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Doctoral Thesis

Networked Transitions: Policy Coordination in Socio-Technical Innovation Systems

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Declaration of Authorship

I, Andreas Paul Kopp, confirm that the work presented in this PhD thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

The following work of the author is partially integrated in this thesis. All this work has been undertaken throughout the time the author was registered at UCL working towards the completion of this thesis.

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Andreas P. Kopp

Bad Krozingen, Germany, April 2021

Abstract

Governments worldwide increasingly address challenges, such as climate change or sustainability transitions, through mission-oriented innovation policies, i.e. systemic policies that cut across sectors to target a societal problem. Achieving such missions requires socio-technical change and often results in so-called multi-technology innovations: technologies that comprise a set of complex, interacting sub-technologies of diverse characters and cater a multitude of socio-technical purposes. These innovations pose a challenge: They trigger coordination problems across policy domains, across government organisations with different interests, capacities, and mandates, as well as across policy design and implementation. However, although coordination problems are not new to public policy scholars, they remain largely unaddressed in the innovation policy context. Likewise, the innovation studies literature hardly considers the influence of public agencies in innovation systems. Combined, this merits the research question: How do public sector organisations and socio-technical innovation systems mutually shape each other, particularly in the context of mission-oriented policies?

This thesis investigates the innovation systems of autonomous vehicles as an example of a multi-technology solution resulting from mission-oriented policies in three highly innovative economies: Singapore, Estonia, and Sweden. Relying on network analyses, semi-structured interviews, and process-tracing, it compares how hierarchical, market-based, and network-oriented policy coordination arrangements shape the public administration's impact on the innovation system and vice-versa.

In conclusion, socio-technical innovations, due to the challenges they trigger, shift policy coordination arrangements towards (intensified) network-oriented approaches. Accordingly, government organisations collaborate to enable the innovation system, rather than controlling it top-down or through market-based arrangements. 'Networked transitions', hence, allow systemic feedback loops to integrate policy design and implementation, to mitigate coordination failures, and to accelerate the system's development towards fulfilling 'the mission'.

Impact Statement

This thesis speaks primarily to policymakers and implementers. Socio-technical innovation and mission-oriented policies are increasingly the tool of choice to tackle global challenges. To prevent coordination problems common to such policies, policy designers and implementers can learn from the examples provided in this study. This thesis shows how public agencies shape innovation systems. It reveals that 'networked transitions', i.e. approaches where public sector organisations collaborate closely with industry and academia and become participants in the innovation system, are best apt to address stumbling blocks emerging from innovation dynamics. Accordingly, feedback loops must be established between policy design and implementation, e.g. via intermediaries.

This thesis also impacts technologists, innovators, and entrepreneurs. Focusing on autonomous vehicles, the empirical components address a technology that is likely to change our mobility patterns as we know them. The insights into different governance approaches for this technology can help innovators and entrepreneurs engage with government organisations and find the best path forward to accelerate the development of this technology.

Academically, this thesis impacts and speaks to two bodies of literature, innovation (system) studies and public administration – a link that received little attention before. The 'TIS+' analytic framework derived in this thesis can help researchers in the future to assess the influence of public agencies in innovation systems, particularly regarding socio-technical change. Given the complex challenges that governments face today and their mission-guided approach to resolving them, the need to understand this role will increase. Among scholars, this conversation has already begun, as the discussions in international fora reveal. Research and innovation organisations such as Vinnova (Sweden), Fraunhofer (Germany), or Innovate UK (UK) are also engaging with this dynamic and can, thus, benefit from the analytic tools provided in this thesis.

In sum, the empirics, concepts, and tools studied in this PhD can provide the foundation for a practice-oriented approach to support those working for or with government and/or in challenge-oriented organisations or projects.

Acknowledgements

The vast opportunities underlying socio-technical innovation in conjunction with the ‘right’ political and economic decisions to the benefit of society and the climate, fascinate me and motivated me to write this thesis. I am convinced that we all – especially those bearing responsibility – face tough decisions over the coming years to ensure that our socio-economic development does not continue to antagonise the environment we live in. I hope that this thesis can offer a small contribution, being of help to those working with or for governments, to decision-makers of all kinds, to innovators, and to researchers.

It would not have been possible to complete this thesis were it not for the unwavering support of numerous individuals and organisations. I would like to thank everyone involved in this process who was generous with their time for their support. It goes without saying that all errors remain mine.

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I have learned to love research and first discovered the realm of innovation policy and sustainability transitions during my Master’s degree at the University of Oxford. Thank you to David Doyle, Leigh Payne, Tim Power, and Diego Sanchez-Ancochea, who led me through my first encounters with theoretical frameworks, literature reviews, and academic fieldwork, and made me want to pursue a PhD. Thank you also to Kimberly Hutchings and Thomas Sattler, my former academic advisors at the London School of Economics and Political Science.

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Thank you.

Bad Krozingen, Germany, April 2021

To My Parents

Networked Transitions: Policy Coordination in Socio-Technical Innovation Systems

Andreas Paul Kopp

April 2021

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List of Acronyms

A*STAR	Agency for Science, Technology, and Research
AI	artificial intelligence
AV	autonomous vehicle
AVRI	Autonomous Vehicle Readiness Index
CARTS	Committee on Autonomous Road Transport (Singapore)
CEO	chief executive officer
CETRAN	Centre of Excellence for Testing and Research of AVs (Singapore)
cf.	*confer,* lat.; (to) compare
CREATE	Campus for Research Excellence and Technological Enterprise
DS	Drive Sweden
E	element
EE	Estonia
EDB	Economic Development Board (Singapore)
EU	European Union
EUR	Euro
F	(system) function
GBP	Great Britain Pound Sterling
GDP	gross domestic product
GIS	global innovation system
GovTech	Government Technology Office (Singapore)
HDB	Housing Development Board (Singapore)
ICT/IT	information (and communication) technology
IMDA	Infocomm Development Authority (Singapore)
ITS	Intelligent Transportation and Logistics Systems (Estonia)
JTC	Jurong Town Corporation (Singapore)
JUG	joined-up government
LTA	Land Transport Authority (Singapore)
MaaS	mobility as a service
MIT	Massachusetts Institute of Technology
MLP	multi-level perspective
NIC	National Innovation Council (Sweden)

NIS	national innovation system
NPM	new public management
NRF	National Research Foundation (Singapore)
NTU	Nanyang Technological University Singapore
NUS	National University of Singapore
OECD	Organisation for Economic Cooperation and Development
OIS	organisational innovation system
PIS	problem-oriented innovation system
PM(O)	Prime Minister (Office)
R&D	research and development
RD&D	research, development, and diffusion
RIEC	Research, Innovation, and Enterprise Council (Singapore)
RIS	regional innovation system
RISE	Research Institutes of Sweden
SAVI	Singapore Autonomous Vehicle Initiative
SDC	Sentosa Development Corporation (Singapore)
SDG	Sustainable Development Goals
SE	Sweden
SEK	Swedish Krona
SG	Singapore
SGD	Singapore Dollar
SMART	Singapore-MIT Alliance for Research and Technology
SNS	Smart Nation Singapore
SIP	strategic innovation programme
SIS	sectoral innovation system
Tal Tech	Tallinn University of Technology
TIS	technological innovation system
TR68	technical reference 68
TRL	technology readiness level
UK	United Kingdom
URA	Urban Redevelopment Authority (Singapore)
US	United States
WG	whole-of-government

"Wenn Sie die Art und Weise ändern, wie Sie die Dinge betrachten, ändern sich die Dinge, die Sie betrachten."

"When you change the way you look at things, the things you look at change."

– *Max Planck, German Physicist and Nobel Laureate* [1]

[1] Source: Die ZEIT (2021, 31)

1 Introduction: The Coordination Problem of Innovation Policy

1.1 Introduction

Riding in an autonomous vehicle (AV) is quite an extraordinary experience[2]. Upon boarding, the doors close automatically, and one immediately notices that "this is very different" (interview: SE16[3]). One can see no steering wheel and no dashboard, no pedals and no gear shift, no handbrake and no rear mirrors. Instead, one sits in a comfortable seat with large windows all around, cameras and sensors are blinking and humming everywhere, screens are flickering, and one can feel the silent buzz of the electric motor. In short, not much reminds one of a conventional car. The vehicle moves without human interaction[4], nearly soundless, carefully accelerating, turning corners, reading signs, stopping at intersections, circumventing obstacles, and emergency-braking in anticipation of cyclists crossing the street ahead. Clearly, a lot is happening inside the vehicle, things one does not see. Knowing this, still, makes it all seem slightly magical.

Getting to the point where AVs roam the streets, even if just for testing, was a long journey – a journey of great ideas and technological advancement but also failures, trial-and-error, research and entrepreneurship, legal disputes, novel policies, and many, many people and organisations (EE09). This thesis is not a book of advocacy for AVs. Instead, it aims to explore how we got to where we are today – through innovation, policy, and a combination of the two. And it seeks to understand how innovations of this type can be governed such that they contribute to resolving the 'grand challenges'[5] of our time.

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[2] This brief experience refers to a test drive with a Navya 'Arma' vehicle, an autonomous minibus, at Lindholmen Science Park in Gothenburg, Sweden, in September 2019.
[3] The data and direct quotes derived from semi-structured interviews that are used in this thesis are systematically coded, indicating a) the case study country to which they refer (SG = Singapore, EE = Estonia, SE = Sweden) and b) a number for easier identification (see Chapter 2 for further details and the appendix for a full list of interviews conducted and their corresponding codes).
[4] Although, a safety driver was on board.
[5] Refer to the glossary in the appendix for detailed definitions of key terms throughout this thesis.

Governments today face many such 'grand challenges' (cf. Reid et al. 2010), also known as 'wicked' problems (Head 2008), e.g. climate change. They are too complex to be resolved by single, top-down initiatives and instead require "new constellations of actors and their concentration" (Kuhlmann and Rip 2018, 450). Consequently, "the focus of innovation policy is currently shifting towards addressing societal challenges" (Hekkert et al. 2020, 76). Governments turn to so-called 'mission-oriented policies' (cf. Mazzucato 2013b, 2018a, 2021; Vinnova 2017). A mission-oriented policy is "a directional policy that starts from the perspective of a societal problem, and focuses on the formulation and implementation of a goal-oriented strategy by acknowledging the degree of wickedness of the underlying challenge, and the active role of policy in ensuring coordinated action and legitimacy of both problems and innovative solutions across multiple actors" (Wanzenböck et al. 2020, 3). Accordingly, missions follow a broader, comprehensive, and holistic approach, range across sectors, and involve stakeholders with diverse interests (cf. Mazzucato 2021; Pollitt 2016).

Missions, by definition, require socio-technical innovation and cause change across socio-technical systems. 'Socio-technical systems' include political, economic, technological, ecological, behavioural, psychological, and sociological factors that define social dynamics, innovation, and transformation through co-evolution, interdependencies, uncertainties, lock-ins, non-linearities, trade-offs, and feedback loops that catalyse each other (European Environment Agency 2019, 23). Moreover, socio-technical innovation often results in multi-technology solutions, i.e. innovations that consist of complex, interacting sub-technologies of diverse characters that cater a multitude of purposes (cf. Markard 2018).

AVs are a prime example of socio-technical innovation. They resemble multi-technology solutions (cf. G. Meyer and Beiker 2014), building on a highly integrated and complex underlying technological system (cf. Schot, Hoogma, and Elzen 1994). AVs partly result from missions, such as safer traffic due to algorithmic decision-making, less pollution due to fewer vehicles on the streets, or increased efficiency and reliability of public transport systems – all wicked problems in urban areas. Altogether, AVs imply socio-technical change, as they have the potential to disrupt human behaviour, alter social structures (Bissell et al. 2020), and improve transport systems (Borrás and Edler 2020, 5).

However, socio-technical innovations, such as AVs, create stumbling blocks for innovators and governments alike. They transcend various policy domains, such as environmental, transport, energy, infrastructure, urban planning, and even cybersecurity policies, involving numerous diverse stakeholders. They cross organisational boundaries, are not aligned with administrative jurisdictions or capacities, and do not fit into existing regulatory frameworks (cf. Ford 2017; Future Agenda 2020). Striking a balance between maintaining governance stability and providing agility in response to new challenges is not straightforward (Drechsler and Kattel 2020). Yet, "governments and the public administration cannot fail, it is not accepted by the public" (EE07). Hence, "we are entering a new era of innovation policy" (Hekkert et al. 2020, 76), in which governments must find approaches that support rather than hinder socio-technical innovations to address missions that benefit the public.

Innovation scholars research aspects that block (or induce) the development of technologies through technological innovation system analyses (TIS) (Anna Bergek et al. 2008, 2015; Carlsson and Stankiewicz 1991; Hekkert et al. 2007; Wieczorek and Hekkert 2012). Here, 'the state' is often perceived as a unitary actor with a unified objective and capacity (cf. Geels 2014, 2018). Yet, while governments and ministries are responsible for designing policies, public agencies[6] or intermediary organisations implement them. They represent distinct policy domains, often have different intentions, and are equipped with a diverse set of knowledge, expertise, and personnel. It follows that government organisations are, in fact, separate stakeholders in innovation systems and, consequently, have the potential to shape socio-technical change differently.

Hence, socio-technical innovations of this magnitude that attempt to contribute to missions that tackle grand challenges reinvigorate one of the oldest yet still most difficult challenges for governments: the coordination across policy design and policy implementation, across policy domains, and across governance levels (cf. Pelkonen, Teräväinen, and Waltari 2008; Swanson et al. 2009). 'Coordination' refers to the "mechanisms that aim to enhance the voluntary or

[6] In this thesis, 'public (sector) organisations', 'government organisations', 'public agencies', 'public administrations', and 'policy implementing organisations' are used interchangeably.

forced alignment of tasks and efforts of organisations within the public sector. These mechanism are used to create a greater coherence, and to reduce redundancy, lacunae, and contradictions within and between policies, implementation, or management" (Bouckaert, Peters, and Verhoest 2010, 16)[7]. Public administration scholars have addressed such coordination challenges (Christensen and Lægreid 2007a; Kaufmann 1991; Peters 1998b, 2015a; Pollitt 2003). However, the role of public agencies as innovation policy implementers and, thus, their 'agency'[8] in innovation systems, remains hardly understood. Yet, unless we comprehend how every part of the government apparatus interlinks with the innovation system – as partner, funder, regulator, evaluator, or consumer – we will struggle to resolve wicked challenges.

This thesis contributes to understanding this dynamic by asking: **How do public sector organisations and socio-technical innovation systems mutually shape each other, particularly in the context of mission-oriented policies?**

Hence, this thesis investigates socio-technical innovation systems in the context of mission-orientation, focusing on the coordination challenges that emerge when governing AVs, a prime example of multi-technology innovation. It combines insights from the innovation system and the public administration literature – a junction that has been under-discussed, despite its relevance (cf. European Environment Agency 2019). The thesis provides a comparative case study of three highly innovative economies at the forefront of AV innovation that reveal distinct approaches to governing AVs: Singapore, Estonia, and Sweden. Accordingly, this PhD contributes to the conceptual discussion regarding the governance of and agency in innovation systems and also highlights a novel, possibly highly influential technology in three case study countries empirically.

This chapter captures the motivation for this research project by addressing the intricacies of AVs, reviews the literature to which this thesis speaks, and outlines its overall structure.

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[7] No single, universally accepted definition of coordination exists (Pelkonen, Teräväinen, and Waltari 2008). Since this thesis focuses on the role of public sector organisations, the definition by Bouckaert, Peters, and Verhoest is used (2010). See section 1.3 for a detailed discussion.
[8] 'Agency' is "the capacity of an actor to act" (Geels 2020, 3; see also Giddens and Sutton 2014).

1.2 Multi-Technology Innovation: Autonomous Vehicles

1.2.1 The Socio-Technical Complexity of Autonomous Vehicles

Autonomous systems have many applications, including military purposes (e.g. Arkin 2018; Sukman 2015), personal care (e.g. Stahl and Coeckelbergh 2016), or transport. The first mention of autonomously manoeuvring vehicles occurred as early as 1939, when the car was not yet a widely owned product and far from a universal mobility tool (Future Agenda 2020). AV technologies developed steadily in the late 20th century, mainly through military organisations' efforts and assisted driving features, such as advanced cruise control, cameras, and sensors. When some of the large, global internet companies (e.g. Google) and newly founded enterprises with entirely new business models (e.g. Uber, Lyft) verged into the autonomous driving space, the advancements accelerated, and hype around the 'driverless car' developed (cf. Stilgoe 2019, 2020). The first large scale testing of the technology began in the 2010s in the USA. As the development of artificial intelligence (AI) accelerated and new partnerships formed, pilot projects of AVs expanded across the globe (cf. KPMG 2020). Today, numerous types of AVs exist, and some manufacturers already include 'autonomous driving' modes in their serial production vehicles (e.g. Tesla)[9]. Experts predict that by 2040, AVs will comprise 25% of the vehicle market globally (West 2016). Figure 1.1 outlines the major milestones of autonomous driving and points out the leading corporate players contributing to the technology's growth.

Manufacturers and operators focus primarily on three types of AVs: driverless shuttles or buses, self-driving car hails, and privately-owned automated vehicles. The literature often speaks of 'connected/electric autonomous vehicles', 'driverless cars/vehicles' or in case of shared solutions also 'shared autonomous vehicles' (cf. Fagnant and Kockelman 2015; Lipson and Kurman 2016; Stilgoe 2019; Vellinga 2017). Similarly, other experts prefer the term 'self-driving vehicles', which can also denote an externally controlled vehicle, i.e. systems relying on infrastructure-based rather than vehicle-based automation, directed

[9] For an elaboration of the experience of using the 'assisted driving' mode, see Stilgoe (2017).

