ROUTLEDGE STUDIES IN ECOLOGICAL ECONOMICS

Paving the Road to Sustainable Transport

Governance and innovation in low-carbon vehicles

Edited by
Måns Nilsson, Karl Hillman,
Annika Rickne and
Thomas Magnusson

ROUTLEDGE

Paving the Road to Sustainable Transport

This book analyses how the governance of innovation can foster sustainability. The quest for innovation is consistently at the top of the agenda for policy makers around the globe, on the supra-national level, as well as for the nation states and all the way down to debates in local governance and policy boards. At the same time, sustainability is a core feature of this dialogue in creating, diffusing and using technologies and products so that human needs can be met, while unnecessary natural resources are not being used or destroyed.

Based on these premises and given the complexity of sustainable innovation, there is an ever growing recognition among policy makers, industries and analysts that the development and diffusion of technological innovations need governing in order to contribute to societal goals such as climate change mitigation and resource efficiency. Such governance does not necessarily mean orchestration, imposing regulation or other policy measures in a top-down manner. Governance can be facilitated through a number of means by various actors at different levels. This book presents a view of governance that involves almost all types of actors related to any specific sector or field.

This book is about how societies around the world can accelerate innovation in sustainable transport. It examines the relationship between policy change and the development of technological innovations in low-carbon vehicle technologies, including biofuels, hybrid-electric vehicles, electric vehicles and fuel cells. Examining this relationship across countries and regions that are leaders in vehicle manufacturing and innovation, such as the European Union, Germany, Sweden, China, Japan, Korea and the USA, the book aims to learn lessons about policy and innovation performance.

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Abbreviations

AAM	American Automobile Manufacturers Association
ACEA	European Automobile Manufacturers' Association
AT-PZEVs	advanced-technology partially zero-emission vehicles
BAFF	BioAlcohol Fuel Foundation
BAIC	Beijing Automotive Industrial Corporation
BEV	battery-electric vehicle
BIT	Beijing Institute of Technology
BTAP	Battery Technology Advisory Panel
CAFE	Corporate Average Fuel Economy (regulations)
CARB	California Air Resources Board
CCA	1967 Clean Air Quality Act 1967 (California)
CCAA	1988 California Clean Air Act.
CCS	carbon capture and storage
CNG	compressed natural gas
CO_2	carbon dioxide
CTL	coal-to-liquid
CUTE	Clean Urban Transport for Europe
CVCC	compound vortex controlled combustion
CVT	continuously variable transmission
DME	dimethyl ether
DMFC	direct methanol fuel cell
ECUs	electronic control units
EP	electric propulsion
EPA	Environmental Protection Agency (United States)
ERA	European Research Areas
EV	electric vehicle
FAME	fatty acid methyl ester
FC	fuel cell
FCV	fuel-cell vehicle
FDI	foreign direct investment
FPGA	field-programmable gate array
FSEM	Fraunhofer System Research for Electromobility
FT	Fischer Tropsch

GAC	Guanzhou Auto Company
GHG	greenhouse gas
GM	General Motors
GMD	Gordon Murray Design
GTL	gas-to-liquid
HEV	hybrid-electric vehicle
HFC	hydrogen-based fuel cell
HFP	Hydrogen and Fuel Cell Technology Platform
HOV	high occupancy vehicle
IC	internal combustion
ICE	internal combustion engine
ICT	information and communication technology
IMA	integrated motor assist
IPRs	intellectual property rights
IS	innovation system
ITRS	International Technology Roadmap for Semiconductors
IVT	infinitely variable transmission
JAMA	Japan Automobile Manufacturers Alliance
JHFC	Japan hydrogen and fuel cell
JPO	Japanese Patent Office
LEDs	light emitting diodes
LEV	low-emission vehicle
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MCFC	molten carbonate fuel cell
METI	Ministry of Economy, Trade and Industry (Japan)
MIIT	Ministry of Industry and Information Technology (China)
MKE	Ministry of Knowledge and Economy (Korea)
MLIT	Ministry of Land, Infrastructure and Transport (Japan)
MLP	multi-level perspective
MoCIE	Ministry of Commerce, Industry, and Energy (Korea)
MoE	Ministry of Environment (Korea)
MOF	Ministry of Finance (China)
MOST	Ministry of Science and Technology (China)
mpg	miles per gallon
NDRC	National Development and Reform Commission (China)
NEDC	New European Drive Cycle
NGOs	non-governmental organizations
NHTSA	National Highway Traffic Safety Administration
NNSF	National Natural Science Foundation (China)
NO_x	nitrogen oxide
NVH	noise, vibration and harshness
PAFC	phosphoric acid electrolyte fuel cell
PEMFC	polymer electrolyte membrane fuel cell
PHEV	plug-in hybrid vehicle

