Coordinating Multi-Technology Innovation Towards Sustainability

– the Case of Autonomous Vehicles in Sweden and Singapore [1]

Andreas P. Kopp[2]
Department of Science, Technology, Engineering, and Public Policy
University College London

Conference Paper

4th International Conference of Public Policy
Montreal, Canada
26-28 June 2019

Abstract

Complex challenges like climate change require transformative solutions, like creating a greener economy and a more sustainable transport system. Such transformations rely also on complex technological innovations, so called multi-technology solutions (MTS). These comprise multiple sub-technologies and are used for a variety of purposes. Connected autonomous vehicles (CAV) fuelled by electricity are an example. MTS such as CAV are affected by several policy domains, like environmental policy, transport policy, infrastructure policy, data protection policy, or health and safety regulations, just to name a few. These domains are often contradicting and innovators of emerging technologies struggle to operate in existing regulatory arrangements. How can we coordinate innovation policy and adjacent policy domains to ensure that the innovation and incorporation of emerging technologies into existing systems can be accelerated?

CAV are a good example for this challenge. Operational in both Sweden and Singapore, and forming a part of their public transportation systems, this paper investigates how innovation policy is coordinated in these two countries and aims to find out what we can learn from the Swedish and Singaporean approaches. Through an innovation mapping exercise and a series of semi-structured interviews I analyse the interaction of actors within the respective innovation network and show which role the government as coordinator of innovation policy can play and how innovation policy design and implementation for MTS can be aligned. Whereas both countries reveal a successful CAV innovation system, the approach in Sweden is more network and market-based, as government agencies operate at arm's length, whereas the system in Singapore is more hierarchical, as purpose-built government agencies operate as more central nodes.

Keywords

Innovation policy; coordination; multi-technology challenges; sustainability transition; autonomous vehicles; Sweden; Singapore

---

[1] This paper contains preliminary results and is work in progress. Not for wider dissemination, please do not quote.

[2] andreas.kopp.16@ucl.ac.uk; UCL STEaPP, Euston House, 24 Eversholt Street, London NW1 1DB, UK

1. Introduction

Addressing complex challenges, like environmental degradation and climate change, through technological innovation can only lead to improvements if the technology invokes a systemic transformation – socio-technical change instead of technical change alone. This, however, often triggers multi-technology challenges, i.e. a situation where one technology can be used for multiple (not necessarily aligned) purposes or where a technology consists of multiple sub-technologies that are connected for a particular purpose (Markard, 2018). Such challenges require multi-technology solutions (MTS[3]). MTS, however, usually affect and are affected by multiple policy domains, and therefore various regulations, policy regimes, standards, or norms, as well as a vast number of political and non-political actors. This leads to the research questions this paper aims to address: How can MTS be governed, in such a way that they effectively address the challenges they are meant to solve? And: What successful practises do we observe in different innovation systems from which we can learn?

Exemplifying this dynamic, I investigate the innovation of connected autonomous vehicles[4] (CAV), a good case of multi-technology innovation (MTI). CAV, usually propelled through electric engines, on the one hand, are complex technologies that comprise multiple sub-technologies, governed through different policy domains. This includes the connectivity from car to car and from cars to their environment (or infrastructure), and the privacy and data protection concerns related to this. It also includes the electric fuel and its generation, as well as the environmental impact of materials used, e.g. for the battery, but also infrastructure, such as charging stations or adequate highways. On the other hand, CAV operate to reduce the need for individually owned vehicles, to improve the first and last mile connections in public transport systems (or they deliver the entire transit connections), and therefore must be reliable. CAV also change the way we handle trade of cargo via land, air, or maritime transport. In short, CAV "have the potential to fundamentally alter transportation systems" (Fagnant & Kockelman, 2015: 167). The policy domains that influence the CAV technology are plentiful – and the technology affects various policy domains, in turn, as we see, for instance, regarding the misalignment of infrastructure and data-protection policy on highways suitable for CAV. Achieving a systemic change, making transportation more environmentally effective and economically efficient, however, also requires a system to coordinate these policy domains, enabling instead of preventing innovation, and providing a framework in which the technology can grow and diffuse in a well governed and safe way.

I hypothesise that the implementation of a multi-technology solution towards a pre-defined public purpose can be accelerated if the innovation policy design and implementation networks are more integrated. The effectiveness of MTS depends on the politico-economic context, the politico-administrative organisation, and coordination structures that enable the integration of policy networks. I will test this hypothesis through the comparative analysis of CAV innovation in Sweden and Singapore. The remainder of this paper is structured as follows: Section 2 briefly

---

[3] MTC: multi-technology challenge; MTS: multi-technology solution; MTI: multi-technology innovation

[4] The term 'connected autonomous vehicles' used in this paper refers to autonomous vehicles as well as to self-driving cars, trucks, or other means of transport that function autonomously (i.e. containing some element of artificial intelligence). The assumption is that both are in one way or another 'connected', either within the vehicles, with the grid, other cars, or surrounding infrastructure. Connectivity technology is, thus, considered an essential part of such vehicles, whichever way this technological element is employed.

outlines the gap in the scholarly literature between public administration and innovation studies that this paper is addressing. Resulting from this short literature review is the analytical framework in section 3, bridging the aforementioned disciplines, particularly revealing the structures that define the outcome of the innovation process. Based on this conceptual lens, section 4 explains the methodology used to gain the findings presented in section 5 of this paper. There, I explore the specific structures and mechanisms underlying the innovation network of CAV in Singapore and Sweden, respectively. I discuss these findings referring to the analytical lens in section 6, before concluding the paper.

2. Literature Review

Innovation dynamics are to a very large extent captured by the innovation studies literature, including very complex developments of advanced technologies and for a variety of socially beneficial purposes (Anadon et al., 2014; Mulgan, 2006; Owen, Macnaghten, & Stilgoe, 2012). Particularly, explaining transitions from one type of technology to another, such as in the sustainability discourse about greening economies, the array of heuristics and conceptual tools is wide, capturing many different perspectives. Often this rests on a systemic view of innovation (Coenen & Díaz López, 2010; Edquist, 1997; Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007; Smits & Kuhlmann, 2004; Wieczorek & Hekkert, 2012), investigating innovation based on geographical lenses, where innovation is analysed within the limits of a state (Nelson, 1993) or a region (Braczyk, Cooke, & Heidenreich, 1998; Cooke, 2001). Alternatively, scholars explore innovation dynamics along sectoral boundaries (Breschi, Malerba, & Orsenigo, 2010; Malerba, 2002) or explain the development of a single technology in 'technological innovation systems' (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008; Hekkert et al., 2007; Markard & Truffer, 2008). Although these perspectives are important and useful to understand how innovation occurs, also for policymakers, and although they are widely discussed in some technology sectors, such as energy (Foxon et al., 2005; Gallagher, Grubler, Kuhl, Nemet, & Wilson, 2012; Kempener, Diaz Anadon, & Condor, 2010; Wilson & Grubler, 2011), the multi-technology lens poses a challenge to them: The multi-faceted dynamics underlying MTS – across sectoral, national, and technological boundaries – comprise a larger set of actors, and therefore require a wider analytical lens. Paired with the more widely applied approach to innovation policy based on missions (Mazzucato, 2016; Schot & Steinmueller, 2018b, 2018a), hence, looking at innovation systems of a single technology, sector, or country is increasingly difficult and also less insightful as a tool for policy advice.