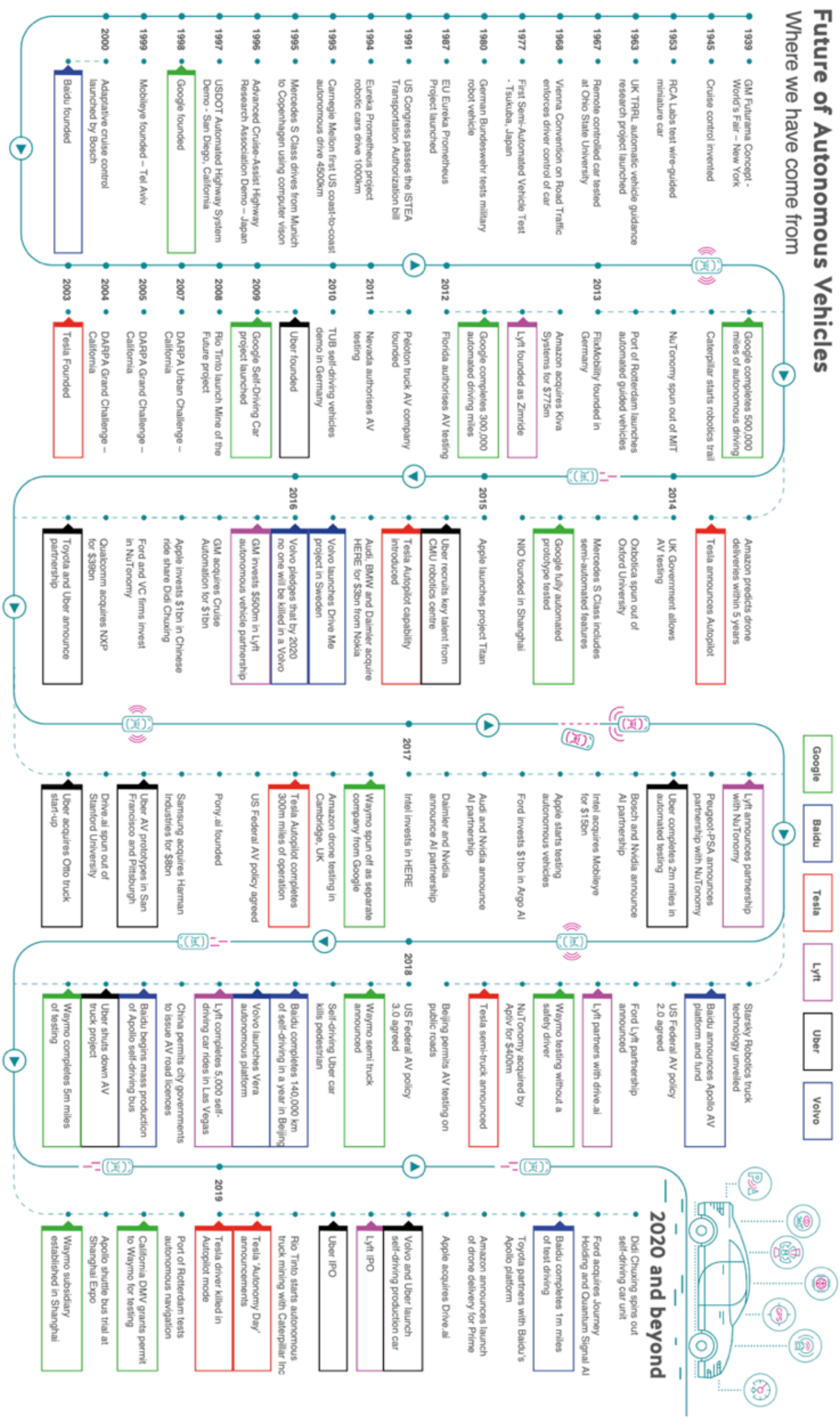

Figure 1.1: timeline of major global developments of the AV technology[10]

[10] Source: Future Agenda (2020, 20–21)

from a control tower (SE04; Vinnova 2018). Since the questions discussed in this thesis address all of these ‘Driving Automation Systems for On-Road Motor Vehicles’ (Society of Automotive Engineers International 2018), the thesis employs the term ‘autonomous vehicle’ (AV), referring to all of the above henceforth. ‘Autonomous’ implies that the system is “capable of making decisions independently of human interference […] but, unlike mere automation, they can make these decisions while facing uncertainty” (Taeihagh and Lim 2019, 105).

Usually, AVs run on electricity rather than fossil fuels (Ainsalu et al. 2018), yet some hydrogen-powered vehicles also exist. AVs comprise a large sub-set of technologies[11], including the propulsion technology as such (motor, gear system, wheels, etc.), automated and situation awareness features (sensors, cameras, algorithms, etc.), connectivity elements (data storage, car-to-car communication, car-to-infrastructure communication, remote control, etc.), safety features (airbags, collision assistance, algorithms, etc.), fuel technologies (batteries, charging mount, etc.), and more (see Figure 1.2) (cf. Bagloee et al. 2016).

The term ‘AV’, in particular, refers to “a motor vehicle that can operate during a whole trip without human interference” (Vellinga 2017, 848). It relies “on artificial intelligence, sensors, and big data to analyse information, adapt to changing circumstances and handle complex situations as a substitute for human judgement” (Taeihagh and Lim 2019, 105). AVs are also digitally ‘connected’ to other vehicles and the surrounding infrastructure (West 2016). This connectivity informs the vehicle, among others, about light signals and speed limits (i.e. vehicle-to-infrastructure communication), but also about the traffic situation and other vehicles nearby (i.e. vehicle-to-vehicle communication) (cf. Bagloee et al. 2016). This study's empiric cases focus primarily on shared autonomous vehicles used as mini shuttles in transport systems. The models ‘EZ10’ and ‘Arma’ by French manufacturers EasyMile and Navya, respectively, are the most commonly used examples (see Figure 1.3). However, the insights gained in this thesis will be relevant for other types of AVs as well.

[11] The technical specificities of AVs are beyond the scope of this thesis. See, among others, Ainsalu et al. (2018), Sell et al. (2018, 2019), Vellinga (2017), Lipson and Kurman (2016), Bagloee et al. (2016), Meyer and Beiker (eds., 2014), or the SOHJOA Baltic Reports (2020b, 2020d) for further details and a general discussions about the technologies used in AVs.

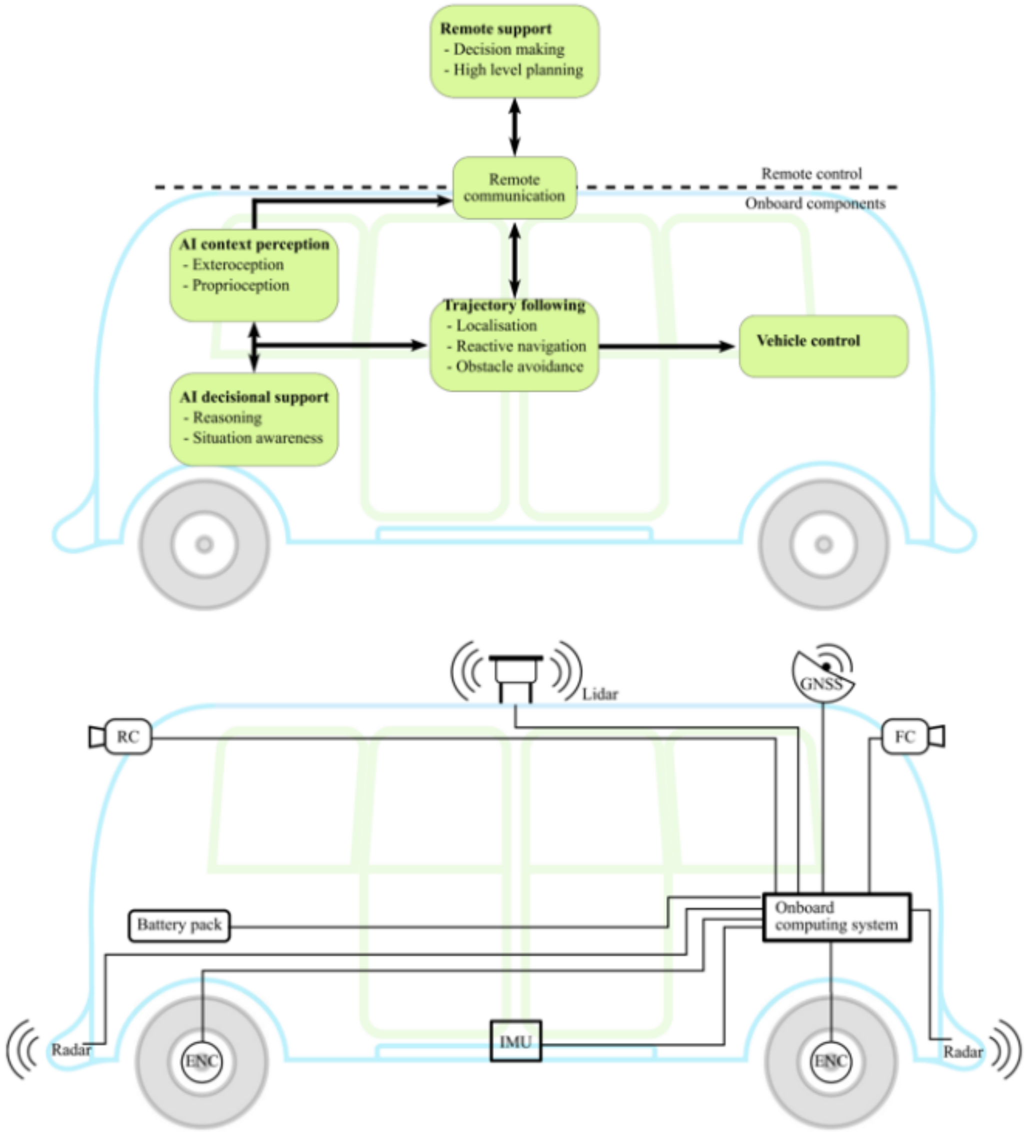

Figure 1.2: AV awareness (top) and camera/sensor technologies (bottom) [12]

Today, AVs can be considered as a fairly advanced technology. "According to [a] growing number of futurists, the main question is only 'when' automated vehicles will take over [the] lead in urban mobility" (Soe 2020, 2). In terms of technology readiness levels (TRLs)[13], full AVs can be classified as a technology on levels 7/8[14]. This is reflected in the considerable interest and increasing development and business activity by large and small vehicle manufacturers, a

[12] RC/FC: rear/front camera, Lidar: light detection and ranging sensor, GNSS: global navigation satellite system, IMU: inertial measurement unit, ENC: encoder (Ainsalu et al. 2018, 15–16)
[13] TRLs assess the sophistication, maturity, and market-readiness of a technology and place them on a scale from 1 (basic) to 9 (mature). The concept was developed by NASA in the US in the 1970s (cf. European Space Agency 2008).
[14] Assessment strategies of TRLs for a particular technology differ across organisations and geographies. This estimate uses the European TRL scale (European Commission 2014).

significant number of start-ups, and generally, a growing sub-sector around the AV technology across the world[15] (Ainsalu et al. 2018). Pilot projects and AV tests demonstrate that AVs can manoeuvre safely in most road situations (cf. Ainsalu et al. 2018). However, AVs are not (yet) a fully mature technology (Ainsalu et al. 2018) as there are still numerous situations where AVs cannot drive entirely autonomously, rather than automatically (cf. Stilgoe 2019). They are, for instance, affected by unpredictable behaviours of other traffic participants, sudden changes in the road layout, or the weather.

In addition to the technical challenges, AVs also have implications on society and human behaviour and may affect our quality of life (Ainsalu et al. 2018). As a consequence, governments face legal, economic, and administrative questions. "As long as these and other crucial questions remain unanswered, the public administration will be hampered in its ability to successfully plan for and introduce automated buses into the transportation system" (Ainsalu et al. 2018, 2). In sum, AVs are among the most complex and complicated technologies we know in current times.

Figure 1.3: AV 'EZ10' by EasyMile (left) and Navya's 'Arma' (right)[16]

[15] The TRLs of different types of AVs should technically be assessed separately (e.g. shuttles, mini-robots, truck platooning). For simplicity, this section refers to the average TRL, indicating that the technology is strongly developed, yet lacks ultimate refinements to make it mature and fully marketable on a larger scale.
[16] Photos: author

The Society of Automotive Engineers classifies six levels of AVs, defining the extent to which they drive, i.e. make decisions, autonomously[17] (Table 1.1). This thesis is mainly preoccupied with AVs of level 'three' and above.

Level	**Automation**	**Features**
0 (driver only)	no automation	vehicle may provide assisted driving features, yet the human is the actual driver of the vehicle (i.e. conventional vehicles as known today)
1 (assisted driving)	driving automation assistance	either steering or braking is assisted by the vehicle, yet not simultaneously; human is the actual driver; includes adaptive cruise control, parking assistant, and active lane centring
2 (partial automation)	partial driving automation	steering and braking is assisted by the vehicle as a support feature; human drivers must supervise the vehicle at all times; includes in addition to level 1 improved parking helpers and a highway pilot
3 (conditional automation)	conditional driving automation	sutomation of full driving task, although with human fallback; drivers have to respond swiftly in case of need and when alerted by the vehicle; includes in addition to level 2 traffic a traffic jam pilot and automated driving technology
4 (significant automation)	conditional driving automation	full automation in pre-determined conditions; if the system is not engaged, the human has to take control; includes in addition to level 3 an improved automated driving system and parking valet technology
5 (complete automation)	full driving automation	the vehicle takes full control of all driving-related decisions; no human action necessary (unless such is desired); includes in addition to level 4 the best automated driving technology known to-date

Table 1.1: AV automation levels[18]

Why are AVs a popular technology, and what are the positive effects and advantages of promoting their development? First, AVs create an opportunity to enhance first/last-mile connectivity significantly (cf. Sell et al. 2019; Shen, Zhang, and Zhao 2018; Woetzel et al. 2018). As AVs can manoeuvre on a needs basis, coordinated by a centralised algorithm, they can provide a first- or last-mile service between homes or workplaces and public transport hubs. AVs can "provide a complementary on-demand service to conventional fixed-schedule fixed-route buses for the first/last mile" (Shen, Zhang, and Zhao 2018, 126). They deliver a more flexible, more weather-safe, and more efficient solution for such connections – for individuals or shared. This aspect becomes particularly

[17] The automation levels and associated categorisations are not undisputed (cf. Stayton and Stilgoe 2020). Refer to Bagloee et al. (2016), KPMG (2020), Soe (2020), Stilgoe (2017), or Stayton and Stilgoe (2020) for further details.
[18] adapted from Future Agenda (2020) and Soe (2020)

relevant as the urbanisation rate across the globe increases rapidly and the need to commute between sub-urban or even rural areas and city centres increases (Soe 2020). One business model that emerged in this context is the so-called 'mobility as a service' (MaaS) approach. Usually, based on a yearly subscription model, customers can use an app to hail an automated shuttle that takes them from their selected pick-up point to public transport hubs (e.g. a train station). Another model is the 'autonomous mobility on demand' approach, which comprises a fleet of AVs accessible at distinct locations throughout a city (Marczuk et al. 2015; Spieser et al. 2014). The autonomously driving cars re-distribute themselves depending on experienced and 'learned' demand patterns to ideally serve customer needs. In both cases, AVs optimise their route based on traffic conditions, passenger demand, and time constraints to provide an optimal service to as many users as possible (cf. Manders et al. 2020; Sell et al. 2019).

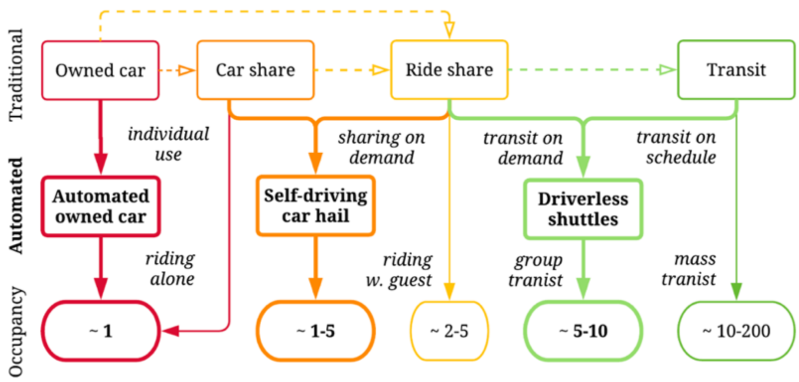

Figure 1.4: AV implementation into existing modes of transport[19]

Second, AVs can contribute to a more environmentally sustainable transport model (cf. Lipson and Kurman 2016; Vellinga 2017), primarily if AVs are used as shared shuttle buses or ride-hailing services. On average, individually-owned "cars are parked 95% of the time" (Barter 2013; also cf. The Economist 2017). A shared AV solution can decrease individual car-ownership and can lead to more efficient use of vehicles, a lower vehicle production rate, less road space reserved for cars, fewer parking spaces, less congestion, a reduction in greenhouse gas emissions and pollution, and therefore, an overall greening of urban areas (Soe

[19] Source: Ainsalu et al. based on Smolnicki and Slotys (2018)

2020). According to a Danish AV expert, AVs' shared use, not the automation per se, makes them an environmentally friendly technology (SE09). For instance, for the City of Lisbon (Portugal), the OECD estimates that 10% of cars could be sufficient to provide the same mobility rate as currently with conventional vehicles (OECD 2015). The same number has been calculated for the taxi fleet in Berlin (Germany) if all cabs were AVs (Bischoff and Maciejewski 2016). Singapore could reduce its taxi fleet by 2/3 (Taeihagh and Lim 2019). Among others, it is for this reason that transport providers aim to integrate AVs into existing transport networks. According to Soe (2020), this will be the first use of AVs that we will see on a larger scale (see Figure 1.4 and Figure 1.5; see Martin (2021) for city space renders of possible future AV scenarios). Furthermore, AVs can improve freight transportation efficiency, e.g. through truck platooning, mini-robot deliveries, or similar (cf. Fagnant and Kockelman 2015).