PM	particulate matter
PNGV	Partnership for a New Generation of Vehicles
R&D	research and development
RME	rapeseed methyl ester
SAIC	Shanghai Automotive Industry Corporation
SASAC	State-Owned Asset Supervision and Administration Commission (China)
SCP	sustainable consumption and production
SiC	silicon carbide
SNM	strategic niche management
SOEs	state-owned enterprises
SOFC	solid oxide fuel cell
SRA	Swedish Road Administration
SSEU	Foundation for Swedish Ethanol Development
STEM	Swedish Energy Agency
SUV	sports utility vehicle
TCO	total cost of ownership
TIS	technological innovation system
TM	transition management
ULEV	ultra-low emission vehicle
UNFCCC	United Nations Framework Convention on Climate Change
USABC	US Advanced Battery Consortium
VMT	vehicle miles travelled
VOCs	volatile organic chemicals
VW	Volkswagen
ZEV	zero-emission vehicle

1 Governing innovation for sustainable technology

Introduction and conceptual basis

Måns Nilsson and Annika Rickne

The low carbon challenge

Climate change and fossil fuel dependency have firmly taken centre stage in international policy and industrial debates. The mainstream of climate research and policy analysis today agrees that developed countries need to reduce greenhouse gases (GHGs) per capita by 80–95 per cent by 2050 in order to limit global warming to 2°C. This target likely requires a stabilization of the level of atmospheric CO_2 at 350–400 parts per million and that global emissions start to decrease in the coming decade. At the same time, the global competition for energy resources has put the energy security question on a par with climate change as a political challenge. In particular, fossil energy dependency is considered to imply significant geo-political and economic vulnerabilities for importing economies around the world. Questions of how long oil and gas resources will last are debated in parliaments and corporate board rooms. Policy makers on every continent are hard pressed to deal with increasing and sharply fluctuating energy and raw material prices, mitigating the threat of climate change and reversing natural resource degradation, all while inducing investment, jobs, growth and welfare in an increasingly fierce global economic competition. Many countries and regions, such as the European Union (EU), have shown that it is possible to reduce environmental stress and still maintain growth and quality of life. For example, energy-related GHG emissions fell by over 8 per cent between 1990 and 2008 in the EU-27 (CEC, 2010). Major improvements in emissions of other air pollutants have come from better abatement technologies within transport, energy and industry actors.

In this situation, the transport sector stands out as one of the few sectors that have not been able to 'bend the curves' on energy use and emissions, much less reverse the unsustainable levels of environmental and resource pressures (IEA, 2010). Transport therefore accounts for a rapidly increasing share of GHG emissions as a result of the combination of continued growth in transport volumes, reliance on private vehicles and continued combustion of fossil fuels with conventional engine technologies, as well as sharply increasing freight volumes and the inability to diffuse low-carbon technologies on a grand scale. In the EU, transport accounts for 32 per cent of final energy consumption and the per capita transport energy use increased by 26 per cent from 1990 to 2008 (EEA, 2010). In the United States, transport-related GHG emissions grew from 1509.3 Tg CO_2-e. in 1990 to 1,866.7 Tg CO_2-e in 2003, a larger amount than any other sector (USEPA, 2006). Projections into the future show that transport-related emissions and energy use will continue to increase at the global level (IEA, 2010). As a result, the quest for low-carbon vehicle technologies has now become one of the principal and most urgent challenges of the global sustainable development agenda. It is widely recognized that more ambitious governance is needed to address this challenge.

