Integrated Sustainability Assessment of mobility transitions: simulating stakeholders' visions of and pathways to sustainable land-based mobility

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Abstract: In this paper, we outline work underway within the EC-funded MATISSE project to develop innovative agent-based simulation models to support learning and decision-making for Integrated Sustainability Assessments (ISAs) of sustainable mobility. The tools we are developing are designed to simulate – and stimulate – 'transitions' (radical systemic innovation) to sustainable futures. In applying the modelling tool to the land-based mobility case, we have used desk research and stakeholder workshops to identify visions of and pathways to sustainable mobility. Future work will use the agent-based modelling tool to assess the impacts of policies on sustainability criteria defined by stakeholders.

Keywords: transitions; mobility; agent-based model; stakeholders; sustainability assessment.

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1 Introduction

This paper reports on research underway within the MATISSE project[1] to develop innovative tools for Integrated Sustainability Assessment (ISA), an interdisciplinary and participatory approach to sustainability policy development and appraisal (Weaver and Rotmans, 2006). The tools we are developing are designed to simulate – and stimulate – 'transitions' (radical systemic innovation) to sustainable futures in particular contexts (Haxeltine et al., 2008). In this paper, we focus on the application of the transition-modelling tool to the land-based mobility case. As we argue later, a transition is required to overcome the persistent problems of unsustainability in mobility systems today. Using stakeholders' definitions of sustainable mobility, and their suggested pathways and policies, the mobility transition model may provide a valuable learning and decision-support tool for sustainable mobility.

This paper presents the mobility transition model, including its theoretical and empirical basis. The following section briefly describes the theoretical framework of transitions we use to guide our model development and frame our ISA of how Europe might undergo a transition towards a more sustainable mobility system. Then, we outline the sustainable mobility visions and pathways we have derived from our review of the literature and recent stakeholder workshops. Next, we describe the application of the modelling framework to the mobility case study. The final section concludes and outlines plans for further research.

2 Transitions in mobility

A 'transition' can be understood as radical systemic innovation (e.g., Rotmans, 2005). Recent studies of transitions have explored disruptive technologies and related institutions (e.g., Geels, 2005), as well as broader shifts in behaviour and institutions at the level of societal functions (e.g., transport, communication, healthcare) (e.g., Rotmans et al., 2001).

Central to the most recent literature on transitions are the concepts of 'niche', 'regime' and 'landscape' (see Haxeltine et al., 2008). The regime comprises dominant actors, institutions, practices and shared assumptions (Rotmans et al., 2001). While it provides stability and cohesion of societal systems, it also tends towards optimising the current system through incremental change, using the capabilities and resources of dominant players. Less structured and at the periphery of the regime, niches have been identified in historical empirical studies of transitions as the typical loci for radical innovation. Unlike the regime, innovation in niches is relatively unconstrained; path-dependencies have not developed and patterns of behaviour and institutions have not become locked-in (Geels, 2005). At the most structured level, the landscape comprises changing economic, ecological and cultural conditions, in which the regime may be more or less well suited to fulfil its functions. As this landscape changes, the regime may experience stress and is typically slow to adapt (owing to path-dependencies, lock-ins, etc.), whereas niches evolve more quickly (Kemp and Rotmans, 2004). A transition is said to occur when an incumbent regime is replaced or radically transformed.

Mobility presents an ideal case study for our work on modelling sustainability transitions. Mobility systems today are characterised by environmental, social and economic unsustainability in a number of respects. Road-based land transport suffers from intractable problems such as congestion, emissions of greenhouse gases and local air pollutants, noise, accidents, depletion of resources, and inaccessibility of amenities and services (e.g., European Commission, 2001a; European Environment Agency, 2006). Policy solutions to tackle these persistent problems have focussed on improving technologies and (to some extent) encouraging modal shift, but these have done little to address the underlying growth in mobility demand (European Commission, 2001b). It has, therefore, been argued (e.g., Kemp and Rotmans, 2004; Nykvist and Whitmarsh, 2008) that a transition in land-based transport is required to move away from the current regime and towards a more sustainable mobility system. Such a transition is more likely to require both technological and institutional changes (e.g., electric and fuel cell vehicles, customised mobility, teleworking, zoning policies) (Elzen, 2005; Kemp and Rotmans, 2004).