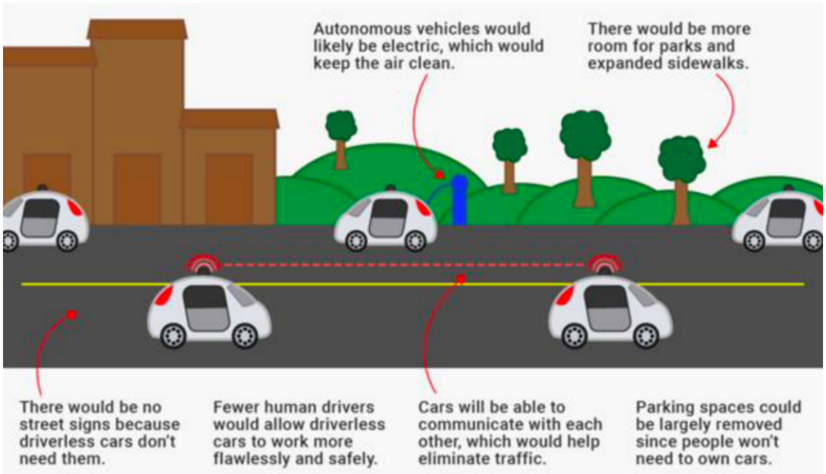

Figure 1.5: future city featuring AVs replacing conventional cars[20]

Third, AVs can improve traffic safety due to “the expected decrease in accidents” (Vellinga 2017, 850) and traffic-associated casualties (Jakobsson and Victor 2017). To date, “90% of road traffic accidents are caused [partially] by human error” (B. W. Smith 2013). As AVs can be programmed to strictly follow traffic rules and have significantly shorter reaction times compared to human drivers, accidents caused by lack of attention or slow reaction can be (largely) avoided. The shared use of AVs reduces the overall number of motorised vehicles

[20] Source: Soe (2020)

on the streets, enabling a safer environment for other traffic participants, e.g. pedestrians or cyclists[21]. Increased safety could, in turn, lower insurance premiums for drivers (Anderson et al. 2016).

Fourth, through first-/last-mile services, AVs can increase the physical accessibility to the public transport system, especially for individuals who are often excluded from such systems due to their age, disabilities, living location, or other vulnerable characteristics. AVs can, thus, be more inclusive, as they provide more individualised mobility solutions and may increase mobility for such groups, in general (Fagnant and Kockelman 2015).

Fifth, AVs can contribute to resolving potential shortages in the labour market. AVs can, for example, be used to transport freight, such as in truck platooning, where trucks follow one another closely using autonomous systems. This practice reduces the number of drivers needed. However, it is essential to note that this can also trigger adverse effects, e.g. for drivers or low-skilled workers[22].

However, AVs and their intended implementation into mobility systems are not without risks – risks that may slow AV innovation. First, the uncertainties regarding autonomous decision-making in all possible circumstances, associated with the potential costs of 'wrong' decisions, are enormous. The numerous incidents and accidents with AVs have shown that the technology, in this aspect, still requires improvements (cf. Stilgoe 2017; Vellinga 2017). This includes an adequate solution to questions regarding liability, insurance, and generally, legal aspects (cf. Brass et al. 2018). For vehicles of automation levels 0-2, this is unproblematic as they are covered by the current legal framework. Yet, this is not the case for the higher levels 3-5. Currently, across most jurisdictions, AVs are only allowed on public roads within the remit of testing licenses. However, the technology requires embedding into a solid, reliable, and acceptable legal framework in the long term. This includes but is not limited to laws and regulations covering vehicle registrations, human drivers, vehicle testing, passenger transport, driver's licenses, liability, criminal offences, and insurance

[21] This is the case for fully automated transport. Mixed-traffic conditions might, in fact be less safe (see below) (EE05, SE04).

[22] This thesis does not address this issue. Bissell et al. (2020), Carbonero et al. (2020), Im et al. (2019), and Manyika et al. (2017) address the impact of automation and AVs on labour markets.

(cf. Soe 2020; SOHJOA Baltic 2020c). This aspect carries a significant ethical dimension that has – inadequately – often been reduced to the 'trolley problem' (cf. Stilgoe 2018; Taeihagh and Lim 2019). What should a vehicle do if confronted with a potentially fatal situation: risk to kill the driver or the obstacle, which could be another human? A more complex debate and a decision to integrate ethical standards in autonomous decision-making, machine learning, and algorithmic coding (not only in AVs) are necessary (cf. Bonnefon, Shariff, and Rahwan 2016)[23].

Second, automated mobility systems rely on the reconstruction (or severe alteration) of existing urban infrastructures (cf. Duvall et al. 2019; Soe 2020). While this can also imply a positive change of the urban landscape (as mentioned above), it evokes high costs for municipalities or regional governments for a considerably long period. Accordingly, this implies that cities/regions must adapt their development plans.

Third, AVs' economic costs remain high and are not (yet) justifiable for municipalities, transport providers, and most private customers. A shared AV mini-shuttle, for example, costs approximately GBP 14,000 per month to rent, plus approximately GBP 4,000 in set-up costs – and this does not include the costs for the operator(s), the mapping of routes, licensing and permit fees, maintenance, or electricity (Soe 2020, 18). Additionally, as AV shuttles are currently still limited to 25 km/h or slower in most jurisdictions, they do not provide a viable, efficient alternative to conventional means of transport.

Fourth, although the technology developed swiftly and improved significantly since the first AVs have roamed test sites, fundamental glitches continue to occur. These include, for instance, the vehicle's localisation technology, where a few centimetres can make the difference between crashing or not, or the cars' scene interpretation skills (Ainsalu et al. 2018). As tests have shown, imaging software trained in summer struggles with the same surroundings in the same street in winter. When trees have no leaves, the vehicles perceive a different environment and fail to process them as previously known (EE04, EE05). This problem also

[23] The discussion concerning ethics in decision-making of autonomous systems is beyond the scope of this thesis. Useful starting points include Bonnefon, Shariff, and Rahwan (2016), Veale (2019), as well as Stilgoe and colleagues (2013; 2012; 2017, 2019, 2020).

applies to roads in poor conditions, e.g. in winter, where AVs become 'confused' (Sage 2016). Similar observations have been made regarding mixed-traffic situations, where AV must react to other traffic participants, i.e. humans (Soe 2020). Although AVs are 'trained' (or programmed) to follow traffic rules, the precise fact that human drivers do not to the same extent follow traffic rules all the time 'confuses' the AV and causes it to stop (or at least to react). AVs (as well as 'connected' conventional cars) also need to be protected from cybersecurity breaches or hacking, i.e. in this case, the intentional yet undesired taking over of the vehicle's control from the outside, as this could lead to fatal accidents (Garfinkel 2017; Gillman 2017). These technological issues require fine-tuning and entirely safe solutions before large-scale implementations, as they ultimately form a safety threat. The advantage of AVs being safer than human-driven vehicles is, therefore, contested for now (cf. Taeihagh and Lim 2019).

Fifth, after all, consumers need to have the willingness to use AVs within the transport system. They must feel safe and trust the technology, which is thwarted when AVs are involved in accidents (Soe 2020). AVs must also decrease in price, as a society will hesitate to accept a costly technology when more economically viable alternatives exist (cf. Fagnant and Kockelman 2015). Human acceptance is particularly required to scale up novel business models that require a behavioural change of a large proportion of society (cf. Hilgarter and Granig 2020). Consumers, and society as a whole, will also have to understand – and accept – the underlying ethical considerations, decisions, and consequences of programming algorithms that 'drive' an autonomous vehicle (cf. Bonnefon, Shariff, and Rahwan 2016).

Overall, this section revealed that AVs are a complex technology and significantly impact society, including unintentional consequences (Taeihagh and Lim 2019) – they are a complex socio-technical innovation. "Automated vehicles coupled with sharing economy concepts would be a very effective measure against large inefficiencies of private cars in cities" (Soe 2020, 10). Some of these advantages follow the overarching goals set forward by the Sustainable Development Goals (SDG) (cf. United Nations 2015). They may contribute to transforming our economies such that the SDGs can be achieved (Sachs et al. 2019). However, their positive impact depends on the implementation of AVs.

Otherwise, AVs can also have adverse effects (cf. Soe 2020; Stilgoe 2019). Currently, “there are no fully-automated market-ready solutions for open-road traffic but rather a pre-programed route automation on low speed with actual drivers involved and responsible” (Soe 2020, 19). Positive effects have not yet emerged fully and are, for now, only predicted. The extent to which the advantages associated with AVs materialise remains to be seen. The variety of sub-technologies used in AVs and the complexity that emerges when these are fused in a single product renders AVs into a prime example of multi-technology solution[24] and its implementation as a major socio-technical innovation.

1.2.2 Multi-Technology Innovations – a Coordination Problem?

‘Multi-technology innovations’ comprise a set of complex, interacting sub-technologies of diverse characters and cater to many purposes. Through the interaction of various technologies, new challenges arise – for innovators and developers, but also for businesses and entrepreneurs, who need to find new or adjust old business models to accommodate the new realities in economic terms, as well as to governments who need to govern them. Why is this the case? As described above, multi-technology innovations trigger coordination problems (cf. A. D. Andersen and Markard 2020). These are due to the large number of stakeholders involved, the fact that they span across policy domains, their impact on society at large, and their link to mission-oriented policies (cf. A. D. Andersen and Markard 2020; Markard 2018).

First, multi-technology innovations involve many actors from across the industry, academia, and government. They do not occur in niches alone but instead draw knowledge and resources from across firms, research projects, and sectors. As multi-technology solutions comprise numerous sub-technologies, i.e. components used as individual products before (e.g. cameras, sensors), and since their manufacturers are often incorporated into multi-technology value chains, the pool of actors involved expands significantly. Sometimes, entities along the supply chains become directly involved in the production and development of

[24] Multi-technology innovation, multi-technology solutions, and multi-technology challenges are used interchangeably throughout this thesis.

the new, emerging technology, as they now optimise their product for a novel use. Coordinating among so many actors with potentially vested and conflicting interests is a difficult task.

Second, multi-technology innovation usually affects and is affected by policies across various policy domains – they are "transcending classical policy boundaries" (Coenen and Díaz López 2010a, 1149). The "increasingly complex interplay of technologies and policies" (Markard 2018, 631) means that more and more policies become interrelated, as changing one becomes a burden to another. Components that had been governed and regulated by separate policies beforehand (if at all) are now combined, which may result in contradictions between different policies or regulations. Components used in AVs for which this is the case include, among others, the electric motor subject to environmental policies, the information technology and communication devices requiring adequate infrastructure, or the cameras and GPS devices subject to privacy regulations and data storage rules. Different policy domains are embodied by various government organisations that design and implement these policies. Coordinating policies from different fields that govern the same (or similar) circumstances is challenging, especially if this includes government agencies with different intentions, guided by conflicting (political) rationales. The phenomenon referred to here is often called the "'complexity paradox' of current public policy: The more complex policy issues are, the more compartmentalised policymaking becomes, fragmented into different and sometimes competing government departments and initiatives" (Mazzucato 2021, 75). Yet, achieving 'missions' by enabling multi-technology innovations precisely "requires working outside of the usual silos, coordinating across policy fields and finding the synergies that turn the components of cooperation into a whole that is larger than the sum of its parts [… across] ministries, departments, regional and local government bodies." (*ibid.*). Hence, more systemic and integrative policies are required "to support clusters of complementary technologies" (*ibid.*). However, policymakers – and implementers – are not used to such technologies, rendering policy learning a further challenge.

Third, multi-technology solutions tend to affect societies at large, as they can provide alternatives to institutionalised and accustomed behavioural traditions.

For AVs, this refers to new mobility patterns, novel forms of urban design, and new ideas about accessibility vs ownership of vehicles. Other multi-technology solutions which may face similar issues include smart agriculture and smart electricity grids. Changes to social behaviour or large-scale transformations provoke the question of value and which social values should be promoted. Coordinating different value propositions and the decisions about value-laden directions within an economy is a challenge.

Fourth, multi-technology innovations often emerge from mission-oriented policies. These are cross-sectoral policies that do not prescribe a specific solution to a problem. Instead, they paint a vision and "tilt the playing field" (Mazzucato 2017b, 9) towards a socially and economically beneficial outcome associate with the broader public good. Due to the scope of missions, the amount of possible socio-technical innovations contributing to achieving them is not fixed. Multi-technology innovations may speak to various missions, which in turn exacerbates the number of stakeholders involved and, thus, the possibility of tensions between socio-technical trajectories. AVs, as discussed above, can address sustainability issues by reducing car ownership and may increase traffic safety, but can also threaten the jobs of drivers and trigger ethical questions. Multi-technology solutions, hence, may require trade-offs between short and long time-horizons, different social groups, technological paradigms, or economic convictions. The necessarily enormous scope of such dynamics paired with the decisions and consequences at stake contributes to the coordination challenges pertaining to such technologies.

Combined, multi-technology innovations pose a coordination problem to governments and public agencies who face the task of aligning innovation, entrepreneurial activities, and a pool of government organisations with old and new policies – bearing the risk of "coordination failure" (K. M. Weber and Rohracher 2012, 1043). This is particularly challenging, if a technology is so new, that those working in or for government are themselves uncertain about the functional and technical details, the associated risks and opportunities, the potential consequences, and their societal impact. In this situation, the public administration as policy implementer acts as a bridge between policy design and the innovation system. Simultaneously, technologies and governance practices continue to develop and evolve in parallel over time, conditioning each other (cf. Hoppmann, Huenteler, and Girod 2014; Swanson et al. 2009). This dynamic aggravates this governance challenge. Hence, the 'coordination' challenge that emerges from governing multi-technology innovation and mission-oriented policies quintessentially requires public sector organisations in innovation systems to bridge the policy design-implementation dichotomy. This thesis explores the relationship between innovation and the coordination of public sector organisations. It builds on the existing scholarship in both fields, as the following literature review shows.

1.3 Literature Review

1.3.1 Introduction: Socio-Technical Innovation Systems

The challenges we face today are large, complex, and global. Climate change, for instance, does not halt at national borders and there is no easy technical fix. Increasing the environmental sustainability of economic activity only transforms society and protects the planet if done at large-scale and if human behaviour changes as well – economies must become carbon neutral beyond convincing individuals to cycle rather than drive. Yet, grand challenges have another feature: They are of such a magnitude that addressing one aspect of a problem causes knock-on effects, resulting in new problems. In other words, such challenges are highly complex – they are 'wicked' (Harmon and Mayer 1986; Head 2008; Head and Alford 2015; Rittel and Webber 1973) and are characterised by contestation, complexity, and uncertainty (Wanzenböck et al. 2020).

Wicked problems require a broader understanding of 'technology' and 'innovation'. Technological innovation hardly ever occurs in a basement or garage and goes beyond the numerous fascinating stories told by successful entrepreneurs make-believe – especially concerning socio-technical innovations. The term 'technology', while generally referring to the "means to fulfil a purpose", entails the whole "assemblage of practices and components" and the "entire collection of devices and engineering practices available to a culture" (Arthur 2009, 28). This includes any form of "knowledge of how to fulfil certain human purposes in a specifiable and reproducible way" (Brooks 1980, 66), which forms an inclusive approach widely used across the innovation literature (cf. Anadon et al. 2014, 2015). The term 'emerging technology' specifically implies a "radically novel and relatively fast-growing technology" (Rotolo, Hicks, and Martin 2015, 1833). Over time, it has "the potential to exert a considerable impact on the socio-economic domain(s), […] the composition of actors, institutions and patterns of interactions among those, along with the associated knowledge production processes" (*ibid.*). Hence, although their "emergence phase is still somewhat uncertain and ambiguous" (*ibid.*), their novelty has immense future potential (Cozzens et al. 2010) to alter the status quo in the economy and how actors interact (Furman, Porter, and Stern 2002; B. R. Martin 1995).

In this sense, 'innovation' embodies the Schumpeterian idea of introducing a novelty into the economic realm: a novel product, an enhanced method of production, opening up a new market, a new source of supply, or the improved organisation of an industry (Schumpeter 1912, 1935, 1942). As opposed to an invention, innovation refers to actually and successfully applying a new process or device "in organisational outcomes and processes" (Dodgson and Gann 2010, 14). This includes institutions and society as a whole, rendering innovations that affect societal behaviour 'socio-technical' (cf. Bekkers, Edelenbos, and Steijn 2011; Geels 2004; Kern 2012; Pollitt 2011). Hence, the concept of 'innovation' needs to be considered in an equally holistic fashion as the term 'technology' to include the entirety of "the process by which technology is conceived, developed, codified, and deployed" (Brooks 1980, 67), and also commercialised, e.g. through "fresh combinations of what already exists" (Arthur 2009, 19). Socio-technical innovation, hence, is about 'implementing change' and, consequently, includes many different actors and stakeholders – not just a few individuals in a garage – In a contemporary and holistic view, thus, innovation refers to "change that is provided by the converging actions of a plurality of institutional and socio-economic actors, aims to produce diffused sustainable economic and social improvements, is connected to technology or codified research or organisation changes, [and] produces the relocation of resources from incumbents towards innovators" (Grillo and Nanetti 2016, 5).

Mission-oriented innovation picks up these notions, attempts to unify stakeholder activities, and guides practices towards a commonly understood and agreed on overarching goal – the mission – geared towards resolving a wicked problem. Mission-oriented innovation (policies) experience somewhat of a revival today. Coined by Richard Nelson (1977, 2011), in parts as a response to the 'moon shot' mindset during the mid-20th century, missions became particularly relevant for highly complex and far-reaching yet difficult to change issues, also known as "ghetto" problems (Nelson 1977, 1) – or wicked problems. Responding to these challenges, missions allow for a broad and holistic approach to innovation by focusing on comprehensive solutions rather than individual policies and technologies, single aspects of a problem, or disciplinary silos. Missions seek cross-sectoral and cross-technology approaches, where particular technologies cooperate within the broader framework of the mission. This results in "mission-oriented innovation systems [that] consist of networks of agents and sets of institutions that contribute to the development and diffusion of innovative solutions to define, pursue, and complete a societal mission" (Hekkert et al. 2020, 76).