At the same time, much hope has been placed on the development and rapid uptake of new low-carbon vehicle and fuel technologies such as the hydrogen-based fuel cell (HFC), biofuels and hybrid-electric vehicles (HEV). However, until recently these new technologies have had difficulties competing on the market. Fortunately, there have been major advancements in technologies and the promise of alternative fuels for traditional combustion engines – such as biofuels and more efficient energy transformation technologies, as well as hydrogen/fuel cells and HEVs – have so far, to varying degrees, been realized in the real world. There are strong variations across technologies as well as across different leading automotive regions and countries, such as the United States, the EU, Germany, Sweden, Japan and China. One example of this variation is Japan and Toyota, which has led the way in creating and diffusing hybrid cars, while Sweden has developed a leading position in ethanol-fuelled cars, both on the supply side of fuel as well as in engine technology.

Given the urgency of resolving the unsustainable trends in transport, today, there is an ever-growing recognition among policy makers and industry analysts that the development and diffusion of low-carbon technology innovations need to be promoted and accelerated through public policy interventions as well as coordinated engagement of the private sector, local decision makers and other societal groups. However, not enough is known about how different types of governance influence innovation processes, and what may be effective governance arrangements to pursue to influence the development and diffusion of sustainable technological innovations such as alternative vehicle concepts and renewable fuels.

This edited volume is an attempt to collect and analyse experiences in different leading countries on the development, uptake and diffusion of different low-carbon vehicle technologies. It uses a governance of innovation systems approach to examine how innovation in low-carbon vehicle and fuel technologies comes about, and how it can be promoted and influenced by various actors. The volume brings together leading scholars to address critical gaps and important debates in governance and innovation research. It explores and synthesizes cutting-edge analysis and research on how innovation systems are being governed for these technologies – and to what effect. Three key questions are in focus:

1 What are the main drivers and enablers of innovation in low-carbon vehicle technologies?

2 What governance responses have been put in place in different jurisdictions and to what effect?
3 How do we move towards more effective governance for stimulating the development, uptake and diffusion of low-carbon vehicle technologies globally?

As the issue of governance of sustainable innovation is treated within several disciplines and with divergent approaches and results, the volume includes researchers representing a broad range of theoretical strands. Our aim is to enhance the integration of and learning between fields. At the same time the focus on a particular set of technologies ensures that the discussion is tightly aligned to common problem areas. To frame this discussion, let us first briefly discuss the two key analytical concepts of the volume – innovation and governance.

Innovation as one solution to the challenge

In line with Schumpeter's bequest to economic strategy and policy, we today view innovation as key to a knowledge-based society and its economic growth (Schumpeter, 1934). Indeed, innovation in its various forms – technological, market-related, organizational, etc. – is often what outlines the competitive edge for firms as well as for countries. In addition to the economic rationale, innovation is also seen as a key to achieving more sustainable development worldwide (Norberg-Bohn, 1999; Pearson *et al.*, 2004). Indeed, achieving sustainable development depends on technological and social innovations coupled with organizational and institutional change geared towards environmental sustainability. One salient example is the climate change issue, in particular in relation to 'post-2012' discussions, where in the light of global difficulties in reaching political agreement, technology is nowadays widely considered the key solution to the dilemma of getting national governments to agree to ambitious carbon reductions while at the same time safeguarding economic development and welfare. Great hopes are also attached to the promise of sustainable technology innovation in other fields of resource use and environmental impact, such as, for instance, non-renewable and renewable resource use, energy conversion and chemicals. Indeed, some of that promise has also been delivered in certain domains.

Any innovation process involves a multitude of activities necessary to bring products and services to the market, where an underlying invention is only a partial aspect of the process. Important activities may comprise scientific work, technology and product development, design, market development, changes in organization, social practices, regulations, building industrial networks, infrastructure and culture (Ashford, 2004). This implies that innovation processes involve the creation, absorption and transmission of knowledge and are highly interactive in character in that they involve continuous learning cycles. The previous view of linearity and the focus on a presumed static event of novelty creation are no longer valid. A departure point in modern innovation studies is that the technological, sectoral, spatial, institutional, organizational, social and economic domains of innovation are highly related and cannot be meaningfully separated in the real world (Ashford, 2004).