We have defined three 'niche areas' in which sustainable mobility may germinate (Nykvist and Whitmarsh, 2008):

1. novel vehicle and fuel technologies
2. transport product to service shift (i.e., from car ownership to increased car sharing and public transport use)
3. reduced mobility demand through changes to lifestyles (e.g., increased use of Information and Communication Technologies (ICT)) and infrastructures (e.g., more mixed-zone developments).

In our initial modelling experiments, we are focussing on these niche areas within the UK. Empirical evidence suggests slow growth of *alternative fuels and propulsion technologies in the UK*, although recently, sales of low-emission conventional-fuel vehicles are increasing more rapidly. Development of the *transport services* niche area (2, above) is somewhat ambiguous, with growth in the car service market and policies to support modal shift, but continued dominance of private car use. Finally, within the *reduced mobility demand* niche area (3, above), there are positive trends such as the growth of ICT for shopping and working, but little growth in use of slow modes and continued urban sprawl. Further details can be found in Nykvist and Whitmarsh (2008).

Landscape changes that may support the development of these niches include: environmental pressures – notably climate change, air pollution, and resource depletion; sector-wide decline of the automotive industry and simultaneous growth of other sectors (e.g., ICT); and a (partial) shift in social values and policies to embrace sustainability (for more details see Nykvist and Whitmarsh, 2008).

In response to these macro-level changes, transport regime organisations (e.g., energy producers and suppliers, automotive firms) have begun investing in novel vehicle and fuel technologies and adapting their business models to include more service provision

(Köhler et al., 2008). Importantly though, we see different regime organisations responding to these landscape pressures in divergent ways. For example, while major automotive firms are investing in ethanol vehicles, the natural gas and oil industries have responded by lobbying the UK government to impose standards to constrain and delay ethanol commercialisation (Taylor, 2006). Across Europe and the world, different car manufactures choose to develop different technologies (Köhler et al., 2008) and local conditions in countries and regions give rise to divergent developments (see Bomb et al. (2007) for a comparison of UK and Germany, and Nykvist and Whitmarsh (2008) for a comparison of UK and Sweden). Debates on which new solution to follow are intensive, particularly in relation to biofuels (e.g., Kennedy, 2007). These examples of tensions are what de Haan (2007) refers to as 'stress' – internal misalignment within the regime – which is typically a precursor to transition. A historical example is the case of the transition from horse-drawn carriages to automobiles, where the old regime collapsed completely before a new regime emerged (Geels, 2005).

3 Visions of, and pathways to, sustainable mobility

The mobility model application is designed to simulate possible transitions in mobility to more – or less – sustainable futures. The model can test the impact on mobility choices of different policies (e.g., congestion charging) or landscape changes (e.g., demographic shifts). Sustainability criteria against which to assess outcomes of modelling experiments are partly drawn from the literature on sustainable mobility (European Commission, 2001a, 2006; Joint Expert Group on Transport and Environment, 2000; SUMMA, 2005). Table 1 presents a sustainable mobility definition from past research (specifically, the EU-funded SUMMA project on sustainable mobility). This highlights the range of social, economic and environmental aspects of mobility.

Table 1 Dimensions of sustainable mobility according to Sustainable Mobility, Policy Measures and Assessment (SUMMA) project

Economic outcomes	*Environmental outcomes*	*Social outcomes*
Accessibility	Resource use	Accessibility and affordability
Transport operation cost	Direct ecological intrusion	Safety and security
Productivity/efficiency	Emissions to air	Fitness and health
Costs to economy	Emissions to soil and water	Liveability and amenity
Benefits to economy	Noise	Equity
	Waste	Social cohesion
		Working conditions in transport sector

Source: SUMMA (2005)

In our work in the MATISSE project, we draw on these existing definitions, but also work together with transport stakeholders to define 'visions' of, and pathways to, sustainable mobility. Stakeholder engagement is relevant to this issue, given the complexity, ambiguity and subjectivity that surround persistent problems of unsustainability, such as transport. ISA has been defined as a heuristic and explorative process that integrates analytical characteristics appropriate for transition analysis with a process architecture that facilitates social learning and reframing. As such, ISA is a fundamentally participatory approach to sustainability assessment (Weaver and Rotmans, 2006; cf. Gibson et al., 2005). This is consistent with a move away from scientific knowledge as exclusive and non-reflexive ('Mode-1' science) towards more inclusive, applied and socially accountable processes of knowledge production ('Mode-2' or 'post-normal' science), which are particularly appropriate under conditions of high uncertainty and risk, value disputes, and urgency (Funtowicz and Ravetz, 1990; Gibbons et al., 1994). Involving stakeholders will not necessarily result in a more sustainable solution; consequently, participation should not be seen as a panacea. However, considering diverse perspectives is more likely to improve the validity and applicability of assessment (Gibson et al., 2005).

