SCIENTIFIC RESEARCH ABOUT CLIMATE CHANGE MITIGATION IN TRANSPORT: A CRITICAL REVIEW

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Abstract

This paper seeks to develop a deeper understanding of the research on climate change mitigation in transport. We suggest that work to date has focused on the effects of improvements in transport technologies, changes in the price of transport, physical infrastructure provision, behavioural change and alternative institutional arrangements for governing transport systems. In terms of research methodologies, positivist and quantitative analysis prevails, although there are signs of experimentation with non-positivist epistemologies and participatory methods. These particular engagements with climate change mitigation reflect mutually reinforcing tendencies within and beyond the academic transport community. We first draw on a revised version of Thomas Kuhn's philosophy of science to explore the path dependencies within transport studies, which are at least partly responsible for the predisposition towards quantitative modelling and technology, pricing and infrastructure oriented interventions in transport systems. We then employ the governmentality perspective to examine how transport academics' engagements with climate change mitigation depend on and align with more general understandings of climate change in UK society and beyond. The analysis makes clear that ecological modernisation and neo-liberal governmentality more generally provide the context for the current focus on and belief in technological, behaviour change, and especially market-based mitigation strategies. While current research trajectories are important and insightful, we believe that a deeper engagement with theoretical insights from the social sciences produce richer understandings of transport mitigation in transport and briefly outline some of the contributions thinking on socio-technical transitions and practice theories can make.

Key words: climate change mitigation, literature review, governmentality, technology, carbon economy, behaviour change, institutions

1| Introduction

While the notions of 'sustainable transport' and 'sustainable mobility' have been part of transport researchers' discourse for several decades, academic interest in the links between climate change and transport has proliferated recently. This new élan is obviously linked to the growing awareness in the realms of public policy, industry, popular media and beyond about the challenges climate change poses to society. It also reflects the concern that transport is a sector where reductions in greenhouse gas (GHG) emissions are particularly difficult to achieve (Kahn Ribeiro et al., 2007; Stern, 2007). This is evidenced by the increase in transport's contribution to total CO_2 emissions in 1990-2008 for both the European Union and the USA (IEA, 2009, 2010). While total emissions fell slightly from 4.0 to 3.9 Gt (-3.9%) for the EU-27, transport's share in these figures rose from 19% to 25% (+0.2 Gt). In the USA total emissions increased from 4.8 to 5.6 Gt (+17%) in the period 1990-2008 but transport's emissions rose by 22% to reach 1.7 Gt in 2008. Road transport is responsible for most emissions in transport in 2008 – 93% of all emissions by transport in the EU-27 and 86% of those in the USA (IEA, 2010). Transport has increased both its relative and absolute levels of CO_2 emissions.

Given these concerns and statistics, it is not surprising that climate change mitigation and energy use reduction feature prominently on the academic transport research agenda. This paper engages with the transport research literature about climate change mitigation and has three more specific objectives. First, it provides a brief inventory of that literature, focusing on the mechanisms through which transport is expected to become decarbonised and the research methodologies employed. Second, the bulk of the paper seeks to explain why transport researchers have engaged with climate change in the ways that they have done. Addressing this question is important, we suggest, because systematically analysing the often taken-for-granted understandings and assumptions underpinning academic transport research allows us to identify both strengths and weaknesses in existing research that might otherwise go unnoticed. These strengths and weaknesses are also identified insofar as appropriate. Third, we briefly explore how the literature can be enriched by drawing on research traditions within the social sciences that have only had a limited influence on transport research so far. What the paper tries to do, then, is to do develop a deeper understanding of the research on climate change mitigation in transport and trigger debate about how the academic community should address what has become perhaps the biggest challenge facing transport in the 21st century.

This paper addresses climate change mitigation rather than adaptation, as the latter has received only very limited attention in the transport literature. However, we do consider both passenger and freight transport across shorter and longer distances. It is not easy to sharply demarcate the academic transport research and multiple criteria could be used in this regard.

Here we concentrate on research that has been published in the main transport journals[1] and in other journals[2] that regularly publish transport-related papers, and/or the work of academics participating in such professional associations as the *Transportation Research Board* (USA) and the *Universities' Transport Research Group* (UK).

2| Academic transport research and climate change mitigation

There are multiple ways in which academic research about climate change mitigation can be classified. Here we consider two ways: one concentrates on the element(s) within transport systems to which attention is directed, the other considers the research method(s) used.

2.1| *Elements in the transport system*

We understand a transport system in a broad sense, as the conglomerate of material and immaterial elements – people, means of transport, fuels, roads and other fixed infrastructures, agencies, laws and rules, prices, norms and values, and so on – that collectively produce the movements of persons and freight though space and time, as well as such externalities as GHG emissions. Such a system functions through the interactions and couplings between the elements involved and it is difficult to isolate a single (type of) element from the whole (Urry, 2007). Nonetheless, as a heuristic strategy, we can ask which types of element within complex transport systems have attracted particular attention in academic transport research about climate change mitigation. We suggest that academic research has dealt with the complexity of transport systems by focusing on how transport can be decarbonised by targeting one or several of the following (sets of) elements: transport technologies, the price or commodity value of carbon, the 'hard' infrastructure, the 'soft' psyche and behaviour of users, and the institutions governing transport systems. We discuss each in turn though it should be remembered that many published studies have considered multiple strategies of decarbonisation focusing on different elements of transport systems simultaneously.

Any quick scan of the published literature will show that much research about transport and climate change considers how changes to such transport technologies as vehicles, aircraft and ships will reduce carbon emissions. There exists a diverse literature about the decarbonisation potential of the uptake and diffusion of alternative power-train designs and alternative fuels – in particular bio-fuels, hydrogen and electricity – and the contribution of fuel efficiency improvements to lower emissions (Kahn Ribeiro et al., 2007; Gilbert and Perl, 2008; Lin et al.,

[1] These include, for instance, *Transportation Research Part A-F*, *Transportation*, *Transport Reviews*, *Journal of Transport Geography*, *Transportation Research Record* and *Transport Policy*.
[2] These include, among others, *Energy Policy*, *Environment & Planning A-B* and *Journal of Environmental Psychology*.

2008; Johansson, 2009; Kromer et al., 2010; Schipper, 2011). Recently a surge of interest in electric vehicles (EVs) has occurred (Karplus et al., 2010; Caperello and Kurani, 2011; Musti and Kockelman, 2011). Various mechanisms for diffusing technological changes throughout transport fleets are explored or assumed in the literature, including regulatory measures (e.g. fuel economy standards) and fiscal/pricing measures (e.g. vehicle scrappage schemes). Many studies explore how much technological change will contribute to VMT and CO_2 emission reductions and/or how much new technology adoption is required to reach emission reduction targets for 2020-2050. Almost all studies suggest that technology's long-term contribution to decarbonisation is likely to depend on macro-economic conditions – fuel prices in particular – and policy decisions regarding carbon taxation and cap-and-trade schemes and land use policies. Yet some authors (Bristow et al., 2008; Kromer et al., 2010; Stanley et al., 2011) are more optimistic about the difference technological change will make than others (e.g. Musti and Kockelman, 2011).