This understanding of innovation relies on evolutionary models of economic activity (Nelson 2017; Nelson and Winter 1982), accounting for the context in which technological progress is embedded. It acknowledges that technological change affects and is affected by past decisions concerning the socio-economic components and organisations it links to (Arthur 1989; Bijker, Hughes, and Pinch 2012b; Boettke, Coyne, and Leeson 2008; David 1985). Technological, organisational, or social 'paradigms' change incrementally (Dosi 1982) over a longer time horizon (Kuhn 1962) and are in permanent competition for adoption (Arthur 1989; Dosi and Nelson 1994; Rosenberg 1982). In other words, to change a socio-technical trajectory, institutions and other societal factors likely have to change as well. This premise holds for all approaches introduced in this section.

As outlined in the introduction, governments increasingly turn towards mission-oriented (innovation) policy to resolve challenges of the 21st century (Mazzucato 2013b, 2015, 2016, 2017b, 2018a, 2018b, 2019, 2021; D. K. R. Robinson and Mazzucato 2019; Vinnova 2019). Accordingly, there is a "need for decentralised, networked entrepreneurial public organisations to be positioned along the entire innovation curve" (Mazzucato 2017b, 7), 'directing' innovation towards a desired, socially valuable outcome (Kuhlmann and Rip 2018;

Mazzucato 2018c; Soete and Arundel 1993). Thus, "state intervention is central to technological and industrial change" (Meckling and Nahm 2018, 521). For this reason, "mission-oriented policies target the development of specific technologies in line with state-defined goals (missions)" (D. K. R. Robinson and Mazzucato 2019, 938)[25]. Consequently, innovation and transitions towards sustainability are inherently and intrinsically political (cf. Habermas 1969; J. Köhler et al. 2019; Salas Gironés, van Est, and Verbong 2020; Schot and Steinmueller 2018a; Stirling 2008).

The mission-oriented policies that address contemporary challenges (as opposed to previous missions such as the moon landing[26]) "are not administered by a centralised decision-making authority in a vertical structure [… but] by public agencies engaged in decentralised and dynamic innovation systems" (D. K. R. Robinson and Mazzucato 2019, 938). This notion opposes the predominantly neoclassical economic thought of the latter 20th century, which, according to some scholars, is responsible for many of the challenges societies face today, such as climate change (cf. Jackson 2017; Mazzucato 2013b, 2021; Raworth 2017; Sekera 2016). This concerns the organisation and the financing of innovation. The state ought to take a more central, risk-taking role and receive some of the (financial) rewards of successful innovations (Lazonick and Mazzucato 2013; Mazzucato 2013a; Mazzucato and Semieniuk 2017, 2018). Moreover, a missions approach can create new markets together with the private sector through nudging (Thaler and Sunstein 2008), regulation, incentivisation, or cooperation (cf. Kattel and Mazzucato 2018; Mazzucato 2013b). In short, mission-oriented policies "tilt the playing field rather than only 'level it'" (Mazzucato 2017b, 9).

Hence, the scope and type of missions and mission-oriented policies are broad (cf. Anadon 2012; Wittmann et al. 2020). Implementing missions requires socio-technical change and often triggers multi-technology innovations. One of the main obstacles for governing missions, socio-technical innovation, and multi-

[25] Mazzucato also uses the term 'challenge-driven' innovation, referring to the challenges meant to be resolved through 'missions' (Mazzucato, Kattel, and Ryan-Collins 2020).

[26] Previous missions were more clearly defined, project-based, and mostly aimed at technical advancements, whereas contemporary missions are broader, socio-technical, and based on a wider mix of actors, institutions, and objectives (Foray, Mowery, and Nelson 2012; Mazzucato 2017a; Mowery, Nelson, and Martin 2010; D. K. R. Robinson and Mazzucato 2019).

technology solutions remains the coordination of actors, regulations, and policies (Wittmann et al. 2020). Accordingly, Wanzenböck et al. state that "a major part of mission-oriented innovation policy lies in ensuring legitimacy, broad engagement, and cooperation among multiple actors" (2020, 2). Hence, to achieve and make the most of 'missions', governments have to coordinate socio-technical innovation and innovation policy.

1.3.2 Coordinating Innovation Policy: a Governance Challenge

1.3.2.1 Approaches to Innovation and Innovation Policy

Socio-technical innovation has been scrutinised through various lenses and perspectives. Other ideas that also rely on an evolutionary understanding of economic activity and innovation can be grouped in four categories: grand normative ideas regarding socially beneficial innovation, socio-technical transition approaches, approaches based on innovation policies, and system-oriented approaches. They will be particularly scrutinised regarding their conceptualisation of coordination and coordination challenges.

1.3.2.1.1 Grand (Normative) Ideas

These grand ideas describe the generally desirable (normative) conduct and outcome of innovation processes and include open innovation (Chesbrough 2003a), responsible innovation (Owen et al. 2013), and social innovation (Mulgan 2006). *Open innovation* suggests that technological advancement should not occur in secrecy and silos but should instead rely on the 'open' interchange of ideas and perspectives (Chesbrough 2003b, 2003a, 2006). The resulting "distributed innovation process based on purposively managed knowledge flows across organisational boundaries" (Chesbrough and Bogers 2014, 14) creates a mutual comparative advantage, as the shared knowledge helps to solve technological problems faster and more efficiently (Chesbrough 2003b; Greco, Locatelli, and Lisi 2017).

Responsible innovation adds a normative dimension to this idea, based on what might objectively be good for society. It is guided by "the (ethical) acceptability, sustainability and societal desirability of the innovation process […] to allow a proper embedding of scientific and technological advances in our society" (von Schomberg 2013, 19). This includes the anticipation of uncertainties and consequences (Owen, Macnaghten, and Stilgoe 2012), self-reflection about scientific conduct (Stilgoe, Owen, and Macnaghten 2013), transparency (von Schomberg 2013), and a democratic foundation of science policy decisions (van Geenhuizen and Ye 2014; Owen and Goldberg 2010).

Social innovation, moreover, advocates not only that innovation should be "motivated by the goal of meeting a social need", but that technology should also be "predominantly developed and diffused through organisations whose primary purposes are social" (Mulgan 2006, 8). This includes synergetic alliances across politics and government, markets and firms, academia and think tanks, non-profit organisations and movements, and even individuals, addressing areas insufficiently met by market demands (Deiglmeier, Miller, and Phills 2008).

In sum, the grand ideas about innovation share the intention to guide innovators and policymakers towards innovations that are 'good for society'. As such, they carry a normative element (although it is doubtful that many would object to the fundamental claims and assumptions on which they are based). They advocate that innovation should, overall, improve people's lives. In doing so, however, they remain on a macro-level where the individual action and role of stakeholders, both public and private, cannot be markedly distinguished. This makes analysing the complexities underlying these ideas difficult. Hence, while delivering a powerful and invaluable message, the three grand ideas only provide general guidance for policymakers, implementers, and researchers. Likewise, they do not specify or address the role of different public sector organisations and, therefore, do not consider the above-mentioned coordination challenges.

1.3.2.1.2 Socio-Technical Transition Approaches

Socio-technical transition approaches capture the overarching dynamics of innovation practices and the tendencies and trends that shape these. As opposed to the grand ideas, they also consider the directionality of innovation (cf. Mazzucato and McFarlane 2018; Pel, Raven, and van Est 2020; Stirling 2009), acknowledging the social embeddedness of technologies in socio-technical systems (Geels et al. 2017). Three major streams within transition studies can be identified: the multi-level perspective, strategic niche management, and transition management (cf. Markard, Raven, and Truffer 2012)[27].

The *multi-level perspective* (MLP) captures transitions over time across three interacting levels (Geels 2002a, 2002b, 2004, 2005, 2011, 2018, 2019, 2020; Geels and Schot 2007; Kemp 1994; Schot, Hoogma, and Elzen 1994; A. Smith and Stirling 2010): niche innovations, the socio-technical regime, and the socio-technical landscape. Niches, the locus of innovation, represent networks of actors such as (small) firms, research centres, but also policy organisations, where new ideas regarding technologies, business models, or behaviour are a result of interaction and learning (Schot and Geels 2007). Eventually, innovations align and “stabilise into a dominant design” as their intrinsic momentum increases (Geels 2002a, 1262) and they ‘emerge’, challenging the incumbent (regime) technologies. The regime represents those established and stable technologies and their associated institutional arrangements, such as markets, industries, policies, or the predominant cultures, beliefs, and preferences (Geels 2002a). Finally, the landscape represents overarching, exogenous factors that affect the mechanisms of innovation by influencing the environment in which change occurs, including broad political, economic, or social trends that can create windows of opportunity for and incentivise innovation in niches (Geels 2002a). Across the three levels, “the activities of these different groups are aligned to each other and co-ordinated” (Geels 2002a, 1259).

Hence, the MLP represents a dynamic, non-linear, and perpetual process, primarily used in the context of transitions towards sustainability (cf. Kern and Markard 2016; Markard and Truffer 2008; Schot and Geels 2008), e.g. regarding the complexities of large technical systems such as electricity grids (cf. T. P. Hughes 2012; Markard and Truffer 2006; Mayntz and Hughes 1988). Increasingly the MLP is also used in other fields, for example, regarding the automotive sector and urban mobility (Geels et al. 2017; Goyal and Howlett 2018), sustainable cities and urban innovation (Fuenfschilling, Frantzeskaki, and

[27] A fourth stream, system-oriented perspectives, will be discussed separately below.

Coenen 2019; Rutherford and Coutard 2014), and sustainable construction (Rohracher 2001). It provides an analytic and heuristic tool attempting to capture these processes, conceptually and entirely, while not claiming to ontologically represent reality (cf. Berkhout, Smith, and Stirling 2004; Geels 2002a; Carlota Perez 2004). Yet, it only addresses the coordinating role of public administrations superficially, lacking detailed attention to the agency of actors.

Strategic niche management develops the MLP logic further focusing particularly on the niche level (Caniëls and Romijn 2008; Kemp, Schot, and Hoogma 1998; Schot and Geels 2008; Schot, Hoogma, and Elzen 1994). It is, therefore, also based on the concept of technological regimes (cf. Dosi 1982; Kuhn 1962; Nelson and Winter 1982) and attempts to manage regime change through the proliferation of niche technologies. It can be defined as "the creation, development and controlled phase-out of protected spaces for the development and use of promising technologies by means of experimentation, with the aim of (1) learning about the desirability of the new technology and (2) enhancing the further development and the rate of application of the new technology" (Kemp, Schot, and Hoogma 1998, 186). The objective of niche management is "to articulate the changes in technology", "to learn more about the technical and economical feasibility", "to stimulate the further development of these technologies", and "to build a constituency behind a product" (*ibid.*, 186). This includes considerations about the influence of government and public agencies as niche managers. The approach stresses the need for the collective behaviour of different actors involved in innovation processes across different levels (*ibid.*, 187). Thus, strategic niche management acknowledges the importance of policy implementation, especially within niche internal processes concerning learning and regulation. It asserts that the novelty in niches and the nature of integrated systems – which inevitably affect multiple stakeholders – poses a problem for governments (Schot and Geels 2008). As such, "niche innovations are rarely able to bring about regime transformation without the help of broader forces and processes" (Schot and Geels 2008, 545). However, strategic niche management does not address the coordination challenge emerging from this issue.

Transition management is a long-term, policy design-focused governance approach attempting to transform socio-technical systems (Kemp, Rotmans, and

Loorbach 2007; Kern and Howlett 2009; Loorbach 2007; Rotmans, Kemp, and van Asselt 2001). It follows the logic of incremental change and prompts experimentation to induce behavioural changes step-by-step, contributing to overarching (sustainability) goals (Scrase and Smith 2009; Voß, Smith, and Grin 2009). The idea emerged in the Netherlands, advocated by the Dutch government (Kemp and Rotmans 2009). "Transition management combines an orientation toward a long-term vision of 'sustainable development' with short-term experimental learning to probe options and find pathways to realise the vision" (Voß, Smith, and Grin 2009, 277). It suggests developing visions and transitions pathways and experimenting with options that can then be monitored, evaluated, and potentially revised (Voß, Smith, and Grin 2009). However, as transition management mainly focuses on policy design (Scrase and Smith 2009), the approach pays little attention to implementation aspects at the core of realising transitions (Voß, Smith, and Grin 2009)[28]. Likewise, the approach insufficiently accounts for power asymmetries by actors involved (cf. Avelino 2009; Hendriks 2009; Kern and Smith 2008), such as public agencies. In other words, transition management intends to overcome institutionalised policy paradigms through governance innovation based on experimentation and experimental learning (Voß, Smith, and Grin 2009), yet does not account for the 'challenge of anticipating implementation in policy design' (cf. Bardach 1977).

In sum, the socio-technical transition approaches are useful heuristics and provide an analytic lens for macro- and meso-level perspectives. They address the role of different stakeholders within transition processes in various ways. However, transition approaches often lack attention to stakeholders' agency in transition dynamics (de Haan and Rotmans 2018) and mostly do not differentiate between different state actors, in general, and between policy design actors and policy implementers, in particular. This means that they miss the specific role of public administrations and cannot provide intervention suggestions for policy implementers, which are, however, central to transition analyses (Bening, Blum, and Schmidt 2015). Similarly, transition approaches acknowledge the multitude

[28] Some exceptions consider the role of politics and political institutions such as Hendriks (2008), Smith and Kern (2009), or Smith and Stirling (2007).

of stakeholders involved in transition processes but do not address the resulting coordination challenges, particularly for policy implementers. These are instead often grouped into general, overarching categories, such as ‘policy learning’.

1.3.2.1.3 Innovation Policy-Based Approaches

Innovation policy-based approaches inform policymakers about specific problems that could be resolved through effective policies. Generally, innovation policy refers to “actions by public organisations that influence innovation processes” (Edquist 2011, 1728). They “capture a broad scope of science, research, technology, and innovation-related policy initiatives” (Kuhlmann and Rip 2018, 448) and are of broadly transformative character (cf. Christopher Freeman and Perez 1988; Kondratiev 1925; Polanyi 1944). In addition to mission-oriented innovation, this includes problem-oriented innovation systems (Ghazinoory et al. 2019, 2020), dedicated innovation systems (Pyka 1998, 2017a), transformative innovation policy (Chataway et al. 2017; Diercks, Larsen, and Steward 2019; Schot and Steinmueller 2018b), and holistic innovation policy (Borrás and Edquist 2019). They focus on macro-level societal issues.

Problem-oriented innovation systems (PIS) combine social and technical innovation strategies intending to resolve a particular (global) problem. It refers to “a network of actors in different technological, sectoral, and social systems of innovation (sub-systems), as well as their interactions and collaborations, with the aim of the diffusion, utilization, and dissemination of knowledge and technology to solve a socio-technical problem” (Ghazinoory et al. 2020, 5). Problem-oriented innovation systems focus on the entirety of the system but remain at a macro-level and stress the innovation aspect specifically geared at resolving a problem (cf. Larson 2017), e.g. through social entrepreneurship (Makhlouf 2011). The approach emphasises the need for collaboration yet does not comprehensively address the resulting coordination challenges. Likewise, it does not include the role of the public agencies in implementing policies.

Similarly, *dedicated innovation systems* respond to societal problems. They suggest that innovation has a direction that needs to be guided to overcome lock-in problems associated with path-dependency (Pyka 2017a, 2017b). They "explicitly go beyond technological innovation and economic growth and allow paradigmatic change towards sustainability: They are 'dedicated' to foster the joint search for transformative innovations" (Pyka 2017a, 3). They build on the linkages, interactions, and interests of established industries and consider their resulting inertia (*ibid.*). Thus, dedicated innovation aims at the economic opportunities that may result from responsible and social innovation (*ibid.*). This implies that "broad transformative approaches require a participation of all societal stakeholders" (Pyka 2017a, 1). Such a large number of actors, in turn, requires coordination, which, other than having a joint, 'dedicated' goal, is insufficiently addressed, however, particularly concerning the public sector.

Transformative innovation policy (Chataway et al. 2017; Diercks, Larsen, and Steward 2019; Schot and Steinmueller 2018b) builds on some of the concepts mentioned above, such as social innovation, responsible innovation, and the sustainability transitions literature. It coalesces political, economic, social, and technological efforts to achieve a "transformation of socio-technical systems", oriented towards resolving critical interlocking challenges (Chataway et al. 2017, 2). Accordingly, it presents itself as a new paradigm for science and technology policies (Diercks, Larsen, and Steward 2019; Schot and Steinmueller 2018b). As such, transformative innovation policy strongly emphasises directionality (Grillitsch, Hansen, and Madsen 2020), complementing the development of novel technologies with considerations about phasing out old ones (Kivimaa and Kern 2016). Therefore, it guides policymakers and implementers alike by setting directions, embracing opportunities, mobilising actors and resources, promoting holistic policymaking, and improving governance (Fagerberg 2018).

Holistic innovation policy (Edquist 2014, 2019) addresses the policymaking aspect for innovation-related activities by the government. Like the approaches mentioned above, it is problem-based and attempts to distinguish the strategies and rationales underlying the rate and direction of innovation processes that resolve social challenges. The goal is to provide the theoretical foundation for innovation policy design (Borrás and Edquist 2019). Therefore, a holistic innovation policy can be defined as "a policy that integrates all public actions that influence or may influence innovation processes. It takes all activities in innovation systems into account" (Borrás and Edquist 2019, 39). The 'holistic' idea implies that it "includes all important economic, social, political, organisational, institutional, and other factors that influence the development, diffusion, and use of innovations, as well as the innovations themselves" (Edquist 1997, 2005 as quoted in Borrás and Edquist 2019, 23). Accordingly, it includes considerations about coordination and highlights collaborative efforts and interdependencies between stakeholders and their influence on innovation.

However, the holistic innovation policy approach falls short of analysing the role of public sector organisations. Instead, it groups public agencies together and attributes them with general state functions, catching governance activities under umbrella terms such as 'change of organisations' or 'change of institutions' (cf. Borrás and Edquist 2019, 25). While this may be adequate for a macro-view on innovation policy, it is insufficient to understand the coordination challenges inherent to innovation policy and the possible avenues to resolve them. Borrás and Edquist argue that "innovation policy design is, accordingly, certainly lagging behind innovation studies when it comes to being broad-based, demand-oriented, or holistic" (2019, 41). Although this might be the case, they still do not address policy implementation, linking policy design and impact. As "innovation should have a purpose" and as "innovations themselves are not interesting, but their consequences are" (Borrás and Edquist 2019, 21), public agencies who affect and are affected by such 'consequences' should be addressed explicitly.