Sometimes, learning loops can be concentrated within an individual or a limited number of people, but the rule is more often that a multitude of individuals and organizations are involved, holding various resources and tasks. The complex and multidisciplinary character of most innovation processes implies that resources, skills and competencies can seldom reside within an individual, or even within a single organization. Cooperation, knowledge exchange and learning become key. It is the combination of complementary resources and competencies – be it knowledge, capital, facilities, etc. – that may bring the creation of new things: innovation. For any specific organization, such as a firm, recombination of resources and knowledge may take place within the borders of the company in a vertically integrated organizational manner. More often, innovation requires not transactions with external partners, but rather intertwining of organizational processes for innovation to come about. Partners include other firms, customers, suppliers, competitors, research organizations, financiers, policy organizations, bridging actors, etc., locally, nationally or in other countries. Such exchange gives access to resources of various kinds, including equipment, proven laboratory methods, blueprints, development tools, etc. Also, discussions may lead to novel ideas, solutions to technical problems or organizational changes such as suggestions for product or process improvement. Often, interaction is direct and facilitated by face-to-face meetings, being set up as bilateral or multi-partner collaboration on scientific development and co-publication, shared platforms for prototype testing, common market efforts, and so on. Sometimes, learning from others comes about through observation rather than by interaction, including, for example, reverse engineering, studying publications, patents or prototype releases at market fairs. In addition, the mobility of people is a main mechanism of knowledge transfer.

To underline this inherently social, interactive learning process of creating innovations, a systems approach to innovation has been put forward under the terminology of ‘innovation systems’ (ISs) (Lundvall, 1992; Nelson, 1993; Edquist, 1997). Such studying of innovation helps us understand both how and why new patterns of organization, technology, production and consumption come about, and provides guidance on how these patterns can be induced or accelerated. An IS may be defined as ‘the groups of organizations and individuals involved in the generation, diffusion and adaptation, and use of knowledge of socio-economic significance, and the institutional context that governs the way these interactions and processes take place’ (Hall *et al.*, 2003: 3). Thus, in this school of thought a set of structural elements and their interconnections are the focus – a set of knowledge areas and artefacts (e.g. technology, intellectual property, products), innovating and innovation-related actors and the inherent knowledge flows and networks between these, as well as the underlying institutional framework (Carlsson and Stankiewicz, 1991). Firms in various parts of the value chain are often the main innovating actors. Research and educational organizations, including universities, are important providers of new knowledge, human capital, etc., but are also intensively engaged in several other activities throughout the innovation process. In addition, there are organizations giving innovation support of various kinds: public organizations and authorities setting conducive policies and institutional arrangements, trade associations, incubators and venture capitalists. An important feature of any innovation system is thus the institutional features setting the rules of the game for the actors and artefacts. The institutions – laws, rules, norms and routines – function as key ordering devices shaping behavioural patterns, and therefore ISs within differing institutions display different patterns of interaction, prevalence of corporate spin-outs, propensity to share knowledge between universities and firms, etc. Innovation processes often include development of a shared vision by dominant actors in a network and evolutions of the institutional landscape in ways that make it open for change (Kaijser, 2001; Kemp *et al.*, 1998).