Alongside technological change, increasing emphasis is placed on economic instruments – especially fuel prices, carbon taxes and cap-and-trade approaches – as means to correct market failure and transport's negative externalities (Hensher, 2008; Bristow, 2009; Hofer et al., 2010; Morrow et al., 2010). The burgeoning literature in this area focuses on four issues:

- The extent to which budgeting and pricing strategies can contribute to transport's decarbonisation and their cost-effectiveness (Hensher, 2008; Moss et al., 2010);
- The question how budgeting approaches and carbon markets should be designed and arranged (Niemeier et al., 2008; Salon et al., 2010);
- The public acceptability of pricing and budgeting strategies (Bristow et al., 2010);
- The distributional effects and implications for social equity of personal carbon trading (McNamara and Caulfield, 2011; Wadud, 2011).

The carbon economy, i.e. any attempt to assign commodity values to and create markets for GHG emissions (Bailey and Wilson, 2009), is incorporating transport, albeit in different forms and at different speeds for passenger and freight, domestic and international travel and for different transport modes.

Less contentious in the eyes of politicians and the general public, is academics' focus on transport infrastructure provision, which is often and increasingly considered in conjunction with land use configurations. The rationale underpinning this focus is that by extending in space and time the availability and accessibility of more sustainable forms of transport, such as walking and cycling, local public transport, high-speed trains (HST) and freight transport by rail, the choice sets available to persons and firms become larger. They are offered more and better opportunities to switch from high to low-carbon forms of transport. What is more, the need to travel is also being reduced by better integrating transport with land use planning (through, for instance, transit-oriented development and densification) and with the realm of recent

Information and Communication Technologies or ICTs (e.g. through telecommuting and video-conferencing initiatives). In short, there now exists a large literature evaluating to what extent the provision of infrastructures for sustainable transport, land use changes and further developments in ICTs can help reduce GHG emissions (Poudenx, 2008; Roth et al., 2008; Givoni et al., 2009; Ewing and Cervero, 2010; Zanni and Bristow, 2010; Åkerman, 2011; Heres-del-Valle and Niemeier, 2011; Tiwari et al., 2011).

Fourthly, a literature has emerged that foregrounds how changes to the attitudes, lifestyles, norms and values of the people who use transport systems can contribute to behaviour change and decarbonisation (Möser and Bamberg, 2008; Klöckner and Böbaum, 2010). Behaviour change is here understood primarily as a shift from car use to more sustainable transport modes, although some studies focus on eco-driving (Barkenbus 2010; Zanni and Bristow, 2010). Studies suggest that changes to attitudes, lifestyles and so on can make a major contribution to the reduction of GHG emissions in transport (Anable et al., 2011), although sceptics believe technological and economic measures will achieve more (Smith, 2008).

Finally, it has been argued that the institutions, i.e. the rules and routines, according to which transport policies are proposed, implemented and evaluated affect climate change mitigation in transport: some institutional arrangements are more effective than others in reducing carbon emissions (Anable and Shaw, 2007; Marsden and Rye, 2010; Silvestrini et al., 2010). Silvestrini and colleagues (2010), for instance, explore how differences in the implementation of the EU Biofuels Directive between four major European cities are explained by variations in support from national government, level of local self-government, support from local businesses, acquisition of EU funds, and participation in inter-city networking. Also, in the margins of mainstream transport studies, authors have argued that transport policy can become locked into a state of high carbon use and have explored how such lock-in can be overcome through radical transitions (Unruh, 2002; Nykvist and Whitmarsh, 2008; Kemp et al., 2011).

2.2| *Research methods*

A wide variety of methods is used in transport-related research about climate change mitigation, depending for the large part on the specific research question addressed. Nonetheless, two wider sets of methods prevail in research that seeks to make clear how emissions can be reduced. First, there are many studies that use recently collected quantitative empirical data and infer conclusions about how climate change might be mitigated in the future from analysing those data using regression or discrete choice modelling. This approach is quite common in studies of how land use policies changing the psyche of travellers can reduce emissions (Möser and Bamberg, 2008; Ewing and Cervero 2010).

Second, various scenario approaches have been used. These include projective or forecast-based scenarios investigating probable and possible futures over the shorter term (Hofer et al., 2010), and prospective scenarios of both possible and plausible futures that seek to induce new thinking over a longer-term time horizon (Köhler et al., 2009; Karplus et al., 2010; Anable et al., 2011). A wide variety of modelling approaches from econometrics and engineering has been employed in these projective and prospective scenario studies. Much research estimates future emissions (often until 2050) from past trends and assumptions about technology development and uptake, price levels and sensitivities, behaviour change, population growth, etc. as the starting point from which different 'futures' can be envisaged. With some exceptions (Köhler et al., 2009, Anable et al., 2011), these studies employ (neo-classical) economics-based worldviews, as the outcomes are largely dependent on the operation of transport and carbon markets and public policy interventions therein. Backcasting approaches have also been used to explore longer-term desirable futures and the different pathways towards them (Hickman and Banister, 2007; Lopez-Ruiz and Crozet, 2010).

The vast majority of academic studies about transport-related climate change mitigation take a conventional scientific approach, which is (loosely) based on positivist epistemological principles. As a consequence, most work is characterised by strongly hierarchical power relations between academic researchers and other involved stakeholders. It is the former who determine what count as proper knowledge, relevant factors, appropriate reasoning and arguments and so on; citizens, firms, policymakers and others have a rather limited say in such matters. Qualitative and/or non-positivist methods that give respondents more power in the research encounter are used rather infrequently, although there are some signs that this is changing. Participatory research designs that give study participants – e.g. industry representatives, policymakers and citizens – a more active role in identifying relevant issues and factors have been adopted in some studies (Hickman and Banister, 2007; Whitmarsh et al., 2009). Especially in research on electric vehicle use can a tendency of increased use of qualitative methods be observed (Heffner et al., 2007; Caperello and Kurani, 2011).