In sum, innovation policy-based approaches share a closer focus on policy and policy implications. Similar to mission-oriented innovation, both problem-oriented innovation systems and dedicated innovation systems acknowledge the need to carefully design policies such that the wide variety of actors involved in transformations (Markard, Geels, and Raven 2020) can collaborate towards resolving a challenge. Although they stress that policy must be integrated, they do not address the coordination challenges that precede this process, particularly regarding policy implementation. Transformative innovation policy points towards the role of administrative coordination but merely suggests focusing on engaging "a range of actors in new initiatives to ensure coordination on the ground" (Daniels et al. 2020, 17). This strategy will be picked up below when discussing coordination efforts in detail. By virtue, holistic innovation policy considers all aspects relevant to fulfilling a policy's purpose. Still, it only marginally addresses the coordination challenges inherent to implementing cross-domain and cross-jurisdictional policies, especially for public agencies. Hence, other than in general terms or by grouping public organisations with overarching 'governance' dynamics, neither approach fully represents the role of public agencies in implementing innovation policy and resolving coordination challenges in socio-technical innovation systems.

1.3.2.1.4 System-Oriented Approaches

While the previous section already addressed some systemic elements to innovation policy, system-oriented approaches are generally common in innovation studies, including areas where the interactions between policies and technologies are highly complex (cf. Anna Bergek et al. 2015). The challenges that we encounter today are increasingly systemic, and tackling them, thus, becomes a systemic endeavour. Combined, this means that the "network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology" increases (Carlsson and Stankiewicz 1991, 93). Innovation processes are usually perceived as systemic, continuous, and non-linear (Edquist 2005), producing sometimes radical yet most often incremental innovations (cf. Fagerberg, Mowery, and Nelson 2005). Such a system – a construct that is "more than the sum of its parts", dynamically intertwined through stocks, flows, equilibria, and feedback loops (Meadows 2008, 188) – contains "messy, complex, problem-solving components, both socially constructed and society shaping" (T. P. Hughes 2012, 45). In turn, the system changes throughout the innovation process as "elements and relationships which interact" evolve (Lundvall 1992, 1). This includes the interaction of multiple systems (Rosenbloom 2020).

Innovation systems, or 'systems of innovation' (usually used interchangeably) (cf. Borrás and Edquist 2019), can be conceptualised in multiple ways, based on the level of analysis across macro-, meso-, and micro-levels (see Figure 1.6).

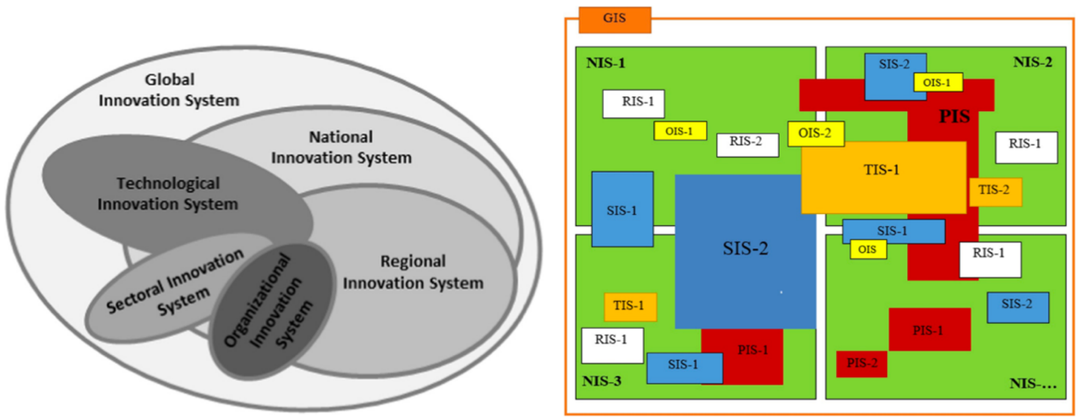

Figure 1.6: schematic visualisation of systemic approaches to innovation[29]

National systems of innovation (NIS) refer to the "set of institutions that (jointly and individually) contribute to the development and diffusion of new technologies on the macro-level. These institutions provide the context in which governments form and implement policies to influence innovation. As such, it is a system of interconnected institutions to create, store, and transfer the knowledge, skills, and artefacts which define new technologies" (Metcalfe 1995, as quoted in OECD 1999, 24). The idea emerged throughout the 1980s and was shaped by economically more liberal approaches and state influence through industrial policies (Sharif 2006). The focus of this approach, hence, rests on contextual factors and the overall environment in which innovation is embedded (cf. E. S. Andersen and Lundvall 1997; Elam 1997; Christopher Freeman 1987, 1995; Lundvall 1992, 2007, 2010; Lundvall et al. 2002; Nelson 1993; Nelson and Rosenberg 1993).

Global innovation systems (GIS) expand the geographical focus onto the global level (Binz and Truffer 2017; Binz, Truffer, and Coenen 2014; Bunnell and Coe 2001; Pietrobelli and Rabellotti 2009; Spencer 2003). Today's globalised knowledge economy creates interlinkages between innovation processes across distant places due to people's increased mobility, expanding knowledge development, and international capital flows (Corpataux, Crevoisier, and Theurillat 2009). The 'internationalisation' also affects, catalyses, and complicates innovation (cf. Carlsson 2006). Hence, the global innovation system

[29] Sources: van Lancker et al. (2016, 41, adapted from Asheim, Smith, and Oughton 2011)(left), Ghazinoory et al. (2020, 8, adapted from Hekkert et al. 2007)(right)

perspective creates a view on technological innovation that conjoins different sub-systems, sectors, and places (Binz and Truffer 2017), including the corresponding supply and value chains (cf. Gereffi 2014; Gereffi, Humphrey, and Sturgeon 2005). The extent to which economies (or innovation hubs) are connected defines the diffusion and further development of innovation (cf. Bento, Wilson, and Anadon 2018; Binz, Tang, and Huenteler 2017) and can lead to global socio-technical regimes (Fuenfschilling and Binz 2017, 2).

Tying the macro- to the meso-levels, *regional systems of innovation* (RIS), in a similar way, regard the system as geographically bound by a region (or sub-region) rather than a country, relying on the physical proximity and entrepreneurial activity of stakeholders (cf. Cooke 2001, 2010; Doloreux 2002). The differentiation between these terms is merely functional. It is heuristically helpful to consider regions consisting of various countries, such as in the European Union or other integrated country groups, e.g. in South America or South-East Asia. In other instances, regions within a country might provide an analytic advantage. These can also cross national borders, e.g. the Copenhagen-Malmö economic area between Denmark and Sweden, or the highly integrated 'bio-valley' region around Freiburg, Basel, and Mulhouse in south-western Germany, northern Switzerland, and eastern France, respectively. Although contextually comprehensive, the geographic proximity-based approaches lack a sophisticated analytical framework. Therefore, they mainly provide overarching conclusions useful to detect systemic deficiencies or generic industrial policies rather than specific aspects that define a particular technology's innovation. In many ways, the spectrum between regional/national innovation systems and global innovation systems is fluent (cf. Chaminade and Plechero 2015).

This is different in *sectoral innovation systems* (SIS) (cf. Breschi, Malerba, and Orsenigo 2000; Malerba 2002, 2005), which investigate innovation on the meso-level and along a sectoral rather than geographical boundary. A sector is understood as "a set of activities which are unified by some related product groups for a given or emerging demand and which share some basic knowledge" (Malerba 2005, 65). Sectors are defined by their "knowledge base, technologies, inputs, and a (potential or existing) demand. They are composed of a set of agents carrying out market and non-market interactions for the creation, development, and diffusion of new sectoral products" (*ibid*.). Hence, the foundation for sectoral innovation systems are knowledge and technology, actors and networks, and institutions (cf. Malerba 2002). Looking at sectors also allows a more detailed analysis of "the rate and type of innovation and the organisations of innovative activities" (Malerba 2005, 64). However, the sectoral perspective lacks the detailed understanding of individual technologies, on the one hand, and the specific influence of any one actor on the system's development, on the other.

On the micro-level, so-called '*organisational innovation systems*' (OIS) capture similar dynamics within (or across) individual firms or organisations. They can be defined as "an innovation network of diverse actors, collaborating with a focal innovating organization in an innovation process, to generate, develop and commercialize a new concept, shaped by institutions" (van Lancker et al. 2016, 42). As such, the organisational innovation system approach unites insights from system innovation research, on the one hand, and from the concept of open innovation, on the other (van Lancker et al. 2016). The approach dives into a firm's inner processes (or other innovators), highlighting aspects such as idea generation, project design, supply chain formation, or testing (*ibid*.). At the same time, it detects the structural and institutional conditions in which firms are embedded, which, consequently, shape innovation processes. These include, but are not limited to, collaboration contracts, intellectual property protection, industry associations, and competitors (*ibid*.). In this light, the role of government actors and their impact on the innovation network is only marginally discussed, let alone the extent to which different forms of policy implementation and coordination by the government influence firms.

Finally, the *technological innovation system* (TIS) perspective combines many of these aspects and adjusts for some of the shortcomings that other systemic innovation heuristics reveal (J. Köhler, Raven, and Walrave 2020). The TIS focus rests on a single technology and on all features, actors, and interactions in the system that shape that technology's development (Hekkert and Negro 2009). Hence, this approach combines macro, meso, and micro-level dynamics. It considers actors and infrastructures in a structural analysis and includes the geographic proximity aspects as well as sectoral specificities in a functional analysis, scrutinising every systemic interaction and the resulting feedback loops. The TIS provides not only a sophisticated analytic lens but also potential intervention points to counter blocking and catalyse inducing mechanisms in the system (A. Bergek et al. 2008; Anna Bergek et al. 2008; Carlsson and Stankiewicz 1991; Hekkert et al. 2007; Jacobsson and Bergek 2004; Johnson 2001; Johnson and Jacobsson 2001; Kieft, Harmsen, and Hekkert 2018; Wieczorek and Hekkert 2012).

In sum, the genesis across the system-oriented approaches remains the same: Technological change is analysed as a consequence of interactions, changes of stocks and flows, and dynamic feedback loops in the respective system. This means that the actions and, thus, the impact of individual stakeholders within the system can be traced – particularly in the TIS approach, which is by definition narrower and, therefore, analytically more feasible. In addition to generic contextual factors, the systemic approaches aim at understanding the impact of policies on the system. To this end, 'system functions' (Anna Bergek et al. 2008; Hekkert et al. 2007) or 'activities' (Borrás and Edquist 2019) can be identified, which, however, differ across approaches (Table 1.2). However, scholars maintain similar general notions and capture the same dynamics despite terminological differences. Generally, scholars have attributed a role to firms and innovators for building and shaping innovation systems (Musiolik and Markard 2011; Musiolik, Markard, and Hekkert 2012) and address the state mainly as a uniform actor (Borrás and Edler 2020; Hekkert and Negro 2009)[30]. It is assumed that policies exist and are implemented in a particular way, mainly leaving aside the political and administrative dimensions – or taking them for granted. These aspects "deserve more attention" (Markard, Hekkert, and Jacobsson 2015, 81), however. On top of that, the individual interests, capacities, interpretations, or positions of public organisations – which define their 'agency' in the system – remains insufficiently addressed (Borrás and Edler 2020; Kern 2015).

Hence, although united in relying on systemic principles, the approaches differ markedly in epistemological and methodological principles (cf. Coenen and Díaz

[30] Borrás and Edler (2020, 7) address 13 different roles of the state, but do not attribute these tasks to specific organisations/actors.

López 2010b) – a discussion that goes beyond the scope of this study[31]. Moreover, these systemic lenses do not provide sufficient sophistication to analyse the coordination-related challenges, as outlined above, despite their relevance.

I. Provision of knowledge inputs into the innovation process	
1.	*Provision of R&D results* and, thus, creation of new knowledge primarily in engineering, medicine, and natural sciences.
2.	*Competence-building*, e.g. through individual learning (educating and training for the labour force for innovation and R&D activities) and organizational learning. This includes both formal and informal learning.
II. Demand-side activities	
3.	*Formation of new product markets*, for example through public procurement of innovation.
4.	*Articulation of new product quality requirements* emanating from the demand side.
III. Provision of constituents for SIs	
5.	*Creation and change of organizations* needed for developing new fields of innovation. Examples include enhancing entrepreneurship to create new firms and intrapreneurship to diversify existing firms, and creating new research organizations, policy agencies, etc.
6.	*Interactive learning, networking and knowledge integration* among different organizations involved in the innovation processes. This implies integrating new knowledge elements developed in different spheres of the SI and coming from the outside with elements already available in the innovating firms.
7.	*Creation and change of institutions*—e.g. patent laws, tax laws, environment and safety regulations, R&D investment routines, cultural norms, etc.—that influence innovating organizations and innovation processes by providing incentives for and removing obstacles to innovation.
IV. Support services for innovating firms	
8.	*Financing of innovation processes* and other activities that may facilitate commercialization of knowledge and its adoption.
9.	*Incubation activities* such as providing access to facilities and administrative support for innovating efforts.
10.	*Provision of consultancy services* relevant for innovation processes, e.g. technology transfer, commercial information, and legal advice.

Table 1.2: key activities in innovation systems[32]

Nevertheless, the TIS approach stands out because it allows an analytic entry route into and connection to the mission-oriented innovation system approach. Mission-oriented innovation, as described above, is mainly focusing on missions that rest on visions for resolving a societal challenge. This usually includes several technologies or socio-technical innovations. Combining many technologies under one analytic umbrella renders conclusions fuzzy and, therefore, less valuable for policymakers; an approach that allows analytical

[31] See Sorrell (2018) for a more detailed account of ontological, epistemological, and methodological aspects of socio-technical transitions.
[32] Source: Borrás and Edquist (2019, 25, as adapted from Edquist 2005, 2011)

access to one technology is more insightful. This enables a detailed analysis of the development of the technology at stake and considers the macro and meso-level pressures, enablers, and stumbling blocks, which shape the development of the technology. As it is also a systemic approach, causal linkages can be drawn between stakeholders, and their interaction can be scrutinised. Hence, the TIS approach provides insights into blocking and inducing mechanisms, in addition to possible intervention points for policies. As this study argues, this includes the activity of public sector organisations and can account for coordination challenges and their impact on innovation processes. None of the other innovation system approaches presented in this review is equally apt, which is why the remainder of this study employs the TIS approach as an analytic heuristic. Chapter 2 discusses the TIS lens and its role in this thesis in more detail.

1.3.2.2 Approaches to Coordinating Policies

A critical problem for modern approaches to innovation and innovation policy, hence, is coordination. Challenges pertaining to the coordination of different government organisations are not new. They have been discussed widely in the public administration scholarship since 'coordination' has proven to be a recurring issue for policymakers and implementers (Dong 2015; Peters 2018c). It is the "eternal and ubiquitous problem in public administration" (6 2004, 131) and "the quest for coordination is […] the philosopher's stone in the sense if only we can find the right formula for coordination we can reconcile the irreconcilable" (Mulgan 2005, 187). Although many aspects thereof are as old as the discipline itself, the pluriformity of contemporary challenges, as outlined above, has exacerbated the issue. This includes, but is not limited to, privatisation, 'agencification', and governance fragmentation during the New Public Management era (cf. G. Köhler 2011; Koppenjan and Koliba 2013; Lodge and Wegrich 2014). Similarly, the "demarcations of policy fields become blurred, with a high level of individualisation, pluriformity of values, information density and dynamics, and mediasation" (Koppenjan and Koliba 2013, 1). As a result, "the public sector is necessarily fragmented" (Kaufmann 1991, 20) featuring "a highly differentiated set of actors" (Kaufmann 1991, 4), especially in innovation-related policies (cf. Griessen and Braun 2008) and particularly regarding mission-orientation and multi-technology innovation, as discussed above.

These public actors are differentiated not only because they have different responsibilities and roles but also because they differ concerning their capacity. "There is no equality assumed among the actors, their relative strengths and potentials" (Kaufmann 1991, 8). Generally, 'capacity' refers to the "'ability', 'efficiency' or 'effectiveness' of certain political, analytical, or operational skills" (Karo and Kattel 2018b, 3) "to achieve a desired collective purpose" (Brinkerhoff and Morgan 2010, 3) – rendering a quasi-binary assessment: government organisations either have it, or they do not. It encapsulates the systemic and structural environment in which governance is embedded (Holmberg and Rothstein 2012; Rotberg 2014), which shapes functionally (compared to legally) what governments can and cannot do (Howlett 2009). More specifically, the public management literature refers to 'capacity' by emphasising implementation, i.e. "the set of skills and resources – or competences and capabilities – necessary to perform policy functions" (Wu, Ramesh, and Howlett 2015, 166). In other words, 'capacity' relies on a set of capabilities, including commitment, engagement, logistics, technical knowledge, support, adaptability, balance, and coherence (Brinkerhoff and Morgan 2010). This includes actors beyond public organisations who might fulfil a particular task on the government's behalf. Therefore, throughout this thesis, 'capacity' is understood as the accumulation of capabilities and competences to achieve a specific task.

Combined, "policy capacities – especially for innovation and other complex public-policy goals where uncertainty is the prevalent condition – a) are located, nurtured and routinised within organisations; b) are often dispersed into a variety of organisations within a system of organisations (policy domain); and c) evolve through organisational search and selection in the context of specific punctuated feedback environments of these organisations" (Karo and Kattel 2018b, 10). This is particularly the case regarding innovation policy. Capacity, hence, is both a necessary requirement for coordination (cf. Howlett 2015; Howlett and Lindquist 2004; Painter and Pierre 2005a; Parsons 2004) and the cause why coordination is required. In other words, if government organisations have the capacity to fulfil their mandate regarding innovation policies, they also have to interact with other public agencies, which requires policy coordination.