As highlighted above, ISs are networks of organizations and individuals, working under a common institutional set-up (laws, practice, etc.), within which the creation, dissemination and exploitation of new knowledge and innovations occur (Cooke *et al.*, 2004). While it is acknowledged that innovation processes are often global, where the connected knowledge formation, resource accumulation and diffusion processes span regions and nations, there are also spatially delimited aspects of innovation. In fact, one of the ways by which the IS approach helps us to understand such dynamics is by focusing on the institutional specificities of various ISs. Clearly, institutions differ between countries – and even within countries – and they differ between knowledge areas (e.g. between various technological settings) or sectors. Therefore, in the analysis of ISs, one draws a border around the specific system, thereby including or excluding actors, artefacts, networks and institutions as being central to the system or not. To some extent all such delineation is by necessity arbitrary, but nevertheless necessary to do a useful analysis. The literature is thus divided into various IS approaches, focusing on different rules for the delineation: national (Nelson, 1993; Edquist, 2004), regional (Cooke, 2001; Asheim and Coenen, 2006), sectoral (Breschi and Malerba, 1997) or technology based (Carlsson *et al.*, 2002). In essence, the approaches share many common elements, and the structural components included are similar, but the system analysed will look somewhat different depending on which approach is chosen. Importantly, this underscores that the IS approaches are analytical constructs helping us to better understand innovation dynamics, but tells us that the systems may be portrayed in several equally accurate ways.

This volume departs from one such IS perspective: the technological innovation system (TIS) approach (Carlsson and Stankiewicz, 1991), emphasizing that we are interested in the emergence and growth of technological areas into specific sectors. Taking technology as the starting point for delineation of a system does not imply technological determinism or underplay, for example, market-based determinants, but rather we set the borders of the system to those actors, artefacts and institutions that relate to specific sets of knowledge areas. In our case these areas relate to sustainable technologies for road transport. What is particularly appealing about the TIS approach is its conceptualization of system dynamics through its focus on functions, or key processes, as is discussed below (Bergek *et al.*, 2008).

Governance of sustainable innovation

Innovation is not only high on the agenda in industrial and economic strategy and policy discourse, but also increasingly salient in relation to the sustainable development agenda. Even so, the policy field of innovation and technology has to a large extent been theoretically and empirically disconnected from the policy field dealing with environment and sustainable development (Kivimaa and Mickwitz, 2006). In recent years, the merging of these debates has become more evident with analytical work on concepts such as sustainable innovation, eco-innovation and sustainability transitions management (Loorbach, 2010; Moors and Mulder, 2002; Foxon *et al.*, 2004; Smith *et al.*, 2005).

Sustainable innovation relates to the strategic challenge of making innovation processes coherent with the drive for environmentally sustainable technologies and practices worldwide. Some evidence suggests that the premises and conditions for sustainable innovation are likely to be different from other types of innovation, in that the goals are more than economic in their character, and to promote innovation generally is not the same as to promote sustainable innovation (Norberg-Bohn, 1999). First, sustainable development provides for an explicit normative direction in the innovation, i.e. a more targeted and precise long-term view of the intended benefits of the innovations going beyond purely economic criteria, relating to specified social benefits. Thus, the novel product, production process, service or business method should result 'throughout its life cycle in reduction of environmental risk, pollution or other negative impacts of resources use compared to relevant alternatives' (Kemp, 2010). Second, sustainable innovation entails public goods that are not necessarily associated with direct user benefits, and the need for public policy to handle different externalities can create policy windows within an innovation process. Third, from a business perspective, factors such as credibility, branding and image may be more prominent than in innovation more broadly. Fourth, international conventions and policy processes set framework conditions that will influence both public and private governance at different levels.

Thus, sustainable innovation is a highly salient policy topic, attracting an increasing interest in governmental, industrial and societal spheres. In contemporary debates we often see the term *policy* replaced with the concept of *governance*. Why does this book follow this trend? The conceptual shift from policy to governance has principally occurred to highlight that processes of preparing, deciding on and implementing measures to coordinate and advance societal objectives increasingly involve – and often should involve – stakeholders other than the nation state, such as NGOs, the private sector and local/regional and international organizations. In such governance, there is a much wider range of possibilities of actor roles and responsibilities involving different combinations of state and private actors.

The term *governance* also signals that the rules and mechanisms that shape interactions between actors, as well as the use of different instruments, have changed. The coordination and incentives necessary for promoting innovation and innovation systems rely not only on traditional public policy instruments such as coercive measures and regulation or R&D funding from the state, but also include forms of social initiatives that fall outside the realm of traditional public policy instruments, including social networks, joint visioning exercises, and public–private–academic partnerships. The concept of governance captures more usefully the main dimensions of these relationships, including: the institutional landscape, network relations between actors, procedures for decision making and coordination, mechanisms for evaluation and learning, as well as broader contextualizing factors such as history and culture (Pierre and Peters, 2006).