2.3| *Summary and first explanations*

It is evident that transport research about climate change mitigation is vibrant and varied, exploring multiple pathways in which carbon use can be reduced. Across the whole field the literature is expanding and diversifying. Nonetheless, a number of more general points can be made. First, it is widely recognised that transport's decarbonisation is a massive challenge that can only be achieved (if at all) by combining means and measures targeting multiple elements within transport systems – means of transport, their users, fuels, prices, regulations, infrastructures, the separation of origins and destinations – simultaneously. Second, much of the published literature concentrates on the contribution technological change to transport's

decarbonisation. Third, a 'logic of provision' permeates thinking, according to which the expansion of high-quality green infrastructures for HST, public transport and cycling/walking and fitting land use configurations is expected to trigger at least some shift towards low-carbon mobility. Fourth, market-based approaches, according to which carbon emissions are commodified and budgeting and pricing mechanisms are used to reduce GHG emissions, are rapidly gaining in popularity. More and more authors seem to believe that carbon budgeting and pricing are not only key pathways for decarbonisation but also provide an overarching framework in which other strategies key be positioned and integrated (Bristow, 2009; Johansson, 2009; Salon et al., 2010; Boarnet, 2010). Fifth, research emphasising behaviour change through psychological mechanisms and grounded in psychological theories is gaining in popularity, at least among researchers examining passenger transport. Finally, in methodological terms, quantitative research underpinned by positivist epistemologies continues to prevail, although participatory and/or qualitative research methods are increasingly used.

To us, these points and tendencies are non-coincidental and reflect multiple processes. Dynamics in the type of funding available (in terms of who supplied it and for what purpose), transport planning processes, and views about what counts as proper scientific knowledge and procedures (epistemology and methodology) are all relevant. However, it seems to us that two key explanations pertain to path dependencies[3] in the evolution of transport studies as an academic discipline, and to developments in the ways of understanding and intervening in climate change in contemporary Western societies more generally. To understand both processes, we draw on extensions to Kuhn's (1962) approach to scientific practices and governmentality scholarship. Differences notwithstanding, these fields are complementary. The governmentality tradition takes as-it-were a 'systems approach', positioning academic research in wider social processes and forces. The Kuhnian perspective considers how scientists as members of scientific communities interact with each other, equipment and the objects of research. Moreover, both analytical perspectives start from the premise that scientific knowledge is produced in and through social practices – routinised behaviours in which bodily action, mental activity, interactions with fellow human beings and material artefacts, tacit know-how and skills, motivations and emotions are integrated (Reckwitz, 2002).

[3] Path dependency are here understood as a situation whereby earlier events and experiences in the historical development of transport studies as an academic discipline pattern the responses to new stimuli, such as the need to decarbonise the transport sector.

3| Path-dependent evolution

3.1| *On paradigms, normal science and tacit understandings*

The sociology of science has become an active (sub)discipline since the publication of Kuhn's *The Structure of Scientific Revolutions* (1962). Numerous theoretical/methodological approaches have been elaborated but Kuhn's approach is still influential and widely used. Its reworked version by Joseph Rouse (1981, 1998, 2003) allows us to understand a series of path dependencies we believe to matter to the transport literature about climate change mitigation.

The notions of paradigm and normal science are central to Kuhn's approach. According to Rouse (2003), a paradigm is not so much a set of beliefs to which a scientific community subscribes – the prevailing interpretation – but rather an exemplary way of conceptualising and intervening in particular situations on which subsequent work can be modelled. Scientists *use* paradigms rather than believing them; accepting a paradigm entails acquiring and using a set of skills instead of understanding and believing a set of statements. Likewise, normal science is "not a particular cognitive attitude toward the objects of scientific research, but a particular way of manipulating and dealing with the world" (Rouse 1981:271), which is firmly grounded in past achievements and the use of equipment. Those past achievements allow science to go on; they are reflexively applied to new challenges and problems, which results in the further articulation and transformation of the paradigm (Rouse 1998).

Rouse (1981) also contends that for Kuhn the use of equipment is central to scientific praxis. Equipment is here understood not just as physical equipment (instruments, PCs, libraries, etc) but also as methodological equipment (standardised techniques, methods and procedures) and intellectual equipment (conceptual and mathematical tools). These tools help researchers to explore and disclose the world. For Rouse (1981:237), they orient researchers towards particular actions because they help to shape three dimensions of practical understanding that were originally distinguished by Heidegger (1962):

- *Vorhabe* or prepossession: One's general yet tacit familiarity with the phenomena one encounters, the background understanding acquired through education and training that makes research possible in the first place;
- *Vorsicht* or preview: Against the background understanding afforded by one's *Vorhabe*, this is one's general and again normally tacit sense of what is problematic in the encountered phenomena and how one might deal with it, how one might go on; and
- *Vorgriff* or preconception: One's largely tacit understanding of what might count as a solution to the problem.

Thus, for Rouse, doing research is a form of 'tool-being', in which the past via equipment 'preselects' future scientific possibilities – what researchers can and might say about phenomena (including new or relatively recently emerged ones, such as climate change mitigation) at some later point in chronological time.

3.2| *Links to climate change mitigation in transport*

The concepts by Kuhn, Rouse and Heidegger help us to understand how the historical development trajectories of transport studies as a discipline and the personal histories of its practitioners affect the transport literature about climate change mitigation. Multiple path dependencies can be identified.

To begin with, thinking of research as equipment-informed 'going on' makes the emphasis on infrastructure provision understandable. After all, especially after World War II, transport studies as a discipline came into existence to regulate and facilitate the growth of automobile transport; a predict-and-provide approach grounded in instrumental rationality developed, which projected demands and met these with infrastructure provision insofar as national and regional budgets allowed (Owens, 1995). This approach was premised on aggregate and deterministic sequential modelling systems, involving the familiar steps of trip generation, trip distribution, mode choice and route assignment. While the four-step model has been criticised extensively and to a certain degree abandoned in favour of stochastic micro-simulation techniques, the discipline's preoccupation with modelling the travel behaviour of the population has remained. Thus, in the context of climate change mitigation transport researchers not only use (activity-based) micro-simulation tools coupled to emissions models (Hensher, 2008; Axsen et al., 2009; Beckx et al., 2009; Musti and Kockelman, 2011), but also employ aggregate models of transport demand and associated emissions with varying levels of sophistication (Bristow et al., 2008; Yang et al., 2009; Karplus et al., 2010; Morrow et al., 2010) to analyse (future) developments in carbon emissions. Many of these models make visible the effects on passenger and freight transport of a wide range of policy interventions into travel systems and societal processes. At the same time, these models are partial: they are particularly successful in quantifying the likely impacts of changes in the built environment and the availability in space and time of particular forms of transport, the per kilometre (km) monetary price of travelling with a given mode, fuel efficiency, fuel type, and in the population composition. Changes in socially shared norms and values that shape how people travel, in institutions and in the role of stakeholders other than consumers and policymakers cannot be represented so easily with those models. The inherent and inherited selectivity in the drivers of changes in transport systems in modelling systems perpetuates the focus on infrastructure provision and built environment measures in studies of climate change mitigation in (passenger) transport.