Exploring sustainability transition dynamics more holistically, the multi-level perspective (MLP) draws together larger 'landscape' trends and norms with existing policy and technology 'regimes' (e.g. incumbent firms, political organisations, or other dominant actors) and 'niche' innovators or entrepreneurs (i.e. where the innovation actually happens) (Geels, 2002, 2004, 2018; Schot & Geels, 2007). The concept, often used also to strategically push specific technologies (Schot & Geels, 2008), in principle also captures the innovation of MTS. However, there are two related limitations to the MLP: First, it focuses mostly on processes and not on actors, insufficiently addressing agency within an innovation dynamic (Sorrell, 2018). As mentioned above, however, analysing the relationship and resulting interaction between actors in MTI networks is important especially because various policy domains are affected. Second, the MLP links regime and niche level only in so far as niche innovations eventually break into the existing regime, once a window of opportunity occurs. Regarding MTS, however, interaction between niche and regime occurs more frequently and sooner, beyond innovation framing regulation (Ford, 2013), playing a vital role in the development of innovations, which among others I will show throughout this paper. In fact, well-coordinated interaction between actors in the regime and the niche can enable the regime to fit in a niche technology more quickly, can equip niche actors with the knowledge needed to adapt their technology to the needs of the regime, and therefore, can accelerate the innovation process overall (see red arrows in Figure 1).

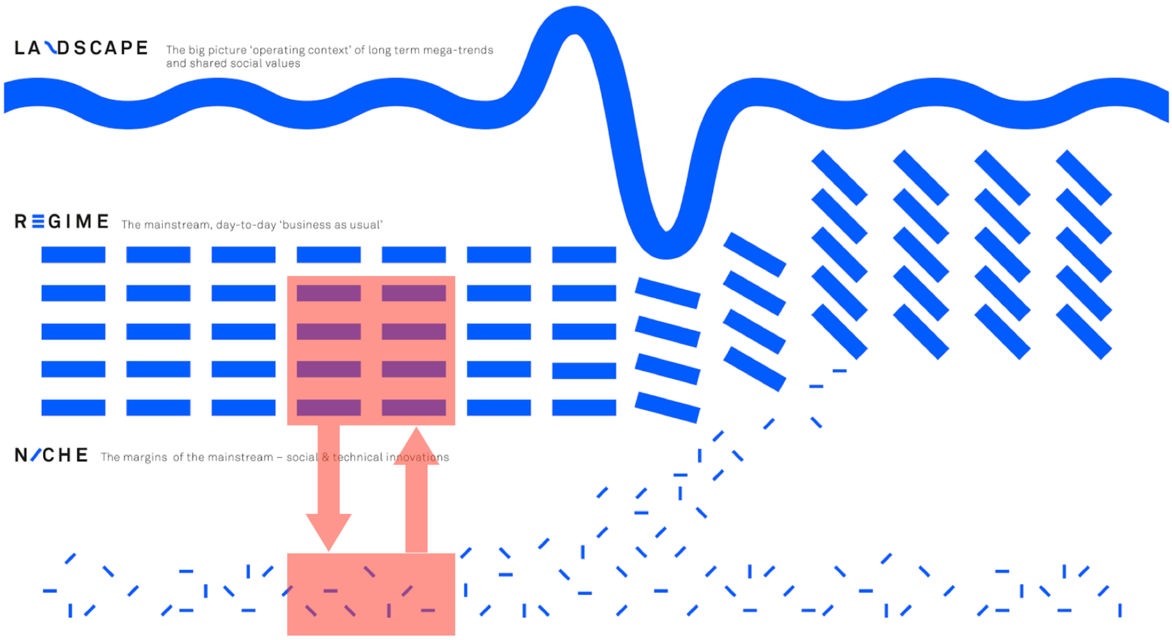

Figure 1: Multi-level perspective, adapted from Geels (2002) and Angheloiu (2017)

This interaction between actors in the regime and the niche, however, also poses a challenge: The innovation network for MTS is comparatively complex due to a multitude of actors and a variety of use-cases of the technology. Consequently, since the state remains a vital actor in the transition process (Johnstone & Newell, 2018; Mazzucato, 2014, 2017) and because MTS often perpetrate various policy domains (as represented in the regime), MTI poses a coordination challenge, which needs to be resolved to avoid constraints on the development of the technology. Politico-administrative coordination challenges are not a new phenomenon in public administration scholarship (Alexander, 1993; Kaufmann, 1991; Peters, 1998), as the increased 'agencification' and fragmentation of government during the New Public Management era (Lodge & Wegrich, 2014) and the move towards network governance approaches (E.-H. Klijn & Koppenjan, 2014; E. H. Klijn, Koppenjan, & Koppenjan, 2015; Koppenjan & Koliba, 2013). Policy coordination has been widely discussed with regard to policy design as "an end-state in which the politics and programmes of government are characterised by minimal redundancy, incoherence and lacunae" (Peters, 1998: 296) and concerning policy implementation where "coordination simply means organising activity in such a way as to handle the problems that arise because the behaviour of each participant depends in some ways on the behaviours of the others" (Simon, 2000: 750). Both policy design and implementation coordination problems can trigger 'underlap' and 'overlap' challenges, i.e. where policy problems fall between the jurisdiction of particular ministries or agencies and are consequently disregarded, or where issues are dealt with by multiple government agents at the same time, therefore possibly causing constraints and contradictions (Lodge & Wegrich, 2014). The extent to which MTS pose this challenge of over- and underlap is unprecedented, especially when MTS are used to tackled challenges such as sustainability for preventing climate change or other problems of a similar scale.

Coordination of networks, hence, "is both a process through which decisions are brought together and an outcome of that process" (Peters, 2015: 3) which is of particular importance regarding knowledge and innovation policies (Braun, 2008). The joint-up government (Pollitt, 2003) and the whole-of-government (Christensen & Lægreid, 2007) approaches have attempted to solve these problems, by aligning policy implementation mechanisms across government and applying "a more holistic strategy using insights from other social sciences" beyond just economics (Christensen & Lægreid, 2007: 1059). More recently, through the idea of 'policy mixes', governments have particularly addressed the necessity to take into account various policy domains when designing innovation policy (Kivimaa & Kern, 2016; Rogge & Reichardt, 2016; Rogge & Schleich, 2018). Of course, the way in which states organize for innovation varies, which has been addressed in the scholarly literature as well (Karo & Kattel, 2016a, 2016b). Yet, combining both approaches, and addressing how policy design and implementation can be organised regarding MTS remains underexplored. In this paper I will attempt to fill this gap, in conjunction with the missing explanation for the interaction of regime and niche level actors, through the study of CAV innovation dynamics in Sweden and Singapore.