In total, four workshops on sustainable mobility have been convened between February 2006 and June 2007: two with more 'expert' European stakeholders – i.e., professionals with knowledge about transport systems and transport technologies (from research/academia, automotive sector, energy sector, NGOs and government); and two with UK citizens – i.e., transport users. (Details of these workshops can be found in Whitmarsh et al., 2007a, 2007b; Whitmarsh and Wietschel, 2008). The workshops elicited stakeholders' criteria for sustainable mobility and their suggestions for how to achieve this future (i.e., visions of and pathways to sustainable mobility). The following paragraphs summarise key findings from these workshops. An important limitation of this stakeholder engagement work relates to the unrepresentativeness of the participants at the workshops in relation to European or UK transport stakeholder groups overall. To mitigate this limitation, the view of stakeholders elicited in other relevant studies is also included in the following discussion where they deal with the same topics addressed in this study.

Table 2 summarises the definitions of sustainable mobility that emerged from stakeholder workshops conducted within the MATISSE project. Overall, we see that environmental, social, and economic criteria were mentioned; yet, environmental aspects (emissions, depletion of resources) tended to be emphasised. For citizens, integrated, public transport was also very important. A comparison of the two stakeholder groups suggests that transport users (i.e., citizens) focussed more on the experiential aspects of transport. The attractiveness/amenity of transport was evidently more important for citizens than for experts who focussed on macro-level pragmatic and technological issues such as energy supply. Comparison of Tables 1 and 2 indicates that MATISSE stakeholder criteria for sustainable mobility are a subset of SUMMA criteria.

Tables 3(a) and (b) summarise stakeholders' preferred policy options for sustainable mobility. Both groups support modal shift and novel vehicle/fuel technologies, while there is more support for measures to reduce demand (i.e., promote slow modes and local lifestyles) amongst the citizen group than amongst the expert group. Economic policies are more popular amongst expert stakeholders than amongst citizens (in part, such differences may arise because of the type of participants who participated in the workshops – i.e., primarily transport technology experts and more environmentally aware citizens – and the variation in question format – pre-defined list vs. open-ended – between the two groups).

Table 2 Stakeholder criteria for sustainable transport

	Experts	*Citizens*
Environmental	Renewable (inexhaustible supply)*	Renewable-fuelled vehicles
	Low/zero emissions – particulates and GHGs, no toxic waste	Low/no pollution, clean vehicles*
	Efficiency	Energy-efficient vehicles
Economic	Competitiveness	Job creation, cheap/affordable
	Flexibility/synergy between sectors	
	Prices reflect real value/externalities	Fiscal/policy change to cut pollution/congestion
	Available infrastructure	Integrated*
Social	Energy supply security	
	Diversity of supply	
	Low/no congestion	Modal shift and reduced demand, local amenities/workplaces (liveability)
	Political, industrial and public support	
	Safety	Safety
	Social inclusion	Public transport*, walking and cycling; accessible
	Personal freedom	Personal transport, moderate travel
		(amenity/utility) reliable/regular, fast, fun, enjoyable, choice, clean, aesthetic

*Most popular responses.

Source: Whitmarsh et al. (2007) and Whitmarsh and Wietschel (2008)

Table 3(a) Citizens' preferred options for future transport

Preferred options for future transport (*MATISSE citizen workshops*)		*Total**
Behaviour/value/infrastructure change	Walking/cycling to work, shops etc.	52
	Car-free developments	38
	Improved public transport	32
	More tele-working (i.e., working from home)	15
	'Home zones'	16
	Car sharing	8
	Bike pool	6
	Car pools/hire	5
	Road–rail system (individual pods on tracks)	5

Table 3(a) Citizens' preferred options for future transport (continued)

Preferred options for future transport (*MATISSE citizen workshops*)		*Total**
RD&D, technology	Hybrid cars (e.g., Toyota Prius)	13
	Hydrogen and fuel cell cars/buses	11
	Biofuel cars/buses	7
	Jet packs	4
	Bus tracking system	4
	GPS	2
	Improved road signage	4
Economic policies	Congestion charging	9
	No change from present	1

*Participants were asked to allocate 10 votes between options (a pre-defined list was provided, but participants could also add options) at the citizen workshops in September 2006 and March 2007.

