructure Systems,* 11(1): 2-8.

Kemp, R. and Rotmans, J. (2009) "Transitioning policy: Co-production of a new strategic framework for energy innovation policy in the Netherlands", *Policy Sciences,* 42: 303-322.

Lawhon, M. and Murphy, J.T. (2012) "Socio-technical regimes and sustainability transitions: Insights from political ecology", *Progress in Human Geography,* 36(3): 354-378.

MacLeod, D. (2011) *Adaptation to a Changing Climate: City Infrastructure Preparedness,* Toronto: City of Toronto.

Markard, J. (2011) "Transformation of infrastructures: Sector characteristics and implications for fundamental change", *Journal of Infrastructure Systems,* 17(3): 107-117.

McCormick, K., Anderberg, S., Coenen, L. and Neij, L. (2013) "Advancing sustainable urban transformation", *Journal of Cleaner Production,* 50: 1-11.

Mees, H-L. and Driessen, P. (2011) "Adaptation to climate change in urban areas: Climate-greening London, Rotterdam, and Toronto", *Climate Law,* 2: 251-280.

Mitchell, T. (2011) *Carbon Democracy*, London: Verso.

MOECC (2015) *Ontario's Climate Change Discussion Paper*, Toronto: Ministry of the Environment and Climate Change.

Monstadt, J. (2009) "Conceptualizing the political ecology of urban infrastructures: Insights from science and technology studies", *Environment and Planning A,* 41: 1924-1942.

NRC (2007) *From Impacts to Adaptation: Canada in a Changing Climate*, Ottawa: Natural Resources Canada.

NRTEE (2009) *True North: Adapting Infrastructure to Climate Change in Northern Canada*, Ottawa: National Roundtable on the Environment and the Economy.

Shove, E. and Walker, G. (2007) "CAUTION! Transition ahead: Politics, practice, and sustainable transition management", *Environment and Planning A,* 39(4): 763-770.

Star, S.L. (1999) "The ethnography of infrastructure", *American Behavioral Scientist,* 43(3): 377-391.

Sturm, T. and Oh, E. (2010) "Natural Disasters as the End of the Insurance Industry? Scalar Competitive Strategies, Alternative Risk Transfers, and the Economic Crisis", *Geoforum,* 41(1): 154-163.

Truffer, B. And Coenen, L. (2012) "Environmental innovation and sustainability transitions in regional studies", *Regional Studies,* 46(1): 1-21.

Tyfield, D. (2014) "Putting the power in 'socio-technical regimes' – E-mobility transition in China as political process", *Mobilities*, 9(4): 585-603.

Unruh, G. (2000) "Understanding carbon lock in", *Energy Policy,* 28: 817-830.

Winfield, M. (2012) *Blue-Green Province: The Environment and the Political Economy of Ontario,* Vancouver: University of British Columbia Press.