In this light, the dichotomy between the coordination of policy design and policy implementation is of particular relevance. The former is output-driven, focusing on "an end-state in which the politics and programmes of government are characterised by minimal redundancy, incoherence and lacunae" (Peters 1998b). If the policy design is well-coordinated, "adjustments have been made in it such that the adverse consequences of any one decision for other decisions in the set are to a degree and in some frequency avoided, reduced, counterbalanced, or outweighed" (Lindblom 1965, 145). This means that policy designers (policymakers) must ensure that policies are well integrated. This is the case where "all significant consequences of policy decisions are recognised as decision premises, where policy options are evaluated based on their effects on some aggregate measure futility, and where the different policy elements are consistent with each other" (Underdal 1980, 162). Hence, coordination "is both a process through which decisions are brought together and an outcome of that process" (Peters 2015b, 3). This task requires policymakers to rely on the predicted or assumed outcome and impact of a policy[33], including the policy implementing organisations' influence. Hence, output-oriented policy coordination assumes a static condition of coordination, as upon concluding the policy's design, it is left to itself, attributing further influences on the policy to exogenous factors (Peters 1998b, 2015b).

Coordinating policy implementation, in turn, "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). In other words, the actors who implement policies rather than the policies themselves should be coordinated. Across the complex, systemic interactions that define public administrations' role and responsibilities, "most actors are engaged in a multiplicity of chains of action" (Kaufmann 1991, 8). Coordination, then, must ensure that "different actions of

[33] A policy represents the 'output' of a policy design process, whereas the implementation by the public administration represents the 'outcome'. The ultimate effect of the policy or the observed change represents the 'impact' (cf. Gehring and Oberthür 2009).

various actors become linked to constitute chains of actions" that address a common policy or issue (*ibid*.). Thus, a well-coordinated arrangement is defined by "the extent to which organisations attempt to ensure that their activities take into account those of other organisations" (Hall et al. 1977, as quoted in Aubin et al. 2014, 22). This assumes a cooperative interaction between public agencies where, "given the limited rationality of all actors and the contestability of all political issues, institutional arrangements should provide possibilities for learning among all of the actors concerned" (Kaufmann 1991, 21). Interestingly, Nelson and Winter (1982), the above mentioned evolutionary economists, also "conceptualised co-ordination as the outcome of organisational and cognitive routines" (Geels 2002a, 1259).

Coordinating both policy design and implementation is key to ensure the intended impact of a particular policy. The interaction between actors involved in designing and implementing policies depends on the individual behaviour of specific organisations (Koppenjan and Koliba 2013), and such interaction processes are non-linear. To convey information about the policy's impact and the result of its implementation back to the policymakers, a mechanism must be in place, e.g. through evaluation procedures, adequate fora, the media, or simply the next election. This renders a network of actors that requires coordination (cf. Agranoff and McGuire 2003; Koppenjan and Klijn 2004; Sørensen and Torfing 2007). Therefore, both policy design and implementation must be coordinated jointly – they must be coordinated within themselves and with each other. Policies must be coordinated *across* policy design and policy implementation. The more complex policies become, the more stakeholders they include, and the more interests they need to align, the more difficult this task will become. Hence, the more complex policies are, the more they require coordination across design and implementation. Wegrich and Štimac refer to this task as 'coordination capacity' of the modern state (2014).

What are the sources for coordination capacity, and how is coordination capacity built up? The coordination capacity sources are diverse but include, among others, authority, power, bargaining, information, norms, and mutual co-optation (Bouckaert, Peters, and Verhoest 2010). These factors define the "various ways agencies communicate their policy intentions and programmes to each other or to a 'coordinator', and how this information is processed with a view to uncovering mutual incompatibilities" (Brickman 1979, 76). Such practices can be highly diverse, which renders different coordination types (Braun 2008), all of which describe the conditions, challenges, or policy coordination failures. The internal-external dichotomy refers to the behaviour of government ministries that can either cooperate across boundaries (internal) or be directed by a super ministry (external) (Scharpf 2000). Similarly, Laranja et al. (2008) describe the strong institutionalisation and regulation as a form of coordination compared to organised learning across organisations and information exchange (Ford 2013, 2017). It also includes Peters' elaborations on negative and positive coordination (2004), referring to whether actors take into account negative backlashes of their actions and simply try to avoid these (negative coordination) or whether they aim at stimulating a win-win situation for all actors involved (positive coordination). These observations render a range of coordination approaches, beginning with no coordination on one end, via the more administrative coordination efforts (such as negative/positive coordination) and the more policy-oriented coordination efforts (such as policy integration[34]) to a solid form of strategic and long-term coordination (Braun 2008). Metcalfe describes such a policy coordination scale of nine levels ranging from "independent decision-making by ministers or agencies" and "information exchange" with other ministries on the lower end to "establishing central priorities" and even a complete and comprehensive "government strategy" on the highly-coordinated end (Metcalfe 1994, 281).

However, coordination capacity reaches its limits concerning innovations in two ways. On the one hand, if technologies are entirely new, they can fall in between the existing jurisdictions of different government agencies. In this case, no one in the government assumes responsibility and no public agency conceives the innovation within its governance mandate. The "situation when a particular policy issue falls between the jurisdictional boundaries of different governmental organisations so that it becomes the responsibility of none" is called 'underlap' (Wegrich and Štimac 2014, 45). On the other hand, when multiple governance

[34] Tosun and Lang (2013, 2017) take stock of coordination aspects regarding policy integration.

authorities perceive an innovation as part of their remit, ‘turf wars’ and tensions can emerge. Such ‘overlap’ occurs when “a particular policy issue [… is] of similar key relevance for the different organisations, with the result that they both/all want to be involved” (Wegrich and Štimac 2014, 46). Complex socio-technical innovations may increasingly trigger policy implementation overlap or underlap.

How can we avoid overlap and underlap? Coordination is not an ‘on-off decision’. Governments cannot simply flip a switch. Instead, coordination is a project that requires planning, effort, repeated attention, and iterations. Yet, even aims regarding the coordination of governance practices likely differ among stakeholders, depending on their core interests. Coordination efforts, thus, can result in purely atomistic approaches where organisations are free agents without mutual obligation to adjust, merely working alongside each other (Brickman 1979). It can also emerge as ‘low coordination’. Here, agencies' activities broadly align with the policy regime's objectives, avoiding duplication (overlap) and focusing on “the joint management of mutually supportive efforts” through “the efficient allocation and utilisation of available resources” (*ibid*., 78). In the ‘high coordination’ scenario, this notion is taken a step further. It is based on system-wide goals that guide every policy programme, encompassing an entire range of public action (*ibid*.). To achieve these coordination levels, the relationship between organisations needs to be clearly defined, including their power discrepancy, their dependency, their financial obligations, and their cognitive frames of reference (*ibid*.).

In this light, two approaches to avoid coordination failures – or to resolve them – have received particular attention in the scholarly literature and policy practice: the idea of a ‘joined-up government’ (JUG) and the ‘whole of government’ approach (WG). Christopher Pollitt advocated for a JUG as famously employed by Tony Blair’s government in the UK from 1997 onwards (Davies 2009; Hood 2005). JUG implies “the aspiration to achieve horizontally and vertically co-ordinated thinking and action” (Pollitt 2003, 35), intending to counter the ‘departmentalism’ dominating the public administration (Christensen and Lægreid 2007a). The long-term, selective, and cooperative goal is to systematically eradicate circumstances where “different policies undermine each other [hence, avoiding overlap], so as to make better use of scarce resources, to create synergies by bringing together different stakeholders [...], and to offer citizens seamless rather than fragmented access to services" (Christensen and Lægreid 2007a, 1060; also cf. Pollitt 2003). JUG includes implementation and policymaking (i.e. policy design) because "implementation 'infects' policymaking, and vice versa" (Pollitt 2003, 37; see also UK Cabinet Office Performance and Innovation Unit 2000, 2001). This demands functioning feedback mechanisms across the policy design-implementation dichotomy and evaluation processes that, in turn, feed into future policymaking. Hence, the dominant rationale is to establish mutually consistent objectives, means, and support, joined-up coordination, and joined-up policy integration (6 1997, 2004; 6 et al. 2002).

Similarly, the WG approach – a response to the New Public Management agenda, structural devolution within governance, and a more insecure world (Christensen and Lægreid 2007a) – represents the continuation and a follow-up of the JUG idea. Compared to JUG, the WG approach relies on broader social scientific insights, other than economics, to enrich decision-making and the structuring of public sector practices (Bognador 2005). When designing and implementing policies, the government should not push a singular, incoherent idea without having a holistic strategy – WG builds an umbrella concept. Hence, 'holism'[35] is inherent to the WG idea, akin to the 'holistic government' approach proposed by Perri 6 (1997; 2002; also see Dong 2015). It stresses the delivery and outcome of services (Barber 2015) and, thus, policy implementation. In sum, "WG activities may span any or all levels of government and involve groups outside government. It is about joining up at the top, but also about joining up at the base, enhancing local level integration, and involving public-private partnerships" (Christensen and Lægreid 2007a, 1060).

How does this look like in practice? Public administration scholars classified three modes of coordination that encapsulate the overarching dynamics suggested by JUG and WG that ensure the coordination of public agencies – and beyond. These are hierarchical, market-based, and network-oriented policy

[35] Holism refers to "the theory that parts of a whole are in intimate interconnection, such that they cannot exist independently of the whole, or cannot be understood without reference to the whole, which is thus regarded as greater than the sum of its parts" (Lexico 2020; based on Smuts 1927).

coordination (cf. Bouckaert, Peters, and Verhoest 2010; Peters 1998b; Thompson et al. 1991). Each defines the purpose of coordination, the sources of power, the characteristics of actors, interaction dynamics, and guidance and control mechanisms. Accordingly, they describe core characteristics of observable coordination patterns in public-administrative practice (Kaufmann, Majone, and Ostrom 1986; O'Toole 1997; Peters 1998b, 2015a; Thompson et al. 1991). This typology also renders a useful analytic lens to ascertain potential intervention measures. Chapter 2 discusses these three coordination modes in further detail.

Governments are aware of strategies that consolidate the challenges associated with the coordination of policies, and many governments around the world practise these approaches (e.g. the UK, Australia, New Zealand). At the same time, however, the JUG and WG concepts are broad, as they by definition aim at incorporating many if not most aspects relevant to a particular policy. They remain umbrella concepts and are helpful to enhance the understanding and awareness of the need for coordination. Yet, advising to 'include all aspects' proves less useful concerning coordinating particular solution-oriented policies in practice, e.g. mission-oriented and socio-technical innovation policies. Here, the starting point is not a specific policy but a larger issue that governments attempt to resolve. Besides, JUG and WG leave many administrative structures unaltered, on the one hand allowing civil servants and policymakers to continue thinking in vertical, siloed patterns of responsibility, and on the other, triggering issues regarding accountability (cf. Davies 2009; Ling 2002; Mulgan 2005).

Scholars working on particularly complex policy problems, therefore, suggest alternative, practicable approaches. In the case of sustainability transitions, for instance, policies target a particular sector (e.g. energy) but should also take into account an assortment of coherent policies regarding economic dynamics, housing, urban planning, or transport. As Rogge and Reichardt (2016) argue, this can only be achieved by designing and implementing 'policy mixes'. This essentially describes an approach to coordinating policies by purposefully crafting them jointly as a mix that addresses multiple issues through various policies and policy areas at once (cf. Flanagan, Uyarra, and Laranja 2011; Rogge and Schleich 2018). They emphasise that "a policy mix goes beyond the combination of interacting instruments – the instrument mix – but also includes a policy strategy, policy processes, and characteristics" (Rogge and Reichardt 2016, 1632). Policy mixes feature prominently in discussions related to sustainability transitions and (eco-)innovation (Costantini, Crespi, and Palma 2017; Edmondson, Kern, and Rogge 2019; Edmondson, Rogge, and Kern 2020; Kern and Howlett 2009; Kern, Rogge, and Howlett 2019; Kivimaa and Kern 2016; Rogge, Pfluger, and Geels 2020). Yet, they often lack the actor-specific view on policy implementation and administration (cf. OECD 2005; Quitzow 2015a).

The purposefully designed alignment of policy "instruments from the same or different domains" (Magro, Navarro, and Zabala-Iturriagagoitia 2014, 370) can ensure that they interact frictionless in a given policy space or system (Borrás and Edquist 2013; Magro and Wilson 2013). A precisely tailored policy mix can "respond to the coordination failures that are derived from a complex policy setting where multiple instruments from different domains, levels, layers, and actors coexist". This creates a 'coordination mix' by design (Magro, Navarro, and Zabala-Iturriagagoitia 2014, 384). A coordination mix can directly address the political sub-system in which the group of policies – or the broader mission – is embedded. Magro et al., therefore, argue for systemic policymaking to account for the complexity and need for coordination across policy domains (areas of responsibility), levels of government, layers of government, and governance actors (2014) – similar to the policy mix approach (Reichardt et al. 2016). Such a purposeful approach can avoid or minimise over- and underlap, policy inconsistencies, and conflict while increasing governance coherence and cohesion (Magro, Navarro, and Zabala-Iturriagagoitia 2014) and policies (cf. May et al. 2005; May, Sapotichne, and Workman 2006). Hence, avoiding policy coordination failures requires systemic approaches to policy design and implementation and a sound understanding of each actor's individual roles in the innovation system, including public sector organisations.

1.3.3 Literature Review Conclusion: the Coordination Problem

The relationship between coordination and innovation (policy) is complex, and the global challenges we face today further complicate it. One predominant issue for mission-oriented, socio-technical innovation and the implementation of innovation policy relates to the coordination of stakeholders and policies. This is a challenge that is not new to public administrations and not unique to mission-oriented policies – however, the contemporary dynamics intensify this challenge. The innovation approaches presented in this review, whether focused on policies, systems, transitions, or norms and irrespective of their inherent value-leadenness and attempted comprehensiveness, can inform the policy design process. However, in isolation, each only tells about a part of the changes required to tackle wicked problems. Accordingly, they do not focus on the technical and practical aspects of socio-technical innovation and make little reference to policy implementation and the role of the public administration. Generally, "the study of policy implementation within the policy sciences remains fractured" (Howlett 2019, 405; see also Howlett, Ramesh, and Perl 2009). Often, these aspects are only included as a part of the overarching 'governance' components in analytic frameworks, assuming a unified approach by state actors and suggesting an understanding of the state as a 'unitary actor'. Policy implementation is often taken for granted by policymakers and other actors in the innovation system (cf. Howlett 2019). In sum, "the study of mission-oriented policies needs to adjust its perspective and pay more attention to governance, implementation processes, and actor constellations […] beyond the dichotomy of the state correcting vs creating markets by taking a closer look at the role of state actors – a blind spot in innovation research" (Wittmann et al. 2020, 24).

Paradoxically, although all presented approaches cross policy domains and imply an increase in the number of stakeholders to resolve a problem holistically, they do not address the inevitable challenge to coordinate actors from different sectors and policy domains. Researcher focusing on mission-orientation began to investigate the issue of public sector capacity in the context of innovation policy, also hinting towards implementation challenges and coordination (cf. Karo 2018; Karo and Kattel 2010a, 2015, 2016a, 2016b, 2018a, 2018b; Kattel and Mazzucato 2018; Mazzucato, Kattel, and Ryan-Collins 2020; Wanzenböck et al. 2020; Wittmann et al. 2020). These studies do not focus on coordination, however. They also insufficiently address the emanating issues concerning highly complex technologies, so-called multi-technology challenges. In other words, analytic frameworks in innovation studies under-capture a) the role of public sector organisations and b) the challenges associated with (policy) coordination. The first question informing the overall research question of this study, therefore, is:

> How and to what extent do public sector organisations influence socio-technical innovation systems?

Governments must have the capacity to understand the complexity of interactions across innovation processes and must be able to incorporate past experiences into future decision-making based on futures and foresight instruments (cf. van Asselt et al. 2010; Mazzucato 2013b; Mazzucato and Semieniuk 2018). They must ensure that "different organisations can effectively fulfil their roles in coordinating and providing direction to private actors when formulating and implementing policies that address societal challenges through innovation" (Mazzucato 2017b, 4). This can be achieved through permanent feedback mechanisms between policy design and policy implementation organisations. Hence, the extent to which the public administration reacts to the requirements that new technologies pose is a matter of system design. In other words, the innovation system may also shape the public administration, which can adapt its practices and coordination arrangements in accordance with the innovation system it aims to govern. The second question informing the overarching research question of this thesis, therefore, is:

> How and to what extent do socio-technical innovation systems influence public sector organisations?

Additionally, from mission-orientation to social innovation, the approaches mentioned above have in common that they lack an analytic tool to gain insights into the coordination challenges in innovation systems and the role of public sector organisations therein. Such an analytical lens is generally missing in the literature. Only once the dynamics and interactions of stakeholders concerning coordination are understood we can derive meaningful and impactful intervention strategies, e.g. through policies. Hence, an analytic lens is essential to understand and tackle coordination challenges in socio-technical innovation systems. The third question to inform this research project's overarching question, therefore, is:

> How can the relationship between public sector organisations and socio-technical innovation systems be conceptualised and analysed?

In combination, these aspects should be addressed jointly. The coordination challenges emerge from the complexity of the technologies and the multitude of actors involved in mission-driven, socio-technical innovation processes. Simultaneously, public administrations as policy implementers form a central part of innovation processes, especially concerning regulation, policy learning, and feedback across system stakeholders (cf. Goyal and Howlett 2020). The public administration scholarship suggests that public sector organisations can align their activities and contribute to a more coordinated form of policy implementation. In other words, insights from the coordination literature can inform innovation studies and vice versa. To improve the understanding of the causal relations between actors and actions when implementing mission-oriented policies and governing complex multi-technology innovation systems, the overarching research question guiding this thesis is, therefore:

> **How do public sector organisations and socio-technical innovation systems mutually shape each other, particularly in the context of mission-oriented policies?**

1.4 Research Project Value and Relevance

The research project is valuable to the groups at the heart of the research question: on the one hand, government officials such as policy designers and implementers, on the other hand, technologists, innovators, and entrepreneurs. Besides, the study also adds value to the academic discussion in innovation studies, political economy, and public administration.