3. Analytic Framework

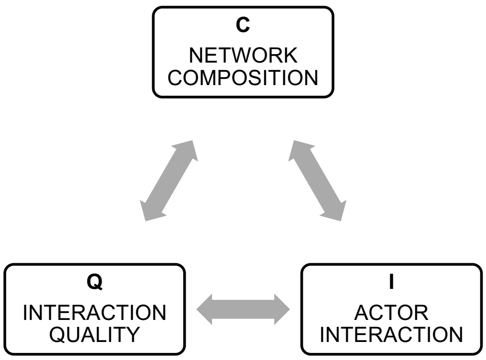

Figure 2: Defining network characteristics

To analyse the process of MTI, I proceed in three steps, aiming to understand the entire innovation policy design and implementation networks and their interaction. This analysis rest in parts on the output-outcome-impact approach (Gehring & Oberthür, 2009) and, thus, indirectly also on the idea of the policy cycle (among others Cairney, 2011). The networks are structured based on the composition of the network (C), the interaction of actors (I), and the quality of that interaction (Q) (Figure 2). First, I analyse the politico-economic context and, thus, the network in which policy is designed. On the one hand, this explains the way in which policymaking in a particular country is set up (the composition), the organisations and institutions underlying policymaking, and the principal actors and their relationship in that context (the interaction). On the other hand, it also accounts for external factors that are not directly represented in the innovation policy network that I analyse. The input, thus, in parts results from the network itself and in parts from exogenous factors. The way the politico-economic context shapes the network of actors in this policymaking space is important because it defines the innovation policy 'output'.

Second, I investigate the politico-administrative organisation, i.e. the way in which policy is implemented, defining the policy 'outcome'. The politico-administrative organisation can, of course, not be viewed in isolation to the context into which it is embedded. Yet, the implementation of innovation policy features different and distinct actors compared to the policy design process (although some might overlap). The actor network shaping the policy outcome, hence, differs and includes a wide array of actors also from the private sector or research organisations. Lastly, I show how both output and outcome define the purposeful 'impact' of the innovation policy, i.e. factual change of or solution to a previously defined problem or challenge. This last step of the analysis primarily serves to reveal to what extent the initial innovation policy has achieved its intended objective, both in terms of featuring a particular technology and regarding the promotion of a (socially or environmentally) beneficial public purpose. Below, Figure 3 depicts the analytic framework I use.

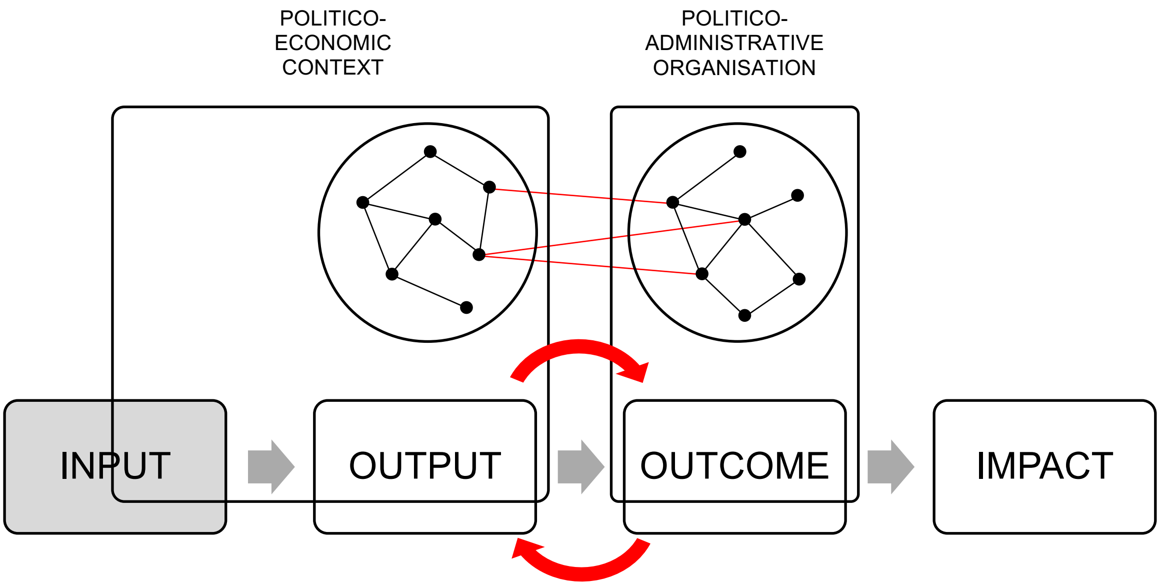

Figure 3: Analytical framework based on policy output, outcome, and impact (adapted from Gehring & Oberthür, 2009)

Of course, in practice, it is difficult to separate the two networks underlying policy design and implementation. Hence, the key aspect will be to explore how the both networks feed into each other and how that interaction can be coordinated. Ultimately, I reveal the key mechanisms that enable this network integration of policy design and implementation and, therefore, show how a system can be coordinated, which can accelerate the innovation towards a public purpose – in the case of CAV in Sweden and Singapore towards autonomous and sustainable (urban) mobility. Integrating the policymaking and policy implementation networks structurally allows for anticipated policy outcomes or eventual challenges during the implementation process, to be included in the policy design process. This step is key because it can prevent a misalignment of policy design and implementation and therefore, the creation of stumbling blocks or bottlenecks. This increase of efficiency and effectiveness is what can ultimately accelerate the innovation process in complex socio-technical systems, or as demonstrated in this paper, for MTS. Overall, these coordination structures connecting the output and outcome realm – and the feedback loops between them – also represent the connection between niche and regime as seen in the MLP (the red arrows depicted in Figure 1), a direct link between specific actors that design and implement innovation policy, which has not been widely discussed in the literature.

4. Methodology

I investigate the research question through a triangulation approach. First, I mapped the innovation systems for CAV in Sweden and Singapore, respectively. On the one hand, this mapping procedure allows us to understand the network composition and actor interaction. On the other hand, this also enables hypotheses about the quality of interaction, which can be tested. Second, I consulted policy documents, government reports, company resources, and other publications related to innovation governance and processes, in general, and CAV innovation, in particular. These documents allowed me to understand the general state of the art of the technology, their historic development, and the institutional arrangements affecting CAV in both countries. Third, I conducted semi-structured interviews with stakeholders involved in the CAV innovation process which I had previously identified (see Figure 4). The conversations were held via Skype or phone between February and May 2019, with a duration of 25-45 min each. Although the interviews followed a previously drafted outline, additional questions and deviations from this structure enabled me to also grasp previously unknown details, which could be included in form of new questions in following interviews. All practices including the recruitment of interview participants conform to the standard ethical and data protection practices at UCL.