Table 3(b) Expert stakeholders' preferred policy options for sustainable mobility

Preferred options for sustainable mobility (MATISSE expert workshop)		*Total**
Behaviour/value/infrastructure change	Support/provision of public transport	6
	Modal shift/car sharing	3
	Local lifestyles/reduced demand/land-use planning	2
	Reduction of energy consumption	2
	Changing/influencing behaviour	1
	Changing attitudes (question need for SUVs)	1
	Abolish paradigm of endless economic growth	1
	Individual transport by car / individual transport	2
RD&D, technology	R&D of new technologies	4
	Subsidies for alternative fuels and infrastructure	2
	Increase vehicle/fuel efficiency	1
	Demonstration projects	1
	H_2 is long-term solution; biofuels only mid-term	1
Economic policies	Pricing policies	6
	Taxation	4
	Shipping and operation taxes/tolls	1
Regulation/targets	Reduced parking in cities	1
	Regulation	1
	Carbon intensity target on fuel supply	1
	No answer	2

*Coded responses to the open-ended survey question: 'What policies are most appropriate to foster sustainable mobility in Europe?' asked at the June 2007 expert workshop.

Previous research to elicit stakeholders' perspectives on transport policies also highlights the need for both technological and non-technological measures to tackle rising transport demand (e.g., Bristow et al., 2004; Jeon and Amekudzi, 2005; O'Garra et al., 2005; Office of Science and Technology, 2005; Sayer, 2003). Compared with another recent survey of UK transport stakeholders (Archer, 2007) – which found that vehicle regulation and tax incentives were most popular – there is less support for regulation and more support for modal shift amongst both groups of MATISSE stakeholders.

The support for demand management measures amongst the citizen groups is noteworthy. Representative UK surveys of public attitudes to transport and transport policy highlight significant challenges to introducing demand management policies. While the UK public expresses concern about pollution and congestion levels (Lethbridge, 2001) and acknowledges the link between transport and climate change (DEFRA, 2002; Department for Transport, 2007), there is growing resistance to measures to curb car use (e.g., raising road or fuel taxes) (Lethbridge, 2001). This highlights the widespread association between driving, on the one hand, and quality of life, status and identify, on the other (Lorenzoni et al., 2007; Steg et al., 2001). This also suggests that the citizens who took part in the MATISSE workshops were more environmentally conscious than the broader UK population.

The findings from these stakeholder workshops and desk research on sustainable mobility (Nykvist and Whitmarsh, 2008) have been used to apply the generic transition-modelling framework (Haxeltine et al., 2008) to land-based mobility (initially in the UK) and identify which policies should be assessed in modelling experiments. The next section provides details of this model application.