Thus, we understand governance as a broader and more fundamental concept than policy, and as such it is able to cover more facets of the social systems coordination necessary to induce and steer innovation processes in, for example, sustainable societal development. Much like the study of innovation signifies a broadening of the analytical framing of economic change, so governance constitutes a broadening of the framing of social coordination – as the catchphrase 'from government to governance' suggests (Hillman *et al.*, 2011).

Analysts have argued that in the past 20 years there has been a shift from traditional regulatory approaches such as standards, bans and taxes to measures and arrangements that focus on consensus, voluntarism and procedure, such as soft law and public–private partnerships (Treib *et al.*, 2007). In particular, the EU has promoted these latter arrangements as a way to increase the efficiency and effectiveness of public affairs through gaining stronger ownership and implementation capacity. However, empirical studies show that 'old-style' regulation and taxation still stand strong (Nilsson *et al.*, 2009). Furthermore, the merits of such a governance shift are constantly called into question, e.g. whether it leads to better problem-solving capacity, be it in innovation policy, environmental protection or public policy more broadly. In addition, recent developments may suggest that it is now reversing: in Europe and elsewhere the use of regulatory standard setting increases as a driver of sustainable innovations through, for example, efficiency standards for cars and domestic utilities and bans on light bulbs (Nilsson *et al.*, 2009). Furthermore, the reality in many sectors – and we will see this pattern clearly when it comes to the transport sector technologies examined in this volume – is that there is a broad blend of governance arrangements that mix traditional top-down regulation with networking, private–public partnerships and other voluntary and informational measures. At the same time as the salience of policy objectives such as decarbonization of energy systems grow, the ways in which governments and other actors are trying to achieve these objectives are becoming increasingly varied and fragmented (Jordan *et al.*, 2003).

The governance perspective on social coordination fits well with the innovation systems concept, not only in terms of its broad analytical framing. Also the institutionalization of the innovation concept in the 1990s signified a shift in how we view the state's role in technological change, different from both the traditional state-interventionist approach and a laissez-faire liberalist perspective. It is based on the recognition of market failures inherent in the process of, for example, technological change, but differs from the neoclassical perspective in that it considers the relations between research, society and business as a key driver of innovation. As is noted above, it views innovation broadly as a complex process of multiple actors, structures and interests, institutional regimes, lock-ins and market barriers. Innovation is therefore a partly managed and partly chaotic process – government can, and should, take a leadership role in managing innovation, but its role is more closely related to networking and facilitating interactions between private and public actors than to a traditional 'linear-hierarchical' model of policy implementation (OECD, 2005a). For example, innovation governance must take a broader perspective and recognize the role of institutions beyond the firm and its immediate network, and include facilitating infrastructures and market demand.

Towards an integrated analytical perspective

As regards governance of technology innovation in the transport sector – the focus of this volume – there are a multitude of measures in place. Regulatory standards and economic instruments have arguably been the traditional measures implemented by national governments. Vehicle fuel standards and emissions standards have been introduced at the national and the EU levels, and most OECD countries impose high taxes on petrol and diesel. Also, R&D support for alternative-fuel vehicles and high-efficiency vehicles have been part of the governance mainstream.

There is, however, only scattered evidence about the measures that have been effective – that is, evidence of where, when and why governance has worked and spurred sustainable innovation. Indeed, although the literature on technological change and innovation now and then touches on governance, policy and institutional responses (e.g. Fagerberg *et al.*, 2006), there is relatively little systematic analysis of what types of governance arrangements affect innovation processes, and in what ways they work. Various illustrations have been published, but we perceive a lack of empirically grounded analysis to enable us to draw out both context-specific and more generic lessons. International benchmarking exercises are popular – e.g. the European Scoreboard of Innovation (European Trendchart on Innovation, 2005) and the OECD Science, Technology and Industry Scoreboard (OECD, 2005b). These are interesting in themselves but do not add much causal insight. In fact, there is surprisingly little written about important governance questions that are relevant both within and outside the transport sector, such as: who is going to 'do' governance for sustainable innovation? What are the appropriate levels and rules of engagement? What instruments are effective?