#	Case Study	Interviewee Organisation	Duration
1	Singapore	Asian Development Bank	25 min
2	Singapore	Singaporean Ministry of Trade and Industry	35 min
3	Singapore	Singaporean National Research Foundation	25 min
4	Sweden	Swedish CAV start-up	25 min
5	Sweden	Swedish Innovation Agency (*Vinnova*)	35 min
6	Sweden	Swedish Research & Innovation Institute (RISE)	35 min
7	Sweden	Swedish Innovation Agency (*Vinnova*)	45 min
8	Singapore	National University of Singapore	45 min
9	Sweden	Swedish Transport Agency (*Transportstyrelsen*)	25 min
10	Sweden	Swedish Transport Administration (*Trafikverket*)	40 min
11	Sweden	Swedish National Innovation Council	45 min
12	Sweden	Swedish Public Transport Provider	35 min
13	Singapore	Singaporean Research Institute	40 min
14	Singapore	Singaporean CAV Company	35 min
15	Singapore	Singaporean Government	40 min
16	Singapore	Singaporean Government	30 min

Figure 4: List of interviewees (as of 23 May 2019)

The important benefit of these methods is the possibility to triangulate information gathered from secondary resources, the organisations' profiles, (policy) documents, and the institutional arrangements on the one hand, with information heard from interviewees, on the other. This process enabled me to not only define the innovation network composition and interaction, but also to analyse the quality of these interactions and their impact on the overall innovation and its impact on the societal challenge it is meant to solve.

5. Findings

Sweden and Singapore are both described as "innovation nations" (interviews 2 and 11[5]), aiming to be at the forefront of technological innovation that is sustainable and inducing economic growth. Although the contexts differ, both countries have significantly contributed to the advancements in the CAV technology and are successfully implementing CAV solutions. What are the specific mechanisms and arrangements that enable the successful innovation of CAV as an example of MTS, addressing traffic congestion, pollution, road safety, and inclusiveness?

a. Sweden

The first CAV trials have been in place for several years, first in protected test areas, later incorporated in the public transport system of suburban areas of Gothenburg and Stockholm. Particularly the attempt in the municipality of *Järfalla* near Stockholm has raised attention (interview 7). Today, the public transport system in the district of *Barkarby* in *Järfalla* includes five fully autonomous buses, fully integrated in the system (interviews 9, 12). The programme has moved into *Barkarby* from the neighbouring *Kista* and is now fully functional, acting as a role model for similar projects around the country. Five additional projects are planned at the moment (interview 9). What makes the Swedish model so successful, however? Why is Sweden ahead of most other countries when it comes to implementing the autonomous vehicle technology in public transportation systems? How is the innovation system underlying the CAV technology coordinated and how are potential difficulties dealt with, particularly with regard to policy and implementation coordination? In short, what can we learn from Sweden?

<u>The politico-economic context</u>

The politico-economic context defines the general set-up of the Swedish governance trucutre, the economic framework, and the overarching mechanisms in which innovation policy governance occurs. In general, the Swedish government apparatus is comparatively small, both in terms of structure and personnel. Ministries often cover multiple policy sectors, many of which are only lightly governed as decision are instead left to county or municipal authorities to handle. The predominant philosophy of public sector organisations is shaped by pragmatism – "the Swedish way" (interview 5), a mindset that is regularly challenged by directives from the European Union (interview 11), of which Sweden is a member. The Ministry of Enterprise and Innovation is responsible for innovation policy, generally. Matters regarding transportation are covered by the Ministry of Infrastructure. The policy jurisdiction of the Ministry of the Environment and Energy is self-evident. In addition to these ministries directly responsible for parts or elements related to

[5] see Figure 4

CAV, the Ministry of Finance plays a key role because it annually allocates funds to the respective ministries, which they can use or re-distribute themselves, as long as their actions are in line with general goals and objectives of the national government. Simultaneously, the Ministry of Finance (in collaboration with the Prime Minister's Office) also publishes a communique to each ministry outlining how the allocated funds should be spent. Note, that this communique remains rather open and vague, giving the receiving ministry a lot of scope for interpretation and manoeuvring (interview 11), thus affecting the distribution of funds for R&D, for joint venture programmes, public-private partnerships, pilots/trials, or other endeavours which can promote a specific technology, in this case CAV. The Ministry of Finance, hence, has the power to direct innovation through the Swedish purse. Additionally, the previously called 'Minister of Policy Coordination' has been renamed (now 'Minister of Public Administration') and has moved to now being based at the Ministry of Finance, indicating the ministry's key role in coordinating government.

One of the most prominent innovation-related organisations set up in Sweden is the National Innovation Council (NIC). The body comprises the Ministers of Finance, Enterprise and Innovation, Environment and Energy, and Education and Research. The NIC is chaired by the Prime Minister personally. In addition, the council comprises ten external advisors and experts from industry, academia, and unions, who meet 3-4 times a year for 5-8 hours each time (interview 11, Edquist, 2018). The primary task of the NIC is to set the innovation agenda for the country. It does not design laws or draft bills. Instead, experts inform the representatives from the government, ideas are developed, and possible coordination challenges are addressed. Crucially, the output of NIC meetings serve as a starting point for the Ministry of Finance when drafting the communiques for the other ministries when assigning the annual budget (interview 11). This makes the NIC a central actor in the policy design phase of innovation policymaking in Sweden and allows the ministries who cover distinct policy domains to collaborate on more complex issues. Paired with the whole-system approach the Prime Minister's Office has been following, e.g. regarding sustainability and the greening of the Swedish economy (see further details below), this makes the NIC also relatively powerful, disregarding its lacking powers when it comes to policymaking directly (interviews 5, 6, 10, 11). Note, that although this appears as a policy driven, top-down approach, it is more of a collaborative endeavour, since the NIC is led by the Prime Minister but has now direct policymaking powers, and since the output of the NIC also carries significant normative value, fostering trends, and setting the agenda in other policymaking bodies (e.g. parliamentary committees, parties, or other interest groups) (interviews 4, 11, Edquist, 2018).

Overall, the NIC prevents policy overlap across ministries and due to the presence of industry and academic experts also largely prevents policy underlap. Particularly for MTS the NIC, hence, offers a direct link between actors involved in the MTS innovation network. In the case of CAV, the composition of the NIC, combined with the quality of high ranking interaction (ministers, directly) ensures that policy obstacles inhibiting the development of CAV can be resolved before they constrain major developments and that stumbling blocks that relate to policymaking, if they occur, can be approached immediately. Specifically, the objective of implementing autonomous public transport solutions in the Swedish transportation system is a result emerging from several meetings of the NIC. The ministers took this agenda item on board when passing on directions and instructions to their ministries and to the agencies that their ministries oversee. As such, infrastructure planning, environmental regulation, the regulations affecting electric vehicle charging (as CAV buses are electrically powered), among others, were into account.

The NIC, as indicated, reflects the prevalent mindset in the Swedish government, attempting to focus on a whole-system transformation, i.e. not to regard a single technology in isolation, but to innovate and change the entire system, sector, or industrial domain (Grillitsch, Hansen, Coenen, Miörner, & Moodysson, 2018). In the case of CAV for public transport this means to "reform and redesign the entire public transport system, from vehicles to roads and consumption behaviour" (interview 10). The goal is to increase the efficiency of the system, which can in turn incentivise Swedish residents to use the public transport system more frequently (interview 6), and to "replace ownership of individual, unsustainable vehicles with access to a reliable public transportation system, including the first and last mile segments" (interview 10).