4 Modelling transitions in mobility using an agent-based approach

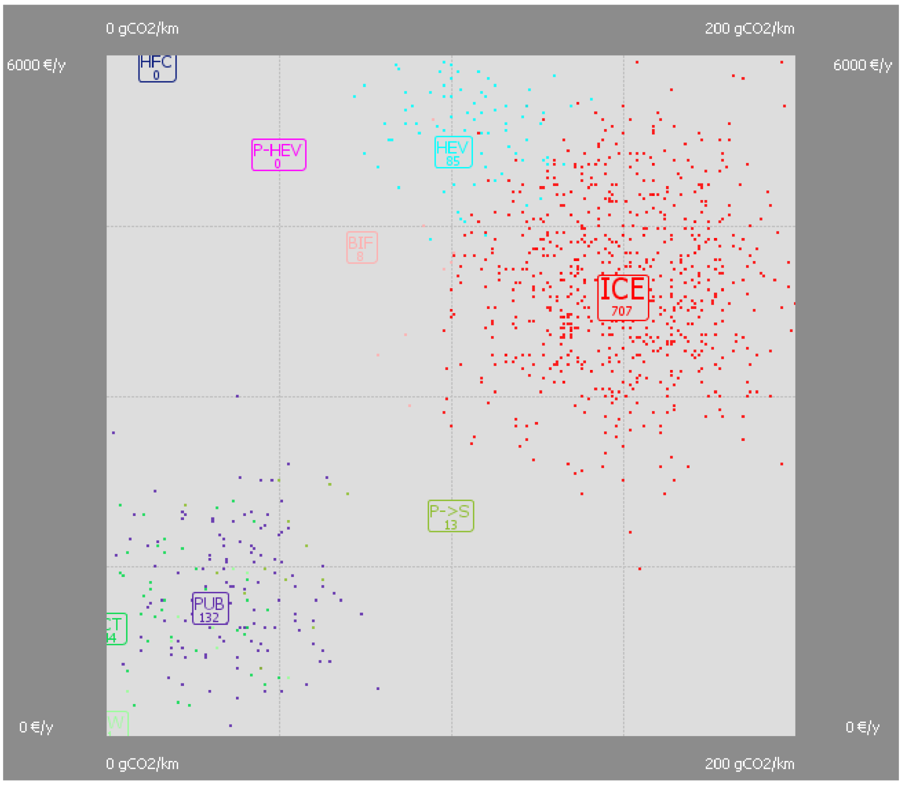
In contrast to other assessment tools, the transition-modelling tools being developed within the MATISSE project highlight the complex interactions between actors and structures and non-linear dynamics within societal systems. The potential for such simulations of social change to add value in multi-criteria decision-making processes is the focus of current work within the project. In modelling mobility transitions, we have drawn on the conceptual framework for transition modelling developed in the MATISSE project (Haxeltine et al., 2008). Thus, our approach has predominantly used 'agent-based' modelling techniques to represent the regime, empowered niches, and niches as aggregate 'agents'. The regime is defined as private mobility using petrol/diesel Internal Combustion Engine (ICE) technology. At time point 0 (year 2000), public transport is identified as an empowered niche. Other niches are: hybrid-electric vehicles, biofuel-powered vehicles, hydrogen fuel cell vehicles, urban ICT-centred lifestyles, car sharing, and slow modes. The model also includes simple consumer/citizen agents who provide 'support' (a broad concept that encompasses generation of resources and power through market, political and cultural processes) to the regime/niche aggregate agents.

Agents are defined over a set of key variables called 'practices'. Practices are broadly defined and include technology production and consumption, transport service provision and use, and infrastructure provision and use. We have identified the least number of practices that can differentiate the various niches, empowered niches, and regime and which impact on the environmental, social and economic mobility criteria identified earlier. These practices are:

- CO_2 emissions (gCO_2/pkm)
- Cost acceptance(€/y)
- Private mobility (pkm/y)
- Public mobility (pkm/y)
- ICT use (alignment with ICT trend; %)
- Built environment (mixed vs. single zone use; %).

Figure 1 shows where consumers/citizens and agents (regime and niches) are located in a chosen two-dimensional subspace of the full 'practice space'. This indicates the (dis)similarity between agents according to their respective interests and activities; in this figure, the difference is in respect of accepted cost and CO_2 emissions. In contrast to most economic models, consumer/citizen preferences and choices are not assumed to be static; rather they respond to changing landscape conditions and the changing power of agents (Haxeltine et al., 2008). Runs of the transition model thus show how the distribution of consumers shifts across this practice space.

Figure 1 Screen-shot of the mobility transition model showing two of the practice dimensions (cost and CO_2 emissions) (Dots represent consumer/citizen; ICE = private-ICE mobility; PUB = public transport; BIF = biofuel vehicles; HEV = hybrid-electric vehicles; P > S = car sharing; HFC = hydrogen fuel cell vehicles; ICT = urban ICT-centred lifestyles; SLW = slow modes)