Yet, the focus on infrastructure provision, as well as the emphasis on pricing measures and technological measures, is also partly a consequence of the existence of paradigmatic exemplars of studies using empirical data that can be extended to new problems. Whilst multiple modelling approaches are employed to explore how different types of interventions in transport systems contribute to their decarbonisation, one particular influential exemplar is constituted by the models derived from random utility theory (RUT) – a version of rational choice theory developed by the Nobel Prize laureate McFadden and his associates from the 1960s onwards (Domencich and McFadden, 1975). These models assume instrumentally rational decision-makers who minimise effort (e.g. monetary price, travel time, waiting time) and maximise satisfaction (e.g. speed, comfort, safety). While a wide range of factors that may impinge on travel decisions can be considered in RUT models, it has become common practice to use them to evaluate differences and changes in the instrumental aspects of choice alternatives – e.g. costs, convenience and availability – in addition to a range of characteristics of the decision-makers. In the climate change mitigation context, RUT models have been used to quantify the effects of changes in vehicle technology, pricing measures, and infrastructure and land use changes on travel behaviour (distance travelled), and to predict vehicle type choice and the future uptake of cleaner vehicles, biofuels, etc. under various assumptions about price and availability (Hensher, 2008; Axsen et al., 2009; Brand et al., 2011; Musti and Kockelman, 2011). Because model outcomes can be aggregated to the population level fairly easily, RUT approaches are complementary to projective and prospective scenario studies of how carbon emissions from transport may develop (cf. Hensher, 2008).

As important pieces of equipment, forecasting models and RUT have become inextricably linked with many transport researchers' practical understandings of the phenomena they study. These tools have structured researchers' *Vorhabe* during education/training in the past and continue to (re)structure this with each new instance of use. The assumptions they embody – e.g. the idea that the total transport activity in an area during a given period of time can be decomposed in a series of dimensions that can be modelled sequentially and hierarchically (as in the four-step model and in virtually all activity-based modelling systems), or the notion that travel choices are primarily utilitarian in nature (as in most RUT applications) – become ingrained in their taken-for-granted worldview. At the same time, they prime researchers towards specific definitions of problems (*Vorsicht*) and sensitise them towards possible solutions (*Vorgiff*). Given that forecasting models and RUT are attuned to showing the effects of infrastructure provision, technology and pricing measures, it is not surprising that transport researchers often couch problems and solutions with regard to climate change mitigation in exactly those terms (e.g. Boarnet, 2010; Stanley et al. 2011). Intensive engagement with those pieces of equipment, amplified by a tendency to remain within one's own comfort zone – in behavioural economics this is known as status quo bias (Kahneman and Tversky, 2000) – among their users, seems to create something akin to disciplinary lock-in. This amounts to a situation whereby other possible

ways of defining the problem and proposing solutions become foreclosed within a scientific community. This is especially likely to occur with problem definitions and solutions that are difficult to quantify with commonly used tools.

Rouse's reinterpretation of Kuhn allows us to understand why transport studies about climate change mitigation are characterised by a focus on physical infrastructure, price and technology and extensive reliance on forecasting models. It does not, however, explain other points and trends, such as the growing popularity of market-oriented solutions and psychologically oriented interventions. Further explanations that situate the academic transport community in a broader social field are necessary, and it is to these that we turn now.

4| Transport research and governmental practices

4.1| *Governmentality perspective*

One influential social science perspective on developments in the interventions of public authorities and other stakeholders in societal processes is the governmentality perspective, which emerged out of the work of French philosopher Michel Foucault. Government is here understood as the 'conduct of conduct' (Gordon, 1991:2) – activities to shape the behaviour of others or the self by working on their or one's own desires, aspirations, beliefs and actions (Dean, 1999). It is not the exclusive realm of public authorities but rather a set of practices that can be undertaken by any actor. Foucault used the neologism governmentality in various ways, among others to denote an analytical perspective on the worldviews, logics and objectivities (rationalities) and practices of government, but also to identify a particular style of government.

Foucault's approach has been developed by others since the mid-1980s. Dean (1999) proposed to analyse styles of government via four interdependent dimensions:

- *Field of visibilities*: how are the objects of government made visible, perceived and apprehended? What is obscured from view?
- *Techne*: what means, mechanisms, procedures, tactics, vocabularies, etc. are employed to modify the actions of the agents to be governed?
- *Episteme*: which forms of knowledge and expertise are implicated in, constitutive of, and produced by government? and
- *Subjectification*: how are the agents to be governed understood, represented and imagined? What are they to become?

In the late 1970s Foucault studied two particular styles of government (Foucault, 2007, 2008). One is the biopolitical or biopower governmentality that has existed since the 17th century; the other is liberalism, which was invented in the 18th century and revived after World War II as neo-

liberalism. *Biopower* focuses on the question how the state can enhance the permanence of its own apparatus and the productive capacities of its territory and inhabitants. In terms of visibilities, the emphasis is on regularities in the processes of life at the population level, which stimulated the development of statistics and the social sciences (episteme) and the emergence of techniques to stimulate the population's wellbeing since 1700 AD, such as sewage systems, laws for improving public hygiene and road construction (techne). These techniques work 'from within': the state seeks to align citizens' interests with its own so that inhabitants internalise its objectives and start to behave accordingly (Foucault, 2007).

For Foucault (2008) *liberalism* is a reflexive critique of biopower, focusing on the question how to thread the line between too much and too little government. This problematic is also central to contemporary neo-liberalism (Foucault, 2008; Miller and Rose, 2008). Here such phenomena as welfare provision, consumption and the environment are understood primarily in relation to markets, which are seen as key mechanisms for re-configuring them (visibilities). Individuals are imagined, and have come to understand themselves, as responsible, active and calculating agents striving for their self-fulfilment through the choices they make in their everyday lives (subjectification). In terms of episteme economics, psychology and other 'psy'-sciences have come to occupy a central role in government. Markets and subjectification processes are enacted through a wide variety of techniques. According to Dean (1999), 'techniques of agency and freedom' seek to enhance the activity and self-government of human agents; examples include contracts, consultation and participatory decision-making. They are complemented by 'techniques of performance' – e.g. benchmarks, quality controls and the identification of best practices – that seek to enhance the performance and trustworthiness of such agencies as service providers, local authorities and professionals. It needs to be appreciated that the neo-liberal governmentality is multiple and dynamic: its manifestations and effects differ across geographical contexts and realms of social life, may contradict each other, and evolve over time (Rutherford, 2007; Miller and Rose, 2008).