The whole-system focus, also referred to as "challenge-driven innovation" (Vinnova, 2017: 1), in conjunction with the NIC output, also helps industry and research organisations to decide where to invest and which (technological) innovations to pursue, ultimately reducing uncertainty for the private sector, yet leaving space to explore and innovate (interview 6). It provides private sector actors with a chance to anticipate not only future developments, but also future policies and regulation. Accordingly, they can accommodate these into their companies' strategies and future outlook, also assisting firms to grow into a desired direction (Vinnova, 2017). This creates, a self-reinforcing dynamic, almost "some sort of self-fulfilling prophecy" (interview 12), as companies innovate towards a direction based on anticipation of regulation, without such regulation being in place. In turn, the government can then follow suit and design policies based on real developments. This creates an advantage for both sides: firms can develop free of regulatory constraints and the government, in turn, can rely on real-world experience of private firms and incorporate this knowledge into the policy design and regulatory processes. This mutually beneficial system then, jointly, propels the whole-system transformation and demonstrates how the output (policy design) and outcome (implementation) spaces are connected in the case of CAV in Sweden – directly leading us to ask how the politico-administrative organisation that defines the implementation stage of innovation policy looks like in Sweden.

The politico-administrative organisation

The politico-administrative organisation describes the implementation space, where policy output is transformed into action. This administration of policy is what I will analyse in this section, including the actors and their interaction in this implementation network. In Sweden, government agencies, similarly to government ministries, also tend to be of relatively small size. For example, organisations such as the Transport Agency (*Transportstyrelsen*), responsible for vehicle registration, licensing, and with regard to CAV, for the trial and operation permits, or the Transport Administration (*Trafikverket*), in charge of all transport-related infrastructure (land, sea, and air), are overseen by the government (in both of these cases by the Ministry of Infrastructure), but operate largely independently. One could speak of agencies at 'arm's length' (Pollitt, 2015).

One of these quasi-independent agencies at the core of the innovation network, also for CAV, is *Vinnova*, the Swedish innovation agency. *Vinnova* does not innovate technologies itself, i.e. it does not research or develop technologies. Instead it helps companies to do so, funds research programmes, creates joint ventures, brings actors in the R&D space together, and fosters collaboration with international partners, both in the private and the public sectors. As such, *Vinnova* also cooperates closely with other government agencies, aiming to innovate within government as much as stimulating innovation throughout the economy. *Vinnova*, thus, sits at the crossroads of public and private organisations within the innovation space, is well connected, and has its own budget (also directly allocated through the Ministry of Finance[6]), with which it can fund initiatives (or simply experiments) it deems useful, with the only caveat that it ought to fit into the wider remit of the government's plans (again, government agencies have a relatively free mandate in Sweden and can independently decide how such budget allocations can be used) (interview 11). As such, *Vinnova* cooperates among others closely with the 'Research Institutes of Sweden' (RISE). The 16 research and technology organisations that form the RISE network are either wholly or at least partially owend by the Swedish state and work across a wide variety of sectors and domains, including life sciences, information and communication technology, materials, transport, and environmental sciences – similar to the German Fraunhofer Society (interview 6). RISE organisations mostly work on a client basis (e.g. industry clients) or directly for the government or *Vinnova* and contribute to understanding the socio-econmic impact of technological advances.

The key technological innovators in the realm of CAV, however, are private firms (and thus, also enact some of the CAV-related innovation policies). Several Swedish car manufacturers, for example, have invested heavily into CAV and related technologies (interviews 4, 12). These include firms like Volvo, Saab, and Scania. However, the CAV innovation ecosystem also comprises significantly smaller firms and even start-ups. One way in which these companies are organised is through shared facilities where CAV are tested. One of these testing sites is located right outside the city of Gothenburg at *Lindholmen* Science Park. One of the important firms there is DriveSweden. The company does neither own nor operate any CAV, nor does it develop or manufacture any technology that is used in CAV. Instead, DriveSweden acts as coordinator between different firms who build, design, programme, or test different parts and technologies of CAV (interview 4). DriveSweden brings other companies together and provides space within *Lindholem* Science Park for those firms to interact and collaborate. In addition, DriveSweden also cooperates with academic institutions (e.g. the University of Gothenburg or Chalmers University), government agencies (e.g. *Vinnova*, the Swedish innovation agency), ministries (e.g. the Ministry of Enterprise and Innovation), and other government authorities (e.g. the municipality of Gothenburg). Several representatives of various government organisations (e.g. the Transport Administration or the Swedish Innovation Agency) sit on the board of DriveSweden and in turn influence the direction into which the company develops.

The main challenge thus far when implementing innovation policies regarding CAV has been the lack of specific regulations for this complex technology. This includes environmental regulation, data protection, safety regulations, communication technology, issues related to liability and insurance, and more – again, ranging across a wide variety of policy domains. For these challenges, the Swedish public administration relies on close interaction with the technology

[6] The Ministry of Finance can also directly allocate a budget to government agencies, not just to ministries who then can pass funds on to the agencies they oversee. Through such measures, the Ministry of Finance (after consultation with the Prime Minister or, for example, after conclusions resulting from NIC meetings) can directly influence the work of an agency or incentivise an agency's work to develop into a particular direction.

innovators and the firms that intend to use a new technology. One possible solution are 'policy labs' which allow government agencies to experiment with regulatory mechanisms that affect new technologies to ensure that the regulation serves its intended purpose without harming the innovation's purpose, in particular, or the Swedish economy, in general. One of the first stumbling blocks for CAV was the permit process for pilot projects, trialling autonomous cars on public roads. (Testing CAV on private roads or specifically defined testing grounds was not an issue, as this is not affected by road safety regulations. However, since the goal was to incorporate CAV on fixed routes as parts of the public transportation system, a real-world test had to be established, to allow the technology to be piloted in real circumstances and an uncontrolled environment.) The existing regulatory regime for road vehicles (dating back decades or more) and public transportation did not lend itself to such trials as they did not, when originally written, foresee the developments of CAV. Hence, a new solution was required.

Establishing a new regulatory regime, however, proved difficult, primarily due to a lack of knowledge on both sides of the debate (interviews 9, 12). The companies struggled to understand what is needed from them in order to obtain a permit for testing, when at the same time the agencies were struggling to accommodate the needs of the industry in the permit process (interview 9). As a solution, several joint sessions where representatives from agencies (e.g. the Transport Administration and the Transport Agency) as well as from the private sector (e.g. DriveSweden, Scania, Volvo, Nobina[7]) met and discussed the needs and issues emerging throughout the process. As a result, the Transport Agency who is in charge of ultimately handing out piloting permits reviewed the process and altered it incorporating the needs of the industry. A similar feature remains in place today: Before submitting their final documents, representatives of companies wishing to apply for a testing permit meet with the Transport Agency and discuss the permit application and all eventual problems and issues that might arise from it. This consultation is free of charge and does not form part of the application process (interview 9). The mechanism assures that both sides understand what is required in the process and facilitates the submission of a well-designed testing permit application. The results from these discussions are taken on board by the Agency to be included in further re-designs of the trial permit application procedure. Upon receipt of the actual application, however, the Agency remains neutral and stays away from any further consultation, as this might compromise the agency's role as independent regulator. Overall, this policy lab process between government agencies and industry serves as a coordination mechanism between stakeholders in the innovation network that prevents stumbling blocks and furthers an effective and efficient progress of technological innovation of CAV.