This problem is not unique to transport innovation. Just how governance should be best arranged to achieve both momentum and direction in technological innovation systems is not well understood, be it in systems such as biotechnology, electricity generation and use, or urban infrastructures. To advance our understanding we must turn to in-depth analysis of real-world experiences of innovation governance. Here, the OECD has been a frontrunner, both on governance for sustainable development (OECD, 2002a, 2002b) and innovation governance (OECD, 2005a). Like this volume, the OECD focuses on instrumental effectiveness – i.e. how to arrange policies and institutions to achieve the goals of the state (such as sustainability). Governance analysis typically also includes a broader facet of political, democratic and legitimacy concerns (Newell *et al.*, 2008). Lafferty (2004) provided one of the first synthetic attempts in which both OECD-type governing effectiveness and political concerns are discussed, not least when it comes to the international aspects of sustainability.

Thus, what role there might be at, for example, the EU level or for global governance in enabling sustainable transport systems remains in many dimensions an unresolved question, and our book aims to make a timely contribution to this debate. The literature has made several propositions about governance of innovation, taking a number of theoretical approaches. In our book we build on several of these strands as presented below, integrating the various levels of analysis into the puzzle, and increasingly gathered, at least in the EU, under the label 'sustainability transitions'. One of the dominant approaches in this field is that of ISs, as discussed above. Like in the broader governance literature, IS research shows that actors other than the state may well be better positioned to initiate or execute governance. Indeed, with a multi-actor perspective inherent in this research strand, it is clear that various actors address how to steer the system in fruitful directions (Hillman *et al.*, 2011; Bergek *et al.*, 2008). With a particular policy focus, a strong interest has developed in the 'triple-helix' cooperation between university, industry and local government and the various actors' roles in governing innovation processes (Etzkowitz, 2003).

In terms of types of governance arrangements, the work on TISs has taught us that the emergence of new technologies requires not only R&D support and market adjustments (such as tax relief), but also other forms of support to strengthen processes within the IS. Analysts often stress governance measures such as the formation of networks, government procurement, assured market sales and subsidy (Nygaard, 2008; Edquist *et al.*, 2000; Jacobsson and Bergek, 2004). In relation to sustainability, the need for technology-specific market measures such as price fixing has been highlighted (Jacobsson and Lauber, 2006). TIS analysts developed a conceptualization of the dynamics of innovation systems, adding to the structural components (actors, artefacts, networks, institutions) also a set of processes (Bergek *et al.*, 2008). The introduction of these is a way to capture the fact that, in order for an IS to emerge and grow, a number of key processes are necessary, usually expressed as: knowledge development and diffusion; influence on the direction of search; entrepreneurial experimentation; market formation; legitimation; resource mobilization; and development of positive externalities (Bergek *et al.*, 2008). While the list is not conclusive or finite, these have been identified as heuristics to strategically guide how and where investments need to be made in order to strengthen the overall innovation system, and to explain the success of various knowledge areas over others. For example, difficulties of technologies 'taking off' can be understood in terms of the absence of certain functions, or poor alignment of different functions. The TIS process approach is applied in several chapters in this book, including those on China, Sweden, the United States/California and South Korea.