4.2| *Environmental governmentalities*

The governmentality perspective has been employed widely to understand environmental regulation (Luke, 1995; Oels, 2005; Bäckstrand and Lövbrand, 2006; Rutherford, 2007; Whitehead, 2009; Paterson and Stripple 2010). Scholars have identified multiple environmental governmentalities to exist alongside each other. One is known as *green governmentality* (GG), which is closely affiliated with Foucault's biopolitics (Luke, 1995). Its basic tenet is that there are limits to the earth's carrying capacity and economic growth. Hence, nature's scarce resources need to be allocated prudently on the basis of instrumental rationality and in a centralised command-and-control manner. To this end, global, top-down monitoring of climate changes and its emblems (melting glaciers, rising sea levels, extinction of particular species, etc.) by supra-

national institutions, such as the IPCC and IEA, is needed. GG is heavily reliant on, and stimulates the proliferation of, natural science expertise about climate change (Oels, 2005).

Alongside GG, *ecological modernisation* – the ecological version of neo-liberalism (Oels, 2005) – has become increasingly dominant since the 1980s in Western Europe and later in the USA and elsewhere (Haaijer, 1996; Bailey et al., 2011). This governmentality comes in different guises but is united in the assumption that economic growth and ecological problems can be reconciled (Haaijer, 1996; Gouldson et al., 2008; Bailey and Wilson, 2009): climate change provides opportunities for innovation and the reinvention of economic relations. EM recodes environmental issues in economic terms, considering climate change the 'ultimate market failure' (Stern, 2007) to be solved by better market performance. Carbon budgeting, trading and pricing are key techniques for the creation of self-responsible and calculating countries (as with the EU ETS), firms and individuals (through carbon taxes and personal carbon allowances). Technological measures are valued positively for their contribution of climate change mitigation (Haaijer, 1996; Mol and Sonnenfeld, 2000; Bailey and Wilson, 2009).

Like neo-liberalism, the EM governmentality is dynamic and geographically differentiated. The latter is exemplified through the technique of personal carbon trading (PCT), which is more widely debated in the UK than elsewhere. Whilst considered ahead of its time by national government in 2008, UK-based academics continue to promote PCT as a radical policy solution (Fawcett and Parag, 2010). It is deemed effective among others because PCT is grounded in a logic of responsibilisation and active citizenship. By "locate[ing] rights and *responsibilities* for the carbon emissions from household energy use and/or personal travel at the *individual* level" (*ibid*,:329, emphasis added), PCT reinforces neo-liberal subjectification processes.

With regard to policy-making, EM approaches advocate reflexive and multilevel governance processes in which the state has traded command-and-control planning for the role of facilitator. Institutional learning whereby societies draw on their reflexive capacities to reform policies and increase their effectiveness is considered critical (Haaijer, 1996; Gouldson et al., 2008). EM also privileges decentralised modes of government with active involvement of the civic society – non-governmental organisations (NGOs) and citizens – whilst also according an important role to supranational and internationally networked institutions (*ibid*.). The more progressive forms of EM rely heavily on Dean's (1999) techniques of agency and freedom, seeking to empower citizens through participatory mechanisms. However, the most progressive EM approaches, which explicitly challenge the consumerism, values and ethics of mainstream Western societies, have been marginalised successfully by techno-economically oriented versions of EM (Haaijer, 1996; Bailey and Wilson, 2009). The latter are based on the (implicit) idea that less far-reaching technological and economic measures suffice to mitigate climate change successfully.

4.3| *Links to transport research*

We should be very careful in establishing direct causal links between the global processes described by Foucault and governmentality scholars, and the rather specific and contemporary research practices of transport academics. Rather than proposing direct causality, we wish to suggest that the governmentalities introduced above provide a key context for transport research about climate change (and indeed other transport-related problems), shaping to a considerable degree its conditions of possibility. Below we elaborate the argument that the emphasis on technology, economic measures, psychologically oriented interventions and institutions as well as the use of quantitative methods is in line with the green and particularly ecological modernisation governmentalities.

4.3.1| Technology

The focus on technology for reducing emissions is entirely consistent with the ecological modernisation (EM) governmentality. This is not only because EM is optimistic about technologies' contribution to climate change mitigation, but also because technology development and diffusion have positive effects for the economy and greater availability of clean transport allows transport to be decarbonised through the (neo-liberal) logic of consumer choice. The emphasis on technology in academic research not only reflects equipment-related path dependencies (see above) but also the popularity of technologically oriented interventions in transport among corporate actors (including the automobile industry) and public authorities, for whom technological innovation is a key mechanism through which EM's marriage of economy and ecology is forged.

The transport literature's engagement with technology is partial. There exist notable differences across studies, which make it difficult to draw general conclusions about how technology diffusion and adoption are addressed. Nonetheless, the literature tends to consider the complexity of the effects of fuel efficiency improvements and alternative fuels only up to a degree (visibilities). For one, differences between households in the uptake of low-carbon transport technologies are often not satisfactorily addressed; too often an average traveller/consumer is assumed. Axsen et al. (2009) and Musti and Kockelman (2011) constitute exceptions in this regard, respectively examining within the context of forecasting future transport-related CO_2 emissions the 'neighbourhood effect', whereby EVs become more desirable as adoption rates become higher, and variations in vehicle type choice along sociodemographic lines. Not only is much more research along these lines required; that work should also consider dynamics over time in the cultural legitimacy – socially shared perceptions as to whether a technology is desirable and appropriate within a socially constructed set of

values, beliefs, norms and understandings (Geels and Verhees, 2011) – of new transport technologies beyond the neighbourhood effect. Technology diffusion is more than a linear process of moving from niche to mass markets in which consumer preferences change. It often entails changes in the cultural meanings of artefacts, which may both facilitate and obstruct the diffusion of new technologies.

Additionally, while the rebound effect of extra kilometres driven with improved fuel efficiency is increasingly considered in prospective scenario studies (Bristow, 2009; Kromer et al., 2010; Morrow et al., 2010), the tendency to separate technological change from behavioural change is widespread in the literature. Technology as a 'hard' intervention is often compared to, juxtaposed with and/or combined into policy packages with, 'soft' measures that seek to bring about behaviour change by reconfiguring travellers' psyche (Bristow et al., 2008; Kromer et al., 2010; see also Johansson, 2009). From a Foucaultian perspective, the separation of technology and psyche/behaviour is productive in the sense of allowing research to proceed but as a discursive technique it also has unintended consequences. It strips technology-oriented interventions in transport systems from their behavioural entanglements, i.e. the fact that technologies only reduce GHG emissions if they are actually used to move people or goods. In this discursive framing, transport technologies are not only positioned as means towards given ends (which are part of the behaviour realm); freed from the vagaries of preferences, values and needs, their contribution to transport's decarbonisation are also made relatively certain and reliable.