Integration of innovation policy design and implementation

Having analysed both the politico-economic context and the politico-administrative organisation, I mapped the actors within the CAV innovation network in Sweden. This CAV eco-system includes many different actors that contribute different parts to the innovation and development of the technology. The network consists of industry players, but government agencies and hybrid organisations (such as research organisations part of RISE) also play a crucial

[7] Nobina, a multi-national company operating across several countries in Northern Europe, is the largest public transport provider in Sweden, also in the areas around Gothenburg/Stockholm, where CAV testing takes place.

role. In the figure below, each node represents one actor (mostly organisations, firms, or government ministries/agencies). Two (or more) actors are linked if they work on the same project or form part of each other's organisation, e.g. through members of one organisation sitting on a stirring board of another organisations. I assumed that if actors are linked, information and knowledge exchanges occur between those actors. What becomes clear is that government organisations (yellow), i.e. ministries and agencies, remain relatively distant from the more central nodes in the network, i.e. nodes that feature more connections with other actors in the network (e.g. *Lindholmen* Science Park as one of the most central nodes, bringing innovators and government agencies together in a central location and incurring collaboration).

Despite the relative distance between the government dominated actors and the industrial and hybrid actors, the ties between the policymaking and the policy implementing sides are present and embodied by the two mechanisms elaborated on above, representing a high quality interaction in the network: the NIC as a means to align policy design, and hence, the innovation policy output, on the one hand, and the policy lab approach as a mechanism to facilitate innovation policy implementation, and thus the innovation policy outcome, on the other. Therefore, we observe a structure that aligns policy design and implementation in a relatively integrated way, including a forward looking, impact-oriented element in both parts: the NIC through a whole-system focus incorporates academic and technology experts and their opinion in its guidance notes, which is acknowledge by the respective ministries when drafting policies or communiques to their agencies (i.e. to policy implementers). In turn, the implementing public agencies, jointly with hybrid (e.g. government funded) organisations (like RISE), incorporate practitioners and thus, the private sector, in its processes, such as through knowledge gathering in policy labs (interview 6). This enables the industry to conduct trials but allows the regulating agency to maintain control of the CAV trials. In other words, knowledge and experience is fed both ways, from policy design to implementation agents and vice versa, creating a feedback loop (red arrows in Figure 3), allowing the Swedish government to create an integrated and coordinated innovation policy process.

b. Singapore

Trials with CAV have been running since 2015 in Singapore across several testing grounds such as One-North (interview 2). Seeing itself as an innovation nation, similar to the likes of Sweden or Switzerland, Singapore intends to be among the first countries to have CAV operational on public roads (interviews 8, 13). What is Singapore doing differently from other countries and what makes the innovation system in Singapore efficient for CAV development? Why is Singapore often seen as "the ideal ecosystem for the innovation of CAV" (interview 14)?

The politico-economic context differs markedly, since Singapore operates with a single-tier government. The city state, thus, faces "significantly less coordination challenges compared to other countries" (interview 1). The Prime Minister's Office (PMO) is the central node in the Singaporean innovation system when it comes to innovation policy design including that for CAV. The PMO passes policy mandates to specific ministries, e.g. to the Ministry of Transport (MoT) for solving the issues related to public transportation in the city (interview 15). The respective ministry then becomes responsible for all matters relating to this mandate, including policies drafted and implemented, as well as regulations enacted and enforced. The approach with regard to solving one of Singapore's most prominent challenges – road congestion – includes the establishment of CAV as a means of transport and its incorporation into the public transportation system, including the first and last mile connections (interview 8). Due to the single-tier governance structure, the topic of traffic congestion and reliability of public transportation has become heavily politicised, especially during the most recent elections, because people see the national government (i.e. the only government) as directly responsible (interview 8).

The politico-administrative organisation reflects the relatively more hierarchical policy model observed in the output generating policy design process, as discussed above. The key actors in the context of CAV are the MoT and the Land Transport Authority (LTA), the transport regulator of Singapore. The purpose-founded CARTS unit (Committee on Autonomous Road Transport for Singapore) sits between the MoT and the LTA and handles the strategic foresight regarding CAV development. CARTS also acts as liaison between different government organisations, e.g. the Economic Development Board or the Urban Redevelopment Authority, practically advocating for CAV as a solution to the city's traffic problems (interview 8). Furthermore, CARTS collaborates with research institutes (e.g. at the National University of Singapore or Nanyang Technological University) and the industry (e.g. CAV start-ups), such as SAVI, SMART, or CREATE[8]. The unit, therefore, connects actors in the implementation space, yet allows government to maintain a central role also when implementing innovation policy. CARTS also initiated a set of collaboration organisations and guides them towards the incorporation of CAV into the public transportation system by providing assistance regarding trial permits and testing grounds (interview 16). These include collaborations between Singaporean and international universities (e.g. NUS-ETH-MIT cooperation) and between universities and private sector firms (e.g. NUS-Nutonomy cooperation). Hence, the integration of policy design and implementation is primarily a result of the position of the LTA and the MoT and their joint CARTS unit within the CAV innovation network and the comparatively top-down policy driven structure embodied by CARTS.

c. Comparative Analysis

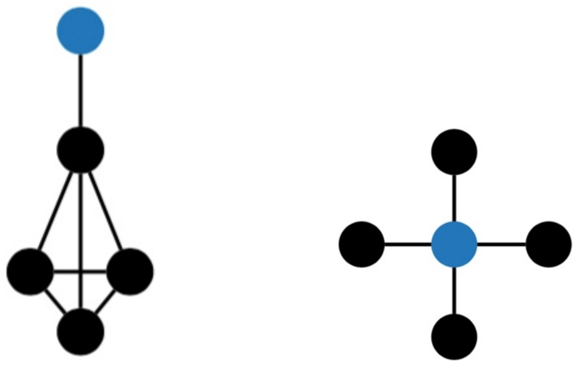

Figure 5: Conceptualisation of the Swedish (left) and Singaporean (right) CAV innovation networks

Consequently, we can conceptually map the CAV innovation systems in both Singapore and Sweden in a more abstract way. For Sweden, this reveals as indicated above the role of the

[8] SAVI: Singapore Autonomous Vehicle Initiative; SMART: Singapore-MIT Alliance for Research and Technology; CREATE: Campus for Research Excellence and Technological Expertise

government and government actors as a more distant agglomeration of actors relatively separate from the centre of innovation. Mind, that this does not mean that there is no interaction between government and other actors, but that the interaction (a) is channelled through fewer organisations (e.g. regulators, the NIC, and *Vinnova* as Sweden's innovation agency), (b) occurs in fewer projects, and/or (c) with lower frequency, e.g. via communiques. Figure 5 below depicts the position of the government (blue) in the Swedish innovation system according to these findings schematically. In Singapore, the same analysis reveals a much more central role of government within the CAV innovation system. Actors are more closely interconnected via the MoT and the LTA. The interaction of these two actors (through the CARTS unit) with other actors in the network is relatively high and relatively more intensive and of higher frequency.