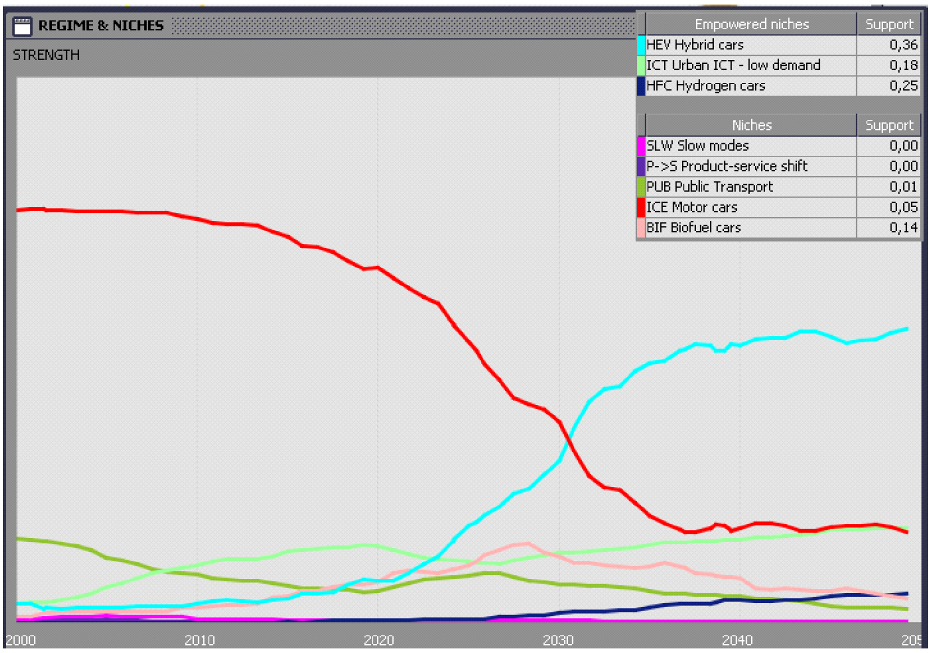


Landscape trends and policy interventions are considered as exogenous 'signals', which affect agents – both directly (via adaptation) and indirectly (via change in consumer/citizen practices, which in turn affects support for agents). Landscape trends in the mobility application include:

- growing consumer/citizen concerns about climate change and emissions
- increased use of ICT (intrinsic value of car reduced)
- rising fuel costs.

Figure 2 shows the dynamic output of an example model run using the initial distribution in the mobility system of consumer/citizen and agent practices shown in Figure 1. This output shows system changes impacting on the 'headline' transition indicator of agent power. In this case, the prevailing private-ICE regime is replaced by a hybrid-electric regime; there is initial growth of the hydrogen niche after 2025. The results from this example run should not be considered a prediction, but rather an indicative simulation of radical societal change processes using novel modelling techniques. Further tests of the mobility prototype model are ongoing. Initial tests show that the model is capable of reproducing the transitions patterns we expect to see (cf. Geels and Schot, 2007), including slow development of niches, followed by a more rapid 'take-off' and then replacement of the regime, as well as failed transitions in which the regime adapts (for more details of typical transition patterns, see Haxeltine et al., 2008).

Figure 2 Screen-shot of a model run in which the prevailing mobility regime (private-ICE vehicles) is replaced (by a hybrid-electric regime). The x-axis represents time (2000–2050); the y-axis represents the power of agents (defined here as support from consumers, where there are multiple agents, support is distributed across agents and always sums to 1)



5 Conclusions

In this paper, we have outlined work underway within the EU-funded MATISSE project to develop innovative agent-based simulation models to support learning and decision-making for sustainable mobility. In the model development, we have used desk research and stakeholder workshops to identify visions of and pathways to sustainable mobility.

Our findings indicate that different stakeholder groups agree on the need to address problems of unsustainability in the transport sector, and identify broadly similar environmental, social and economic criteria for sustainable transport. Many of these have been raised in previous research (e.g., SUMMA, 2005) and are reflected in European transport policy aspirations (European Commission, 2001a). Furthermore, our analysis has exposed different priorities and concerns amongst the stakeholder groups who participated in the research. Amenity of transport was more important for citizens, while experts focussed on pragmatic and technological issues. Both groups favoured modal shift and novel technologies, and citizens also supported demand reduction measures, to foster sustainable mobility. However, other UK research on citizens' attitudes suggests that there are significant challenges to introducing demand management policies (lessons from the London Congestion Charge show, though, that attitudes may change in favour of demand management policies after their successful introduction; Downing and Ballantyne, 2007). In sum, the diverse interests and expertise of stakeholders exposed through our research have proven valuable in defining socially robust concepts of sustainable mobility that can inform the ISA process.

Drawing on this stakeholder engagement work and on other sustainable mobility studies, we have identified key areas of innovation (niches) and activities (practices) to include in our mobility transition model. Future work will focus on using the simulation model to assess the impacts of policies and other landscape changes on the sustainability criteria defined by stakeholders. Policies to be tested in initial modelling experiments will include economic, regulatory, voluntary and informational measures to support R&D of new transport technologies, foster modal shift, and reduce mobility demand.

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Note

[1]Methods and Tools for Integrated Sustainability Assessment (MATISSE), See www.matisse-project.net