The idea that transport technologies are means towards ends and that their contribution to decarbonisation can be separated from intentions, aspirations and behaviour is problematic. It can be questioned by drawing on Science, Technology, and Society (STS) studies. A key lesson from actor-network theory (ANT) – one of the leading analytical frameworks within STS studies – is that new technologies tend to act as mediators that change practices rather than intermediaries that realise predefined goals (Latour, 2005). Upon interaction with new technologies, people's behaviours and intentions are often reconfigured and novelty is inserted in existing routines. It is extremely difficult, if not impossible, to anticipate which aspects of behaviours and routines will change. Technological innovations come with fundamental uncertainty, which impose real limits on the predictability of outcomes and on modelling approaches. Hence, when considering the potential contribution of technological changes to decarbonisation, researchers should be much more careful in attributing determinate effects to technological interventions and pay more attention to the minutiae of practices in which technologies become enrolled (see also Section 5).

4.3.2| Pricing and budgeting

The emphasis on, and belief in, economic approaches to decarbonisation in transport operating via pricing and budgeting mechanisms is fully compatible with, and linked to, the EM governmentality and neo-liberalism more generally. While transport researchers have long since emphasised the importance of monetary prices to travel decisions, the more general shift towards market-based approaches and the carbon economy have reinvigorated the idea that "[p]ricing is absolutely critical" (Bristow, 2009:28). Interestingly, authors defend downstream carbon trading approaches amongst others by positioning it as a technique of agency and freedom (Dean, 1999): it both enhances and deploys the capacities of individuals (McNamara and Caulfield, 2011), households (Niemeier et al., 2008) or local communities (Salon et al., 2010) to self-govern emissions levels. Actors are evidently imagined as responsible, active and calculating – neo-liberal – subjects who need not be told what to do when carbon markets function properly.

However, these strategies assume that individuals, households and communities are endowed with the competence to allocate their monetary/carbon budgets such that their interests are served in the best possible way. They thus assume that travel choices are primarily governed by an economic, utility maximising logic. While this assumption is common in transport studies (see Section 3.2), there is increasing evidence that other, more-than-rational factors, such as symbolism and affects, play an important role in travel practices (Steg, 2005; Anable et al., 2011) and are entangled in complex ways with rationality (Randalls, 2011). Further, the above arguments regarding the introduction of novelty in existing routines can be repeated. Randalls (*ibid*.) argues that personal carbon trading will mean that people will re-orient their lives, aspirations and livelihoods and use trading schemes in much more differentiated ways than economic theory suggests. Hence, more may change with trading/pricing schemes than the ways in which people allocate carbon/monetary resources given pre-defined goals, perhaps to such a degree that the outcomes of such schemes become indeterminable. The voluntaristic model of (boundedly) rational, calculating and self-responsible subjects that is characteristic of neo-liberal governmentalities needs to be broadened. Richer conceptualisations of subjectivity are required if the full range of effects of market-based approaches to climate change mitigation on individuals (municipalities) are to be appreciated (even if this means that scholars' ability to predict those effects are sacrificed).

4.3.3| Changing psyche

The growing reliance on notions and modes of reasoning from social/behavioural psychology can, just like the popularity of market-based approaches to climate change mitigation, be linked to neo-liberalist styles of government and subjectification processes. As Rose (1999:231)

documents, neo-liberal discourses of the self hold that individuals actively construe their own life and such domains as work, family, leisure or transport as meaningful and satisfactory in and through the choices they (are obliged to) make. A unique lifestyle is the result, which people are expected to be able to justify and make intelligible to others in terms of motives, needs, aspirations, personal values, likings and so on. Influential models from social/behavioural psychology, such as the Theory of Planned Behaviour (TPB) (Ajzen, 1991) and Norm Activation Model (NAM) (Schwartz, 1977), are compatible with, and even enhance, this form of subjectification.

The growing popularity of these models for understanding the 'softer' side of climate change mitigation in passenger transport also reflects that, aided by their quantitative character, they are simultaneously individualising and totalising. Not only do they allow the decision-making processes of individuals to be laid out in separate components; by positing an average or representative subject, they also allow generalisations and the identification of regularities in psychological mechanisms at the population level. They are thus in keeping with biopower thinking. The attractiveness of TPB, NAM and related models in the context of transport related climate change mitigation stems at least in part from the possibilities they offer to target such specific factors as the attitudes, perceptions of control and personal or social norms of individuals within larger populations with dedicated policy interventions (e.g. awareness and promotion campaigns).

The self-responsible, active subject positions promoted through such social/behavioural psychology models as TPB and NAM are arguably more textured than those in most utilitarian analyses of behaviour. Nonetheless, these models and the transport studies based on them also expel several issues into invisibility. First, because of their totalising ambitions, the degrees of freedom in terms of the number of factors impinging on behavioural intentions and the structure of relations between those factors are limited. There are clear restrictions on the extent to which differences between people and between situations in terms of drivers of intentions can be captured. Second, models such as TPB and NAM are static, as the dynamics over time and feedback processes are generally not considered. Third, those models intellectualise behaviour (Reckwitz, 2002) as they assume that behaviour is first and foremost driven by conscious thought. However, work in sociology, human geography and other fields – known as practice theories (*ibid*.) and theories of affect (Thrift, 2007; Clough, 2008) – has shown that conscious thought is but one of many factors involved in behaviour; semi-conscious factors, embodied capacities and tacit know-how are often at least as important. The sidelining of all these processes in the transport literature may be one factor explaining value-action gaps, which is another silence in most psychology-informed studies about travel behaviour change. These gaps refer to the difference between stated values and intentions and actual behaviour (Blake, 1999; Shove, 2010), and constitute significant challenges to such models as TPB and NAM.

Hence, we believe that research about travel behaviour change should not only draw on social/behavioural psychology but also on alternative conceptualisations from the social sciences.

4.3.4| Infrastructure

While the focus on interventions in transport infrastructure and built environment in much research primarily reflects path dependencies in the discipline's historical evolution, it is certainly not incompatible with more general ways of understanding and acting towards climate change. It fits in rather well with the neo-liberal logic of consumer choice, according to which climate change is to be mitigated via the voluntary choices of individuals, households, firms and organisations. It also resonates with the EM/neo-liberal notion that public authorities should enable and facilitate rather than reduce choices and behaviours.