Those working in or for governments can learn from this thesis how to approach coordination challenges related to complex, emerging technologies. The networked approach to policy coordination requires different mechanisms and mindsets in public sector organisations about the interaction with other actors in the innovation system, both public and private. Such approaches feature collaboration, cooperation, and a 'networked transition', working with rather than for or against innovators in the private sector. Simultaneously, governments learn that policy design and policy implementation need to be closely aligned, irrespective of them mainly being enacted by different public organisations. Accordingly, feedback loops can channel information and experience about policies from the implementing organisations back to the policymakers – a process that is often overlooked. Governments must ensure that the experience of policy implementers is re-implanted into policymaking. This approach best prepares governments to design and implement mission-oriented policies that are useful to tackle our time's grand challenges.

Innovators and entrepreneurs working directly on or with novel, complex technologies may appreciate this study for its insights into the engagement procedures and interaction strategies of the stakeholders involved in innovation systems. This thesis will show that this includes not only technologists, engineers, developers, or business analysts and innovative entrepreneurs but also governments and other public sector organisations. Especially technological innovations that have a significant social impact, e.g. because they imply that the society at large changes (parts of) its behaviour, are unlikely to occur without the (purposeful or accidental) intervention of (a) government (actor). Since socio-technical innovations are regulated, funded, advocated for, or opposed by government actors, innovators must engage with the government if they wish to advance, market, and commercialise their technologies. The study will outline which strategies are best apt to create a functioning and mutually beneficial interaction network around emerging technologies, consisting of actors from industry, government, and academia. Being aware of this 'network' strategy can shorten the time to establish such a network, avoid blocking mechanisms that slow innovation, and catalyse and accelerate socio-technical processes.

To colleagues in academia, this thesis indicates the public administration's influence on innovation systems and, vice versa, the effect of innovation systems on public sector organisations. This role of public agencies should be considered when analysing innovation systems. For this purpose, this thesis provides a novel addition to a commonly used analytic framework in innovation studies. In the 'TIS+' framework, 'public-administrative elements' complement the TIS approach. Researchers will find the TIS+ framework particularly useful to identify governance challenges and bottlenecks associated with emerging technologies, (policy) intervention rationales, and causal relationships between public sector organisations. Hence, the framework complements existing analytical approaches by adding the missing yet invaluable public-administrative perspective. It considers the whole socio-technical system, widens the scope of sustainability transitions and innovation systems approaches, and contributes to understanding how (sustainability) transitions can be accelerated (Markard, Geels, and Raven 2020; Roberts and Geels 2019).

1.5 Thesis Outline and Organisation

This thesis is structured in seven chapters. **Chapter 1** outlined the coordination problem associated with mission-oriented innovation (policies) and multi-technology innovation based on the example of AVs. The chapter also analysed the literature in two academic disciplines: innovation studies and public administration. On the one hand, existing research in innovation studies, particularly in transitions research and innovation policy analysis, undermines the role of policy implementing organisations. Coordination challenges resulting from innovation policies and complex technologies highlight this gap. On the other hand, while having paid meticulous attention to coordination challenges, the public administration literature often skips the policy design-implementation dichotomy. This aspect is becoming increasingly relevant as global challenges trigger more complex policies and technologies. Combined, the chapter pointed to the shortcomings in the existing literature and devised the research questions that inform this study, intending to bridge both scholarly fields, informing policymakers, implementers, researchers, and technologists.

Chapter 2 sets out the conceptual and analytic frameworks that guide this thesis. Based on systems thinking and the principles of evolutionary economics, this thesis builds on three foundations: the technological innovation systems framework native to the sustainability transitions scholarship within innovation studies, public-administrative elements derived from institutional change theory and the political economy literature, and the policy coordination modes within the public administration literature. In combination, the three foundations feed into the novelly introduced 'TIS+' framework, which forms the primary tool for analysis of the empirical case studies. Moreover, the chapter outlines the research methodology used and points to the limitations of this study.

After that, **Chapter 3** elaborates how innovation, innovation policy, and approaches to governing both have changed over recent decades, relying on institutional change narratives and a longitudinal analysis across three eras: post-1945, post-1990, and post-2008. Furthermore, the chapter explains how the institutional change perspective links to the suggested public-administrative elements used as an analytic lens in this thesis.

The empirical analysis of this thesis follows in **Chapter 4**, **Chapter 5**, and **Chapter 6**. Sequentially, these chapters analyse the approach to governing AVs in the three case study countries. First, the Singaporean case shows how the hierarchical mode of policy coordination structures governance and innovation practices yet changes due to the challenges emerging from the AV innovation system. Second, Estonia's market-based case, where the state generally takes on a more distant role, reveals similar insights. Third, Sweden traditionally features a rather network-oriented approach to policy coordination, which also proves useful to governing complex technologies, such as AVs. All case studies include a politico-economic context analysis to understand the countries' underlying dynamics and feature a network analysis of the innovation system for AVs in the country. By employing the novel TIS+ framework, the chapters render a detailed understanding of public-administrative influences on the AV innovation system – and vice versa. Ultimately, the empirical chapters derive conclusions about each case study's approach to policy coordination and innovation governance.

Finally, **Chapter 7** concludes this thesis. It pulls together the insights gained in the case studies and compares the findings, highlighting the innovation network, the innovation system's blocking mechanisms and ways to resolve them, and policy coordination changes. The chapter also derives implications and recommendations for policy designers and implementers, innovators, entrepreneurs, and researchers, and outlines future research pathways.

2 Coordinating Innovation Systems – the TIS+ Analytic Framework

2.1 Introduction

As mission-oriented policies by definition cross sectors and technologies – and therefore also policy domains, jurisdictions, and government authorities – they incorporate a multitude of stakeholders and inevitably trigger coordination challenges. Coordination challenges are not new but have hardly been discussed in the context of innovation policy. The complexity of modern socio-technical innovations in the context of global issues increases coordination challenges further. Hence, the influence of public sector organisations can make or break innovation systems – or at least accelerate or slow their development. Grasping the dimension of coordination challenges requires a conceptual framework that combines all actors, their interactions, and the outcome of their interactions.

For this reason, this thesis relies on a 'systems logic' as an underlying conceptual framework (cf. Carlsson and Stankiewicz 1991; Jervis 1997; Meadows 2008; Mingers 2006; Seddon 2008; Smits and Kuhlmann 2004). The systems logic is helpful for three related reasons: First, the systems logic emphasises the non-linearity of innovation processes. Instead, innovation processes are highly complex and follow an interconnected and catalytic dynamic over time, where actors, outcomes, and impacts influence and reinforce each other through "cumulative causation" (Suurs et al. 2010, 421)[36]. This is particularly the case for multi-technology solutions that comprise various components and are used for several purposes and in different situations, often resulting from mission-oriented policies. A system approach to capturing these reciprocal influences sheds light on causal relationships and ensures – as much as that is possible – a complete picture of innovation, innovators, and contextual parameters.

[36] This dynamic can also develop 'downwards', creating a "vicious cycle" (Suurs et al. 2010, 421).

Second, the systems logic captures governance arrangements across policy design and policy implementation, allowing to analyse the relationship[37] between policymakers and the public administration (cf. Seddon 2008). Policymakers incorporate various ‘input’ factors into their decision-making process, such as political, economic, and social parameters as well as overarching dynamics and global trends that condition the innovation eco-system. They produce a formally prescribed policy – the ‘output’ and the endpoint of the policy design phase (cf. Gehring and Oberthür 2009). The public administration implements the policy and shapes it through interpretation and discretion (cf. Lipsky 1980). This represents the ‘outcome’ of the policy process and depends on the dominant administrative culture, its capacity, and its capabilities. The factual, observable real-world change represents the policy’s ‘impact’ (cf. Gehring and Oberthür 2009) – which should resemble the initial intention of policymakers. A systemic analytic approach allows to detect the feedback loops that inform policy designers about the implementation phase and its impact – this process can be referred to as ‘backward integration’. The extent to which both policy design and implementation are integrated into both directions defines the policy’s ‘success’.

Third, the conceptual systems logic allows a feasible and intuitive way to connect innovation and governance processes. A system analysis can include policymakers, implementers, but also innovators, entrepreneurs, researchers, and in parts even society. This renders a ‘whole-system orientation’ (cf. Grillitsch et al. 2019). It also accounts for country contexts, the diversity among state actors, and the fact that the state cannot be considered as unitary or homogenous across innovation and governance processes – and their integration – especially in the context of mission-oriented policies and socio-technical innovation.

In sum, to analyse the impact of public administrations on socio-technical innovation in the scope of mission-oriented innovation systems, this thesis relies

[37] Actors in systems are also called system ‘components’, e.g. ministers, government agencies, incumbent firms, or research organisations. Their ‘relationship’ refers to their linkages and/or independence (Carlsson et al. 2002, 234). These interdependencies resemble feedback loops which describe how the behaviour of one actor positively or negatively affects other components and their corresponding systemic impact. They can have catalytic/enabling or inhibiting effects (cf. Anna Bergek et al. 2008; see also Meadows 2008). Feedback loops form a key system characteristic: “The system is more than the sum of its parts” (Blanchard and Fabrycky 1990, 2).

on the systems logic. Policymaking and policy implementation can be viewed through a systemic lens, where stakeholders in a particular setting interact. The result of this interaction creates feedback loops, which in turn affect other actors or system conditions. While primarily using the structural and functional analytic framework of TIS, the thesis complements this approach with elements that allow the analysis of the role and impact of public administrations.

In essence, the combination of the TIS analysis, the public-administrative analysis, and the coordination analysis yields the 'TIS+' analytic framework and forms a core contribution of this thesis. It represents a novel approach to combine the analytical lens of innovation (system) studies with insights from the public administration scholarship. The 'TIS+' is a valuable addition to both scholarships because it allows for the joint analysis of innovation and governance systems, identifies the impact of public sector organisations on innovation systems, and observes changes in governance arrangements to accommodate the specificities and requirements of particularly complex, mission-oriented innovations. The 'TIS+' framework guides the analysis of the three case studies in this thesis and is key to answering the research questions raised in Chapter 1.

This chapter first introduces the foundations for the TIS+ framework – the functional TIS analysis, the novelly introduced public-administrative elements, and the hierarchical, market-based, and network-oriented policy coordination modes. Consequently, the chapter explains how the 'TIS+' approach works in practice and how it ensures that the role of public administrations is adequately included in innovation system analyses. The chapter also elaborates on the research methodology, explains the research design, and accounts for limitations.

2.2 Analytic Framework: the 'TIS+' Model

This section introduces the primary analytic framework of this thesis. It builds on the TIS framework used in innovation studies, on novelly introduced public-administrative elements derived from the institutional change scholarship, and on policy coordination modes used in the public administration literature. Hence, the analytic framework rests on three initially separate foundation blocks that have not yet been combined in the scholarly literature.

2.2.1 Foundation I: Technological Innovation Systems

2.2.1.1 Politico-Economic Context of the System

Investigating the political and economic context in which both the innovation system and the public administration are embedded forms the first step to prepare the system analysis. Thus, it provides the basis for the analytic framework. 'Context' is defined by technological, sectoral, geographical, political, and economic parameters that externally influence the system (cf. among others Anna Bergek et al. 2015; Anna Bergek, Jacobsson, and Sandén 2011; Binz, Truffer, and Coenen 2014; McDowall et al. 2013; Sandén and Hillman 2011). Attributing attention to the context of innovation systems (Anna Bergek et al. 2015; Edsand 2017) also falls in line with the multi-level approaches in (sustainability) transition studies (cf. Geels 2002a). The politico-economic context defines the interaction of the parameters that shape the policy coordination approach a country dominantly employs. It also highlights the central actors in the political and economic landscape concerning the technology, the innovation system, and mission-oriented innovation policy and brings forward the complexity which defines socio-technical innovation as systems evolve over time (cf. Jacobsson and Bergek 2004; Jacobsson, Sandén, and Bångens 2004). Policymaking, thus, "will have to be context-specific to acknowledge the particularities of different sectors and places" (Rosenbloom et al. 2020 as quoted in Markard, Geels, and Raven 2020, 5). The politico-economic context analysis is structured in five steps:

First, TIS do not operate in isolation from other technologies and thus from other TIS. The relationship between two (or several) TIS defines how the respective technologies and, consequently, the participating actors interact (Suurs 2009; Suurs and Hekkert 2009). This interaction shapes the development of all TIS involved, as they can, for instance, compete or complement each other (Sandén and Hillman 2011), e.g. when technologies struggle for the same resources within a value chain (Anna Bergek et al. 2015), when they require each other to succeed (cf. Rothaermel 2001), or when technologies replace each other or come to the end of their life-cycle (cf. Markard 2020). Thus, "each TIS forms a potentially important context of other TISs" (Anna Bergek et al. 2015, 54) (see below).

Second, the sectoral context to which the technology belongs also shapes how it can be innovated (this can be multiple sectors). Studies of entire sectoral innovation systems, as outlined above, highlight this interdependence between technologies (cf. Malerba 2002, 2005). To understand the sectoral context in which TIS, policymakers, and implementers operate, we should grasp the size and breadth of the sector, the extent to which the technology in focus is integrated therein, and the principal actors, networks, and institutions that define the sector (Anna Bergek et al. 2015). Ongoing (larger) changes and overarching dynamics in the sector will be of equal interest to understand the development of single technologies (Wirth and Markard 2011).

Third, technological innovation occurs in a defined geographic space, and innovation-related interaction among actors occurs throughout geographies (Anna Bergek et al. 2015). Geographic factors that determine the performance of TIS structures and functions, including the interaction of actors, the formation of networks, the availability of resources, the formation of markets, or the co-evolution of TIS across regions, etc. have been analysed and found highly impactful (cf. Binz, Truffer, and Coenen 2014; Heiberg, Binz, and Truffer 2020; McDowall et al. 2013; Quitzow 2015b; Vasseur, Kamp, and Negro 2013). For the purpose of this study, with its focus on public-administrative impact, it is sufficient to understand the extent to which geographic or geopolitical factors determine the innovation system or the behaviour of policymakers and implementers at large, e.g. if they pose significant barriers or opportunities (Gosens, Lu, and Coenen 2015).

Fourth, both innovation (policy) and policy design/implementation occur in a political context, especially regarding technological transitions (cf. Hess 2014) and mission-oriented innovation – "innovation is political" (Salas Gironés, van Est, and Verbong 2020, 1; see also Schot and Steinmueller 2018b). This refers to political conditions, significant political events such as elections, and societal interests (Meadowcroft 2011), but also to power dynamics (Avelino and Wittmayer 2016), party politics (Aklin and Urpelainen 2013), and political coalitions (Kern and Smith 2008). Understanding the political conditions is helpful to put general dynamics into perspective.

Fifth, the macroeconomic context influences most if not all technology and policy actors (cf. Cherp et al. 2018; Malerba 2002). Although economic and business-related aspects also feature in the TIS analysis, an understanding of the macroeconomic situation in which the TIS unfolds is obligatory. This includes, but is not limited to, the awareness of economic crises or tensions, larger and overarching consumption patterns, as well as international trade flows.

Step	Focus	Factors
1	**Technological context** Guiding question: Which technological factors define the context in which the (AV) technology operates?	• TIS-TIS relations (competition, synergies) • value chains and resources needed • exnovation dynamics • life-cycle analyses
2	**Sectoral context** Guiding question: Which sectoral factors define the context in which the (AV) technology operates?	• sectoral actors/networks/institutions • sectoral integration of the technology • existence of similar technologies • overarching sectoral changes/transitions
3	**Geographical context** Guiding question: Which geographical factors define the context in which the (AV) technology operates?	• geographical landscapes • geo-political aspects and conflicts • resource availability
4	**Political context** Guiding question: Which political factors define the context in which the (AV) technology operates?	• political events, debates, tensions • international commitments • political arrangements • coalitions • power dynamics
5	**Macroeconomic context** Guiding question: Which economic factors define the context in which the (AV) technology operates?	• economic events, crises, booms • trade flows, competition • international agreements • demand/supply patterns

Table 2.1: politico-economic context analysis summary[38]

Importantly, this context analysis serves as a basis for the remaining analyses in this research project and is not at its core. It is therefore also not regarded as a separate foundation for the analytic framework. Nonetheless, context variables can determine the influence of specific actors, dynamics, and system functions and should therefore be well understood. Crucially, public sector organisations do not simply form part of the context but instead are a central part of the innovation system, as they actively participate in and interact with other system components (cf. Edsand 2017). Table 2.1 summarises the context factors.

[38] adapted from Bergek et al. (2015)

2.2.1.2 TIS Structures and Functions

The TIS approach formed throughout the 1990s and early 2000s and has been developed further ever since, primarily (yet not exclusively) within the sustainability transitions community and concerning the emergence of sustainable technologies (A. Bergek et al. 2008; Carlsson and Stankiewicz 1991; Hekkert et al. 2007; Jacobsson and Johnson 2000; Wieczorek and Hekkert 2012). As opposed to systemic approaches focused on national states (Christopher Freeman 1988, 1995; Lundvall 2007; Nelson 1993), geographic regions (Cooke 2010; Doloreux 2002), or industrial sectors (Malerba 2002, 2005), the TIS approach analyses a specific technology and establishes the causal links between all components that shape the development of the technology (A. Bergek et al. 2008, 409). TIS are defined as "socio-technical systems focused on the development, diffusion, and use of a particular technology, in terms of knowledge, product, or both" (A. Bergek et al. 2008, 408). Akin to the system definition above, an innovation system's components are actors, networks, and institutions (Carlsson and Stankiewicz 1991). Yet, as opposed to national or sectoral systems, the TIS approach comprises a significantly lower number of actors, networks, and institutions, which allows for a more specific and detailed analysis (Hekkert et al. 2007, 417). "The TIS framework can be extended to include an explicit consideration of how complex dynamic processes of a TIS generate system changes" (J. Köhler, Raven, and Walrave 2020, 2). As such, TIS analyses "take into account both endogenous and exogenous structural elements that influence the dynamics of the system" (Markard, Hekkert, and Jacobsson 2015, 78) – precisely what is necessary to understand the role of public agencies.