In both cases, hence, the government plays a key role in coordinating the innovation network, yet through different means: in Sweden, relatively more distant, through a network-based approach, that relies on market dynamics to bring together those actors that are able to contribute to the innovation of CAV. The government through the at arm's length operating innovation and transport agencies can maintain a direction with a whole-system focus, yet leave enough room for testing and the interpretation of regulations (including the policy lab model) to allow the industry to more effectively develop technologies and, thus, relatively quickly make the technology available to be incorporated into the public transportation system[9]. In Singapore, the government maintains a much more central role, creating a coordination structure that is relatively more hierarchical. Although the government also pursues a whole-system focus, their orientation is more on the relatively narrow traffic congestion problem than on the relative far-reaching sustainability mission (as in Sweden). I compare the two cases of Sweden and Singapore in Figure 6:

	Sweden	**Singapore**
Politico-economic context	• Federal governance structure • Central innovation policy coordination (National Innovation Council) • Whole-system orientation, purpose driven (sustainability) • Policy guidance only (via Ministry of Finance)	• Single-tier government structure • Central innovation policy coordination (Prime Minister's Office) • Whole-system orientation, policy issue driven (reliability of transport system) • Policy control (via Ministry of Transport)
Politico-administrative organisation	• Regulatory agencies at arm's length • Close interaction of industry and government agencies • Policy lab model for CAV trial permits	• Regulatory agencies close to government ministries (LTA) • Hierarchical interaction between government and industry
Policy design-implementation integration (coord.)	• Network-based, market driven policy coordination	• Hierarchical, policy driven coordination

Figure 6: Sweden's and Singapore's CAV innovation system in comparison

[9] The coordination heuristics of hierarchy, market, and network is based on (Peters, 1998, 2015) .

6. Discussion and Conclusion

In summary, on the one hand, we can observe a catalytic and cyclical dynamic regarding the development and innovation of CAV in Sweden, where policy outcome feeds into the creation of policy output (policy design-implementation integration) through mainly two coordinating mechanisms: the NIC and policy labs. In Singapore, on the other hand, the CAV innovation system it relatively more hierarchical, even though a large amount of actors both private and public are involved in the innovation processes. The MoT and the LTA, primarily through their joint CAV technology-focused CARTS unit maintain a central role both in the design and implementation of innovation policy regarding CAV. Policy output and outcome can, thus, be aligned and due to the single organisation at a central position in the innovation network also well integrated, again taking both the policy and innovation impact into account.

We can, thus, preliminarily conclude that governing MTS requires closely integrated innovation policy structures, yet that the mechanisms that comprise these structures can vary from more market-driven (Sweden) to more policy-driven (Singapore). In both cases, however, a whole-system orientation facilitates the incorporation of a large network of actors and a relatively high intensity of interaction where the government is relatively more (Singapore) or less involved (Sweden). Taking the impact into account when designing and implementing innovation policy can, as observed in both case studies, accelerate the innovation dynamics, because it reduces stumbling blocks, like policy over- and underlap or regulatory uncertainty, before they emerge and constrain innovation. Additionally, this leads to a re-enforcement of the whole-system approach because it takes into account more actors and an even wider context. Overall, we see that direct and high-quality interaction in a well-structured composition of actors ensures an accelerated innovation of purposeful technologies, ensuring integration of policy design and implementation, and avoiding coordination challenges. This analysis explains the interaction between actors on the niche and regime level and, thus, contributes to further understanding the interaction of regime with niche level actors according to the MLP, in the context of MTI, before a window of opportunity emerges (Geels, 2002). In other words, a closely integrated innovation policy network can help for such a window of opportunity to emerge, as the case of CAV in Sweden demonstrates.

There are several limitations to these conclusions and a few areas for future research result from this study. Primarily this refers to the fact that additional data might be necessary to confirm the innovation system dynamics in Singapore. Due to the limited access to government representatives and a relatively closed system within the Singaporean government, this task might be challenging, but should be possible. Furthermore, comparative cases in other countries and/or concerning other MTS could shed light on similar structures implemented elsewhere[10]. ■

[10] In part, this is the objective of the doctoral dissertation project underlying this conference paper.

Bibliography

Alexander, E. R. (1993). Interorganizational Coordination: Theory and Practice. *Journal of Planning Literature*, *7*(4), 328–343.

Anadon, L. D., Matus, K., Moon, S., Chan, G., Harley, A., Murthy, S., … Clark, W. C. (2014). *Innovation and Access to Technologies for Sustainable Development: Diagnosing Weaknesses and Identifying Interventions in the Transnational Arena* (No. 2014–01). *Sustainability Science Program Working Paper Series*. Cambridge, USA.

Angheloiu, C. (2017). *A systemic perspective on the breakthrough of rock'n'roll*. Retrieved from https://medium.com/system-innovation-field-notes/a-systemic-perspective-on-the-breakthrough-of-rockn-roll-e6718b930858

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the Functional Dynamics of Technological Innovation Systems: A Scheme of Analysis. *Research Policy*, *37*(3), 407–429.

Braczyk, H.-J., Cooke, P. Philip N. ., & Heidenreich, M. (1998). *Regional Innovation Systems: the Role of Governances in a Globalized World*. UCL Press.

Braun, D. (2008). Lessons on the Political Coordination of Knowledge and Innovation Policies. *Science and Public Policy*, *35*(4), 289–298.

Breschi, S., Malerba, F., & Orsenigo, L. (2010). Technological Regimes and Schumpeterian Patterns of Innovation. *The Economic Journal*, *110*, 388–410. https://doi.org/10.1093/icc/dtq051

Cairney, P. (2011). *Understanding Public Policy*. Basingstoke, UK: Palgrave Macmillan.

Christensen, T., & Lægreid, P. (2007). The Whole-of-Government Approach to Public Sector Reform. *Public Administration Review*, *67*(6), 1059–1066.

Coenen, L., & Díaz López, F. J. (2010). Comparing Systems Approaches to Innovation and Technological Change for Sustainable and Competitive Economies: An Explorative Study into Conceptual Commonalities, Differences and Complementarities. *Journal of Cleaner Production*, *18*, 1149–1160.

Cooke, P. (2001). Regional Innovation Systems, Clusters, and the Knowledge Economy. *Industrial and Corporate Change*, *10*(4), 945–974.

Edquist, C. (1997). *Systems of Innovation*. Routledge.

Edquist, C. (2018). Towards a Holistic Innovation Policy: Can the Swedish National Innovation Council (NIC) Be a Role Model? *Research Policy*, *48*(4), 869–879.

Fagnant, D. J., & Kockelman, K. (2015). Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations. *Transportation Research Part A: Policy and Practice*, *77*, 167–181.

Ford, C. (2013). Innovation-Framing Regulation. *Annals of the American Academy of Political and Social Science*, *649*, 76–97.

Foxon, T. J., Gross, R., Chase, A., Howes, J., Arnall, A., & Anderson, D. (2005). UK Innovation Systems for New and Renewable Energy Technologies: Drivers, Barriers and Systems Failures. *Energy Policy*, *33*, 2123–2137.

Gallagher, K. S., Grubler, A., Kuhl, L., Nemet, G., & Wilson, C. (2012). The Energy Technology Innovation System. *Annual Review of Environment and Resources*, *37*, 137–162.