4.3.5| Institutions

The emphasis on the role of institutions in effective climate change mitigation in the transport sector also aligns with neo-liberal governmentality and EM approaches. After all, EM approaches attach great importance to institutional learning and reflexive multilevel governance, and critical evaluation of the economy of government is an important feature of neo-liberalism (Dean, 1999; Foucault, 2008). In the transport context key questions evolve not only around issues of governing too little or too much but, also around issues of whom or what agency can govern most effectively. Several neo-liberal and EM themes feature in the transport literature about climate change. These include the benefits and dangers of devolving responsibilities to local and regional authorities (Anable and Shaw, 2007; Marsden and Rye, 2010), as well as the changing role of the state, with authors arguing that the responsibilities of national-level authorities should shift from command-and-control planning towards instigating, facilitating, coordinating and empowering niche-developments, such as new technologies and governmental practices, in public-private partnerships (Kemp et al., 1998, 2011). Thus, academic studies of institutional arrangements for effective climate change mitigation in transport both emerge from neo-liberal governmentality and reflect on processes immanent to this style of government.

4.3.5| Methods

Whilst reflecting broader trends in such social sciences as sociology, human geography and urban and environmental planning, the emerging trend towards participatory and qualitative methods in climate change mitigation research in transport research also resonates with neo-liberal governmentality. It is the research variant of Dean's (1999) techniques of agency and

freedom through which the civic society is mobilised and more active subject positions are created for non-scientific experts.

At the same time, the dominance of such quantitative methods as models for forecasting future emission levels and regression-type analysis undergirded by positivist epistemologies is consistent with the biopower or green governmentality. This is because these methods allow all carbon consumption in transport activities, which are spatially and temporally distributed across a wide geographical area (typically a country) and time-span (e.g. a year), to be condensed into a centralised account located in a single or several desktop computers. They create what Latour (2005) calls oligoptica – specific sites where the spatially and temporally distributed effects of (future) changes in transport technologies, population composition, land use configurations, and so on, can be observed and monitored. These sites make possible and aid the management of the biosphere's resources. They allow researchers and others to provide answers to questions about how violations of boundaries on the biosphere's carrying capacity as a consequence of growing carbon consumption can be avoided, and about how (public) resources available for climate change mitigation can be allocated prudently given those boundaries.

The deployment and development of such quantitative methods as forecasting models generate other governmental effects as well. First, virtually all forecasting models used in transport research about climate change mitigation enact time as a linear, objective and singular dimension, and changes occurring at t_1 are in principle equivalent to those at t_2. Although this understanding of time is common in transport studies and the (social) sciences more widely, it implies that CO_2 emissions of quantity *x* saved will have the same effect in, say, 2020 as in 2040. This (intuitively agreeable) approach entails the favouring of what John Urry (2011:21) calls a gradualist understanding of climate change. Climate change is thus regarded as relatively slow and linear rather than as abrupt, involving thresholds and rapid shifts. Catastrophist understandings of climate change, which revolve around non-linearity and on Urry's reading are supported by numerous and varied events in the early 2000s (e.g., extreme weather, unprecedented melting of Arctic/Antarctic ice), could be accommodated better if forecasting models and related methods drew on complexity theory. Since these are predicated on nonlinearity, they make the urgency of taking action *now* would become visible more clearly (Collins, 2010). By incorporating more advanced conceptualisations of time in models and scenario approaches, scholars can offer more nuanced insight into the effects of the timing of measures to decarbonise transport.

Secondly, forecasting models also help to reproduce the authority of academic transport studies. While specific methods and results may be challenged from within as well as outside the academic community, quantitative models – more so than qualitative methods like in-depth interviews or ethnographies – confer a sense of objectivity on their developers/users and are

capable of generating authority and impact outside academia as well as new research money (cf. Latour, 1987). So, the use of, and reliance on, these methods among transport researchers not only reflects path dependencies and status quo bias. We suspect that they are also popular because their specific and unique capacity to conveniently summarise complex tendencies in carbon use within transport systems and populations reconfirms the societal relevance of academic transport research and helps to secure its continued existence.

5| Discussion: social science contributions

Transport researchers engage in diverse and rich ways with issues of climate change mitigation in the transport sector. Nonetheless, certain ways of thinking and doing research with regard to transport's decarbonisation prevail. There is a strong emphasis on mitigation via technology, economic instruments and infrastructure provision, and to a lesser degree on reconfigurations of travellers' psyche through information campaigns and social marketing and of the institutional arrangement of transport governance. Insights from engineering, (neo-classical) economics and to a lesser degree psychology prevail and most research is predicated on the use of quantitative methods embedded in positivist epistemological frameworks. This pattern is the consequence of mutually reinforcing trends within and beyond the academic transport community. It is not only reflective of the life-histories of transport studies as a discipline and community of practice, but also continuously produced and reconfirmed through the power that the outcomes of techno-economic, and to a lesser degree psychological, approaches generate within and especially outside academia, where green governmentality and ecological modernisation constitute the main frameworks for tackling climate change mitigation. With the likely expansion of market-based approaches to climate change mitigation local, national and international authorities in the coming decade, the basis of climate change-related transport research in techno-economic thinking is likely to be reinforced.

Techno-economic and psychological thinking provides compelling insights into transport's decarbonisation. Yet, like all scientific perspectives, techno-economic and psychological approaches are inevitably partial: they articulate the objects of knowledge/government in particular ways, expelling certain of their facets into invisibility. Examples of sidelined facets include the societal embedding of new transport technologies, the inherent uncertainty and novelty new technologies and such economic instruments as PCT insert into travel behaviours, the semi-conscious more-than-rational dimensions of those behaviours, and the non-linear and catastrophist dimensions of climate change. Insights, concepts and methods from other disciplines, and particularly the social sciences, can be used to confront rather than silence these and other uncertainties, complexities and intricacies of climate change mitigation in

transport. More specifically, we contend that drawing on a range of social science traditions comes with at least three benefits:

- Climate change mitigation in transport can be understood as a multiplicity of context-dependent social processes;
- A wider repertoire of research methods (e.g., ethnography, participatory action research) and epistemological frameworks (e.g. feminism, post-structuralism) becomes available; and
- Different sets of research questions are opened up.

Space constraints prevent us from exploring each benefit in great depth. We therefore focus on the additional insights that would be gained from deeper engagement with two specific research traditions – work on socio-technical transitions and practice theories. They are non-positivist in nature and imagine climate change mitigation as complex social processes.

A *socio-technical transition* is a major shift or step change, in which an existing socio-technical system – a cluster of aligned elements including technology, regulations, consumer practices, cultural meanings, markets, infrastructure, scientific knowledge, supply and maintenance networks – is durably reconfigured (Kemp et al., 1998; Geels, 2002, 2011). More specifically, a transition implies that a micro-level *niche* (an initially unstable configuration in which radical technological innovations emerge that are shielded from market mechanisms and carried by a small group of actors) under the influence of macro-level or *landscape* developments (broader economic, political, demographic and cultural changes) fundamentally change the prevailing meso-level *regime* – the practices, competences, knowledges and material artefacts that constitute the dominant transport system(s) in a society at a given moment in time (Geels, 2002). Such a transition is imagined as a co-evolutionary process involving many actors and social groups and usually spanning several decades. The literature on transitions can be divided in two groups. One studies the longitudinal processes of past transitions in different domains, including transport (Geels, 2002, 2005, 2011); the other examines which institutional arrangements foster the durable reconfiguration of current regimes through niches in the near future (Kemp and Loorbach, 2006; Kemp et al., 2011). The former group is predicated on thinking from evolutionary theory and interpretative sociology (Geels, 2010). Research in this area often adopts a historical case-study approach but has more recently also sought to understand innovation journeys (Geels and Verhees, 2011) in contemporary transport (Nykvist and Whitmarsh, 2008), including the introduction of EVs (Dijk and Yarime, 2010; Van Bree et al., 2010).