The deployment of low-carbon vehicle technologies, also a focus of this volume, is one part of the solutions towards sustainable development in the transport sector. But it is clear that the challenge of sustainable development is increasingly considered to depend on more substantial transitions of socio-technical systems, including restructured production and consumption patterns, organizations, institutions and actor configurations. The multi-level perspective (MLP) analyses technological change through a niche–regime–landscape framework (Geels, 2011), in which systems transitions depend on the destabilization of the incumbent regime (what in sociology has been called the organizational field). This perspective emphasizes the interlocking and mutually reinforcing institutional, technological and cognitive structures, including user practices, social relations and networks that create stable structures which shape (if not determine) trajectories of social and technological development. From the MLP, a Dutch school on sustainable innovation has developed so-called transition management (TM). An adjacent literature on strategic niche management (SNM) is concerned with nurturing 'socio-technical' experiments for learning about innovations, and creating networks between producers, users and governments (Kemp *et al.*, 1998; Schot *et al.*, 2002). Both TM and SNM are often portrayed as governance arrangements or systems in themselves. Visioning and coalition-building processes, as well as learning from niche-level experimentation, are often emphasized in TM, which links it clearly to several functions in TIS. Increasingly, scholarship discusses the conditions and governance arrangements under which socio-technical transitions may develop, but empirical work is mostly on historical accounts of past transitions (Grin *et al.*, 2010). One difficulty in the empirical study of socio-technical transitions is to be able to observe a transition when you are in the middle of it. There is a clear risk of bias; as you have higher resolution of information in near time you are prone to consider the current day and age to be a moment of historical opportunity and change rather than a period far in hindsight. Even so, ambitious attempts exist to trace ongoing (and even future) transitions. Some attempts have been made at merging perspectives. For example, Smith *et al.* (2005) link MLP and governance analysis to certain aspects of their suggested heuristic typology for mapping 'transition contexts'. Geels and Raven (2006) usefully remark that isolation versus protection from within the regime may be a critical factor in shaping governance. Also, the level of stability of rules can be decisive. For example, a technology that is located outside the dominant regime may suffer a range of institutional constraints and governance 'deficits'. Despite these attempts, critical debates in governance research have not been fully linked to the problem of innovation, and there is as yet not much literature that integrates the various aspects of governance with that on innovation processes, or innovation processes with that on sustainability. A first challenge is how to structure empirical evidence about the diffusion of different governance arrangements. A second is how to carry out research to gather evidence about the actual effectiveness of different governance arrangements for fostering innovation processes. In a recent paper, the editors of this volume outline a theoretical framework aimed at supporting such analysis of how governance affects and fosters innovation systems (Hillman *et al.*, 2011). The purpose is to help generate empirically grounded and theoretically robust advice on how different types of governance arrangements influence innovation processes. The framework builds on the technological innovation systems approach. The key processes identified as necessary for the development, diffusion and use of innovations – knowledge development and diffusion, direction of search, entrepreneurial experimentation, market formation, legitimation, resource mobilization and development of positive externalities – are placed in focus for the governance of the system. Both regime and landscape factors are included as crucial for the governance process. The main task for governance of technological innovations would then be to foster such key processes under the influence of external factors.

Empirical focus and chapter outline

Our empirical focus, within the broader issue of sustainable innovation in the transport sector, is on innovation and governance related to a limited selection of low-carbon vehicle and fuel technologies, in particular biofuels, hybrid-electric vehicles, electric vehicles, and fuel-cell vehicle technologies (introduced by Paul Nieuwenhuis in Chapter 2). The book analyses cases of innovation governance in a number of countries around the globe: China, Germany, Japan, South Korea, Sweden, the United Kingdom and the United States. Two chapters examine the EU as a whole. Why do we take an interest in these countries? First and foremost, we want to cover some of the main vehicle-manufacturing countries in the world today. China tops the list with 18,264,667 vehicles produced in 2010 – a very substantial increase from 9,345,101 in 2008 – followed by Japan (9,625,940 in 2010); the United States (7,761,443), Germany (5,905,985) and South Korea (4,271,941) (OICA, 2010). We especially want to cover the home countries of the top vehicle-manufacturing groups. Here the top three are Toyota, General Motors and Volkswagen. When it comes to heavy vehicles, Sweden joins the picture, with the top five manufacturing groups (above 16 tonnes) being Isuzu (Japan, 478,530 units in 2007), Daimler (Germany, 446,128), Volvo (Sweden, 341,875), Toyota (Japan, 240,038) and Hyundai (Korea, 159,237) (OICA, 2010). Although hybridization and biofuels are less-developed fields in the heavy vehicle sector, there are clearly important developments on the way. For example, Volvo AB in 2011 put its first hybrid truck on the market.