Geels, F. W. (2002). Technological Transitions as Evolutionary Reconfiguration Processes: A Multi-Level Perspective and a Case-Study. *Research Policy*, *31*, 1257–1274.

Geels, F. W. (2004). From Sectoral Systems of Innovation to Socio-Technical Systems: Insights About Dynamics and Change from Sociology and Institutional Theory. *Research Policy*, *33*, 897–920.

Geels, F. W. (2018). Disruption and Low-Carbon System Transformation: Progress and New Challenges in Socio-Technical Transitions Research and the Multi-Level Perspective. *Energy Research and Social Science*, *37*, 224–231.

Gehring, T., & Oberthür, S. (2009). The Causal Mechanisms of Interaction between International Institutions. *European Journal of International Relations*, *15*(1), 125–156.
Grillitsch, M., Hansen, T., Coenen, L., Miörner, J., & Moodysson, J. (2018). Innovation Policy for System-Wide Transformation: The Case of Strategic Innovation Programmes (SIPs) in Sweden. *Research Policy*, *48*(4), 1048–1061.
Hekkert, M. P., Suurs, R. A. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. H. M. (2007). Functions of Innovation Systems: A New Approach for Analysing Technological Change. *Technological Forecasting and Social Change*, *74*, 413–432.
Johnstone, P., & Newell, P. (2018). Sustainability transitions and the state. *Environmental Innovation and Societal Transitions*, *27*(February 2017), 72–82.
Karo, E., & Kattel, R. (2016a). *How to Organize for Innovation: Entrepreneurial State and Organizational Variety* (Technology Governance and Economic Dynamics No. 66). Tallinn, EST.
Karo, E., & Kattel, R. (2016b). Innovation and the State: Thinking of Government as "Technology Maker" and Implications for Public Administration Research. *Administrative Culture*, *17*(1), 5–17.
Kaufmann, F.-X. (1991). *The Public Sector: Challenge for Coordination and Learning*. W. de Gruyter.
Kempener, R., Diaz Anadon, L., & Condor, J. (2010). *Governmental Energy Innovation Investments, Policies, and Institutions in the Major Emerging Economies: Brazil, Russia, India, Mexico, China, and South Africa* (Energy Technology Innovation Policy Discussion Paper Series No. 2010–16). *Energy Technolocy Innovation Policy*. Cambridge, USA.
Kivimaa, P., & Kern, F. (2016). Creative Destruction or Mere Niche Support? Innovation Policy Mixes for Sustainability Transitions. *Research Policy*, *45*(1), 205–217.
Klijn, E.-H., & Koppenjan, J. (2014). Complexity in Governance Network Theory. *Complexity, Governance & Networks*, *1*(1), 61–70.
Klijn, E. H., Koppenjan, J., & Koppenjan, J. (2015). *Governance Networks in the Public Sector*. Routledge.
Koppenjan, J., & Koliba, C. (2013). Transformations Towards New Public Governance: Can the New Paradigm Handle Complexity? *International Review of Public Administration*, *18*(2), 1–8.
Lodge, M., & Wegrich, K. (2014). *The Problem-Solving Capacity of the Modern State: Governance Challenges and Administrative Capacities*. Oxford, UK: Oxford University Press.
Malerba, F. (2002). Sectoral Systems of Innovation and Production. *Research Policy*, *31*(2), 247–264.
Markard, J. (2018). The Next Phase of the Energy Transition and Its Implications for Research and Policy. *Nature Energy*, *3*(8), 628–633.
Markard, J., & Truffer, B. (2008). Technological Innovation Systems and the Multi-Level Perspective: Towards an Integrated Framework. *Research Policy*, *37*(4), 596–615.
Mazzucato, M. (2014). A mission-oriented approach to building the entrepreneurial state, (November), 27.
Mazzucato, M. (2016). From Market Fixing to Market-Creating: a New Framework for Innovation Policy. *Industry and Innovation*, *23*(2), 140–156.
Mazzucato, M. (2017). *Mission-Oriented Innovation Policy*. London, UK.
Mulgan, G. (2006). *Social Innvation: What It Is, Why It Matters and How It Can Be Accelerated*. Oxford, UK.
Nelson, R. R. (1993). *National Innovation Systems: a Comparative Analysis*. Oxford University Press.
Owen, R., Macnaghten, P., & Stilgoe, J. (2012). Responsible Research and Innovation: From Science in Society to Science for Society, with Society. *Science and Public Policy*, *39*, 751–760.
Peters, B. G. (1998). Managing Horizontal Government: The Politics of Co-Ordination. *Public Administration*, *76*(2), 295–311.
Peters, B. G. (2015). Policy Capacity in Public Administration. *Policy and Society*, *34*(3–4), 219–228.
Pollitt, C. (2003). Joined-up Government: A Survey. *Political Studies Review*, *1*(1), 34–49.

Pollitt, C. (2015). Decentralized Management: Agencies and "Arm's Length" Bodies. In T. Bovaird & E. Loeffler (Eds.), *Public Management and Governance*. Abingdon, UK: Routledge.
Rogge, K. S., & Reichardt, K. (2016). Policy Mixes for Sustainability Transitions: An Extended Concept and Framework for Analysis. *Research Policy*, *45*(8), 1620–1635.
Rogge, K. S., & Schleich, J. (2018). Do Policy Mix Characteristics Matter for Low-Carbon Innovation? A Survey-Based Exploration of Renewable Power Generation Technologies in Germany. *Research Policy*, *47*, 1639–1654.
Schot, J., & Geels, F. W. (2007). Niches in Evolutionary Theories of Technical Change. *Journal of Evolutionary Economics*, *17*(5), 605–622.
Schot, J., & Geels, F. W. (2008). Strategic Niche Management and Sustainable Innovation Journeys: Theory, Findings, Research Agenda, and Policy. *Technology Analysis & Strategic Management*, *20*(5), 537–554.
Schot, J., & Steinmueller, W. E. (2018a). New Directions for Innovation Studies: Missions and Transformations. *Research Policy*, *47*(9), 1583–1584.
Schot, J., & Steinmueller, W. E. (2018b). Three Frames for Innovation Policy: R&D, Systems of Innovation and Transformative Change. *Research Policy*, *47*(9), 1554–1567.
Simon, H. A. (2000). Public Administration in Today's World of Organizations and Markets. *PS: Political Science and Politics*, *33*(4), 749.
Smits, R., & Kuhlmann, S. (2004). The Rise of Systemic Instruments in Innovation Policy. *International Journal of Foresight and Innovation Policy*, *1*(1/2), 4.
Sorrell, S. (2018). Explaining Sociotechnical Transitions: A Critical Realist Perspective. *Research Policy*, *47*(7), 1267–1282.
Vinnova. (2017). Challenge-Driven Innovation - Societal Challenges as opportunities for growth.
Wieczorek, A. J., & Hekkert, M. P. (2012). Systemic Instruments for Systemic Innovation Problems: A Framework for Policy Makers and Innovation Scholars. *Science and Public Policy*, *39*(1), 74–87.
Wilson, C., & Grubler, A. (2011). The energy technology innovation system. *Energy Technology Innovation: Learning from Historical Successes and Failures*, 11–29.