Work along these lines is particularly helpful for at least three reasons. First, the notions of socio-technical system and regime draw attention to a broader range of elements and social actors and the positive feedback between those elements than conventionally considered in transport studies of climate change mitigation. It draws attention to the critical role of, and interactions among, lobby organisations, the media, financial agents like venture capital

suppliers and insurance companies, designers, material and machine suppliers, and so on alongside public authorities, transport companies, vehicle producers and consumers. Secondly, historical analyses of past transitions tell us much about the – often contingent – factors conducive to step change. Thirdly, technologies are not considered objectively given but socially interpreted ('constructed'); their social interpretations affect the trajectories of technological innovation and diffusion processes. Hence, the societal embedding and cultural legitimacy of technological development is considered essential (Geels and Verhees, 2011): new technologies need to become integrated in relevant industries and markets (business environment), match regulations, rules and standards (regulation environment) and fit with existing social norms and beliefs (wider society). Recent research suggests that the cultural legitimacy of EVs in Europe and North-America has not been large enough to trigger a transition towards electric road transport. Despite environmental regulation, the car industry has largely focused on incremental innovation in internal combustion engines (Dijk and Yarime, 2010). It is unclear whether strongly enhanced support measures for green cars will be feasible in the near future as there is as yet no cultural sense of urgency among the general public (Geels, 2011).

In *practice theories* behaviour is understood as routinised and as the integration of four sets of elements (see also Reckwitz, 2002; Shove and Walker, 2010): the material – objects, infrastructures, human bodies; the procedural – know-how, competences; the symbolic – meanings, identities, norms; the affective – feelings, emotions, moods, atmospheres. There are at least two key differences with (neo-classical) economics and (social/behavioural) psychology. First, there is less emphasis on conscious decision-making as the key driver of behaviour. It is recognised that practices mostly originate in semi-conscious processes. Secondly, the individual is not imagined as an autonomous, sovereign actor and displaced from centre-stage: s/he is the carrier of practices and the place where different practices intersect (Reckwitz, 2002; Halkier and Jensen, 2011). The focus is on her/his recruitment and defection from a given set of practices (Watson, 2011). Practice theories are highly variegated, inspired by a wide range of theorists – from Heidegger and Latour to Butler and Giddens. Empirical work tends to draw on ethnographic methods (e.g., participant observation, video-ethnography, diaries, auto-photography), and in-depth interviews based on theoretical rather than statistical sampling (Halkier and Jensen, 2011).

A key advantage of practice theories is their imagining of behaviour as the interweaving of the material, the procedural, the symbolic and the affective. Neither neo-classical economics nor psychological models of behaviour foreground this integration of elements and tend to privilege one or a few sets of such elements. Note that practice theories also provide an alternative to the common methodological strategy of separating (sets of) factors that influence behaviours and identifying their unique effect and relative importance, as is common in statistical/econometric analysis. It is emphasised instead that the material, procedural, symbolic and affective need to

be closely aligned for travel practices to become less carbon-intensive. Another stronghold is that movements through physical space are understood as continuously unfolding and as relational accomplishments (Shove and Walker, 2010): travelling or moving goods is "practically … done, re-done and slightly differently done" (Halkier and Jensen, 2011:106). Not only is heterogeneity in general foregrounded; the sheer variety of ways in which technologies are appropriated and used within practices is highlighted (Hand and Shove, 2007). The use of 'old' and 'new' artefacts, such as bikes or EVs, is understood as inherently unstable, subject to continual re-alignment triggered by changes in an individuals' life-course, and by collective concerns and anxieties about care, comfort, quality, ethical behaviour (*ibid*.; Dowling, 2000). Instability also follows from the position of those artefacts as junction points between multiple systems of meaning and competence (Hand and Shove, 2007). The use of practice theories in the transport context has been modest so far, but has great potential in understanding the multiple ways in which new transport technologies and such techniques of agency and freedom as PCT are embedded and re-embedded in dynamic social practices and hence how much carbon is actually consumed.

We do *not* suggest that current practice in transport research about climate change mitigation should be displaced by these alternative analytical perspectives – they inevitably come with their own blind spots. Also, existing competencies and excellence should be retained. We rather envisage something resembling Longino's (2002) engaged pluralism, according to which researchers employ different theoretical perspectives, use different epistemologies, methodologies and methods, and study different facets of climate change mitigation in such a manner that no perspective, method or facet takes precedence over, or marginalises, any of the others. Researchers should try to learn from and about the work by colleagues in different traditions, engage in debate with them regarding their evidence, methods, assumptions and reasoning, and use such debates to reflexively engage and extend their own assumptions and research. Whilst communication across research traditions poses significant challenges, it is our firm belief that pluralism will ultimately produce richer, more textured understandings of effective climate change mitigation in transport than at present.

Social science perspectives also open up new research questions. Transport research on climate change mitigation tends to revolve around the reduction of carbon use *given* existing economic, social and political systems and ideals. Because transport's decarbonisation poses such a massive challenge, the emphasis on reduction is completely understandable. For critical social scientists, however, questions about deep cuts in carbon use in transport are inextricably linked to such issues as the organisation of contemporary societies, the role of transport therein, justice and ethics. Questions we believe should be addressed if decarbonisation is to be sped up include the following:

- What is the kind of world that we would like to live in and find desirable and how should mobility be configured in that world?
- Why are the responsibilities for decarbonisation primarily located with individuals, the producers of transport technologies and (local) administrations and not with those stakeholders promoting economic growth as necessary to a nation's or region's wellbeing and propagating consumerist lifestyles? How should responsibilities be distributed between the OECD and other countries?
- Will a neo-liberal logic of choice and voluntary action suffice to enact rapid systemic rather than incremental change in carbon use in transport?
- Will neo-liberal ways of decarbonising transport not exacerbate inequalities in travel patterns along lines of gender, race/ethnicity, class, residential location and their intersections?
- Will business models in manufacturing and leisure/tourism based on current global production chains and aviation networks remain feasible?
- Is mobility in principle a right to which people are entitled?

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