TIS analyses rest on structural and functional components (Wieczorek and Hekkert 2012). 'Actors' represent the core components of the system and include public and private stakeholders. 'Networks' refer to formal and informal ties between actors and can emerge around supply chains or trading patterns, but also around research and development efforts, funding structures, and specific projects. 'Institutions', as widely discussed in the political science literature and also in Chapter 3 below, include formal laws, regulations, organisations, and arrangements, as well as informal norms, values, cultures, and routines (cf. North 1991; Ostrom 2011). This structural analysis builds on the context analysis and forms the backbone of a TIS analysis. It is usually implicitly included when investigating dynamic TIS functions, which rely on the structural system factors.

These 'TIS functions' or 'system functions' (henceforth 'functions') define the strength, sophistication, and quality of a TIS, focusing on the processes that condition the innovation system to perform its tasks (Johnson 2001). Thus, the functions are dynamic rather than static, unlike system structures, and "show the state of a specific innovation system in a defined moment of time" (Wieczorek and Hekkert 2012, 77). The TIS literature defines various functions, yet scholars partially diverge regarding some of the detailed definitions and terminologies[39]. Quintessentially, they represent the same dynamics, however, as captured in Chapter 1 (cf. Borrás and Edquist 2019). In this thesis, I rely on the set of seven functions as defined by Anna Bergek et al., one of the founders of the functional TIS approach (A. Bergek et al. 2008; Johnson 2001). These functions are 'knowledge development and diffusion' (F1), 'entrepreneurial activity and experimentation' (F2), 'guidance of the search' (F3), 'market formation' (F4), 'resource mobilisation' (F5), 'legitimacy creation' (F6), and the 'development of 'positive externalities' (F7) (*ibid.*)[40]. The different system functions impact each other through feedback loops between functions (Hekkert et al. 2007). Consequently, functions positively or negatively catalyse each other.

The functions are summarised in Table 2.2, which also outlines how each function can be operationalised. The operationalisation allows to observe and measure quantitatively or investigate and define qualitatively the extent to which a particular function has developed and indicates the quality of each function, such that it can be cross-compared to other functions and/or cases (A. Bergek et al. 2008; cf. Anna Bergek et al. 2015; Anna Bergek, Jacobsson, and Sandén 2008; Dreher, Kovač, and Schwäbe 2016; Edquist 2005; Hekkert et al. 2007; Wieczorek and Hekkert 2012).

[39] cf. among others Bergek et al. (2008), Carlson et al. (2002), Edquist (2005), Galli and Teubal (1997), Hekkert et al. (2007), Jacobsson and Bergek (2011), Johnson (2001), Rickne (2000), and Wieczorek and Hekkert (2012)

[40] Some of these functions may at times overlap, e.g. 'market formation' and 'entrepreneurial activity', or 'knowledge development' and 'entrepreneurial activity'. To avoid analytic overlap, consult the operationalisations in Table 2.2.

Function	Definition	Operationalisation
F1 Knowledge development/ diffusion	'Knowledge development and diffusion' demarcates the breadth and depth of the basic and applied knowledge base, qualitatively and quantitatively, for a technology, including the capacity of the actors (Anna Bergek et al. 2008; Wieczorek and Hekkert 2012) and their capability to combine knowledge with other system elements (Anna Bergek, Jacobsson, and Sandén 2008, 578), i.e. its diffusion. Since "R&D and knowledge development are prerequisites within the innovation system, this function encompasses 'learning by searching' and 'learning by doing'" (Hekkert et al. 2007, 422), but also imitation or experience with similar technologies (A. Bergek et al. 2008, 414).	• bibliometrics (citations, volume, orientation) • R&D projects (number, size, orientation) • R&D expenditure • patents (number, orientation) • university engagement (professors, conferences, events) • Google (scholar) statistics • government intervention for network formation
F2 Entrepreneurial activity and experimentation	'Entrepreneurial activity and experimentation' refer to the way firms dive into uncertain, novel technologies and create opportunities (Anna Bergek, Jacobsson, and Sandén 2008, 578). It includes the number and quality of new entrants, but also "the breadth of technologies used and the character of the complementary technologies employed" (Anna Bergek et al. 2008, 416), i.e. "turning the potential of new knowledge, networks, and markets into concrete actions to generate – and take advantage of – new business" models (Hekkert et al. 2007, 421).	• new entrants (number, size, diversification of incumbents) • applications (type, number, operator) • breadth of technologies used • character of complementary technologies developed • adoption rates
F3 Guidance of the search	'Guidance of the search' captures the "activities within the innovation system that can positively affect the visibility and clarity of specific wants among technology users"(Hekkert et al. 2007, 423). They create "incentives and/or pressures" and are based on "visions, expectations, and beliefs in growth potential, […] actor's perceptions of the relevance of different types and sources of knowledge, […] regulations and policy, […] articulation of demand from leading customers, […] technical bottlenecks or […] crises in current business" (Anna Bergek et al. 2008, 415). The 'guidance' emerges from private and/or public actors, and/or from interest groups or society as a whole.	• qualitative belief in growth potential • regulatory pressure (tax regime, standards, laws) • interests of leading consumers/customers • media presence and reaction (articles, statements) • (inter)national declarations of intent • political programmes (or intentions)
F4 Market formation	'Market formation' describes the development of a market, including the competition of established versus new technologies, its demand, and the associated "institutional change, e.g. the	• capacity installed/used (production rate) • units sold or demanded (purchasing patterns)

	formation of standards" across 'niche/nursing markets' (Erickson and Maitland 1989), 'bridging markets' (Andersson and Jacobsson 2000), and ultimately, 'mass markets' (Anna Bergek et al. 2008, 416). It refers to the size of the market and describes its structure, entry barriers, and incentives (Wieczorek and Hekkert 2012).	• market size and market share • actors' strategy • investment rate and volume • (note: mind market phase nursing/bridging/mature)
F5 Resource mobilisation	'Resource mobilisation' refers to "the extent to which the TIS is able to mobilize competence/human capital through education in specific scientific and technological fields as well as in entrepreneurship, management, and finance, financial capital […], and complementary assets such as complementary products, services, network infrastructure, etc." (Anna Bergek et al. 2008, 417). As such, "resources, both financial and human capital, are necessary as a basic input to all activities within the innovation system" (Hekkert et al. 2007, 425), as it can catalyse other functions and create systemic knock-on effects (and beyond).	• human capital formation (training and stock) • financial capital expenditure • complementary asset creation • seed/venture capital volume • public funding availabilities • supply chain adjustments (and new entrants)
F6 Legitimacy creation	'Legitimation' defines the "socio-political process of legitimacy formation through actions by organisations and individuals" (Anna Bergek, Jacobsson, and Sandén 2008, 578) and, thus, the way "the new technology and its proponents [are] considered appropriate and desirable by relevant actors" (Anna Bergek et al. 2008, 417), both legally and culturally. Overcoming the 'liability of newness' (Zimmerman and Zeitz 2002), e.g. through advocacy coalitions (Hekkert et al. 2007), "is a prerequisite for the formation of new industries and […] new TIS" (Anna Bergek et al. 2008, 417).	• alignment with current legislation • consumer acceptance or choice • interest group formation (advocacy coalitions) • political debate • observed regulatory alignment (changes) • inclusion of user innovation (cf. von Hippel 2005)
F7 Positive externalities	'Positive externalities' of an innovation system "reflect the strength of the collective dimension of the innovation and diffusion progress" and "indicate the dynamics of the system since externalities magnify the strength of the other functions" (Anna Bergek, Jacobsson, and Sandén 2008, 578), invoking a positive, cyclical, catalytic effect for the system (Anna Bergek et al. 2008), affirming feedback loops (Hekkert et al. 2007, 426) and creating momentum for the technology.	• pooled labour markets • specialised intermediate goods • information flows and knowledge spill-over • positive momentum

Table 2.2: definitions and operationalisations of TIS functions[41]

[41] adapted from Bergek et al. (2008), Hekkert et al. (2007), and Wieczorek and Hekkert (2012)

2.2.1.3 Analysing TIS

Analysing a TIS requires a system boundary to maintain a feasible scope (cf. Hillman and Sandén 2008). Usually, TIS are considered international, as technical knowledge and socio-technical expertise and experience disperse rapidly across country borders (cf. Carlsson and Stankiewicz 1991). In a globalised world with global value chains, this is of little surprise. However, when combining the TIS approach with a policy-focused analytic lens, as scholars have done concerning policy design (Edmondson, Rogge, and Kern 2020; Kern, Rogge, and Howlett 2019; Kivimaa and Kern 2016), setting a boundary that corresponds to national borders – and policy jurisdictions – becomes useful. Such boundary setting is by no means uncontested (cf. Binz, Truffer, and Coenen 2014; Heiberg, Binz, and Truffer 2020), as international influences can hardly be filtered or ignored. However, it is common practice to rely on national boundaries for TIS analyses (Coenen, Benneworth, and Truffer 2012) and for this study legitimate and useful (cf. Markard, Hekkert, and Jacobsson 2015).

Hence, TIS analyses focus on the innovation system as a whole, its sub-components, its actors, and the interdependencies between actors. These interdependencies are best portrayed as feedback loops that accelerate or slow the development of the innovation system. Systems with more robust feedback loops can generally be thought of as more sophisticated and further progressed, indicating that all functions are well established. Systems where this is not the case usually reveal weaker linkages between actors and weaker system loops. 'Blocking mechanisms' in the system can prevent the further growth or deepening of the system as a whole (Johnson and Jacobsson 2001). Simultaneously, causal links can emerge that induce, i.e. mutually catalyse, the system (Johnson and Jacobsson 2001). Feedback loops also change over time and shift, depending on additional contextual factors (cf. Pierson 2004; Pollitt 2008). Multiple TIS can also interlink (and in fact, this is the case for most TIS). It might be the case that interlinkages between different TIS are complementary, in competition, result in blocking mechanisms, or induce one another, e.g. TIS that share parts of a value chain. Similarly, TIS can interact and be in symbiosis, neutral towards each other, parasitic, in commensalism, or in amensalism (cf. Sandén and Hillman 2011), which can block or catalyse them.

The scope of TIS analyses may differ. Understanding the role of public sector organisations in the respective AV TIS and their impact on each system function requires an in-depth investigation of the TIS, on the one hand, and the public administration, on the other. To do so, the following section introduces the second foundation of the TIS+ framework.

2.2.2 Foundation II: Public-Administrative Elements

The second foundation on which the TIS+ framework builds – and what represents the 'plus' (+) to the TIS framework – draws on insights from the public policy and public administration scholarships (cf. Karo and Kattel 2015, 2016b, 2018b) as well as the political economy and institutional change literature (cf. Mahoney and Thelen 2010; Streeck and Thelen 2005). I introduce four 'public-administrative elements' that analyse the impact of public administrations on the innovation system. The analytic focus hereby is on their agency and role in the system when implementing policies and feeding back their experience to policymakers. These elements are 'centrality and leadership', 'capacity and independence', 'creative regulatory experimentation', and 'common goal-orientation'. They are mutually exclusive and commonly exhaustive, thus covering the entire span of characteristics and features that define a public agency's influence on the innovation system. While investigating public sector organisations in general, this analysis is particularly focused on executive and regulatory agencies that form part of the AV innovation systems.

2.2.2.1 Public-Administrative Element 1: Centrality and Leadership

Across policy design and implementation, and throughout the TIS, some actors are more central to the (innovation) network than others. Central actors feature relatively more connections to other network stakeholders, e.g. through joint projects, funding arrangements, an institutional arrangement, or other partnerships. Centrality is therefore related to the topology of the innovation network. Similarly, actors approach their role in the innovation system differently, as some take on a more leading and proactive role, whereas others might be followers and react to leading actors. The leading actors could be the network coordinators – or (purposefully or not) leave that role to another actor. The tasks of a leading actor are diverse. They include setting an agenda to which other actors in the network respond, distribute funds (which can come with obligations or responsibilities), or command and control other actors. It might be the case that the central actor is also the leading actor in the network. Any actor in the innovation network can be such a central actor. It might be, for example, that a purposefully created unit becomes most central or takes on a leading role. Concerning the TIS, central and/or leading actors can influence how the system develops. They can create, mitigate or resolve blocking mechanisms or can generate inducing mechanisms. The 'centrality and leadership' of actors can be observed through the following aspects:

- the existence of a relatively more central actor in the innovation network, i.e. an actor that is more connected to others than other actors in the network (this factor relies on network metrics as elaborated below in the methodology section; see network centrality),
- the extent to which actors are connected to the same or other types of actors (actor diversity), e.g. political, technical, research, etc.,
- the extent to which more central actors have agenda-setting powers and can shift the focus of the innovation system (or power, e.g. over other actors, in general),
- the extent to which central actors consider their impact and alter their preferences accordingly (depends on the existence of an institutionalised forum or interaction mechanism and on an actor's reputation),
- and the extent to which less connected actors in the network take up the recommendations or directions set by the more central actors.

2.2.2.2 Public-Administrative Element 2: Capacity and Independence

The implementation of policies is also defined by the 'capacity and independence' of public-administrative organisations – aspects in which agencies can differ enormously. Public sector organisations can be tasked to execute and deliver policies or to regulate products/processes. Executive agencies provide a service to citizens and operate in the public interest yet are responsible to the elected officials in the government. Agencies are usually attached to parent ministries or line ministries, i.e. the ministries to which they report, who are responsible for their work, and who ultimately mandate and fund the agency. The question arises how independent of this line ministry (or the government, generally) public agencies can make decisions? Do they operate under the direct and immediate supervision of the ministry or the government? Do they operate 'at arm's length'? Are they fully independent and operate based on discretion? At times, line ministries might attempt to control implementation or force it into a particular direction, limiting the freedom of the public agency. Similarly, public organisations differ in terms of capacity. This includes not only financial and human resources but also knowledge and experience in dealing with specific (policy) problems. Capacity also hinges on the organisation's position in the innovation system and its connectivity in the network. 'Capacity and independence' can be investigated by observing the following aspects:

- the type and specificity of mandates that agencies receive from the government and their ability to digress from these mandates,
- the budget allocation process and the flexibility or freedom how to spend this budget,
- the extent to which agencies interact with the government or industry actors, respectively,
- mechanisms that define how agencies report back to the government,
- the extent to which agencies actively pursue knowledge exchange between each other and also with other actors in the innovation system,
- and the extent to which agencies participate in other system events.

2.2.2.3 Public-Administrative Element 3: Creative Regulatory Experimentation

New and emerging technologies do not operate in a regulatory vacuum. Instead, stakeholders in the innovation system are embedded in regulatory regimes – may they be more or less directly related to the new technology of concern (cf. Ford 2017). The public administration has to implement existing regulation and can only implement current policies, which is the task of regulatory agencies (as opposed to executive agencies who deliver a particular public service). This also applies if a new technology falls outside the remit of a specific regulation – until policymakers change the regulation. (AVs, for instance, are regulated by policies that never foresaw a vehicle without a driver. For example, such regulations demand rear mirrors or windshield wipers, which an AV with cameras and sensors does not need.) It might be the case that regulations overlap, i.e. they cause confusion as to which regulatory regime manufacturers, users, or businesses have to adhere to (cf. 'overlap'). In other cases, it might be that technologies fall into regulatory gaps, falling in between existing regulatory domains (cf. 'underlap'). Overlap and underlap – and the associated uncertainties – create stumbling blocks for industry actors and innovation entrepreneurs and might contradict the goals established by governments (e.g. concerning sustainability or competitiveness).

Agencies that regulate[42] can 'experiment' with regulations to avoid constraints to innovation while at the same time maintaining regulatory standards concerning safety and security, the environment, or privacy. The legal framework permitting, regulatory agencies can devise 'creative solutions' to accommodate – possibly only temporarily – stakeholders' needs in an emerging innovation system (e.g. until the policymaker has rectified the situation). Such experiments can include, for example, temporary exemptions from regulatory obligations, policy labs, or regulatory sandboxes. 'Creative regulation' can shape the willingness of industry players to invest, develop, and test technological innovations. Experiments of this sort may lead to amendments of the law by policymakers. Public agencies might not in all policy areas allow for experimentation, however, which can then impact the further development of the TIS. The following aspects can be observed when investigating 'creative regulatory experimentation':

- the existence of policy labs or regulatory sandboxes,
- the extent to which governments and public agencies discuss creative solutions to regulatory challenges,

[42] This might also be an executive government agency tasked with regulatory responsibilities for a particular technology.

- the number of pilot projects that operate under regulatory exemptions,
- the extent to which organised initiatives promote regulatory change concerning a selected technology,
- the extent to which regulatory agencies and other actors in the innovation system exchange regulatory knowledge, e.g. ensuring that manufacturers are conscious of the legal framework and that regulators understand the technical specificities,
- and the existence of amended or new regulations as designed by policymakers.

2.2.2.4 Public-Administrative Element 4: Common Goal-Orientation

The orientation towards particular overarching goals in the innovation network provides a direction for the behaviour of system stakeholders. In mission-oriented innovation systems, this goal is equivalent to the mission (or a part thereof). However, different government organisations (and other actors in the system) might have opposing or unaligned goals, depending on the leadership, responsible policy area, or other constraints. The state is not a unitary actor. For example, goals might differ across ministries of coalition governments (and their agencies), where politicians of different parties control different ministries. Similarly, government agencies might compete for funds or power and, therefore, counteract another agency's efforts. In some cases, the policy objectives of two (or more) agencies might be misaligned, quasi by portfolio design, e.g. as observed in many countries across the environmental and the economics ministries[43]. Although agencies might generally be aligned along particular missions, their ideas about the process of how to achieve them could diverge. In such cases, public organisations create (unintended) externalities.

This public-administrative element explores whether a common goal exists and, if so, how it looks like, how it is designed and agreed upon, and how the existence of this goal shapes the behaviour, decisions, and preferences of actors.

[43] The economy and the environment can be aligned and coalesced to render both economic well-being and environmental sustainability – a conviction that many missions as designed by governments or international organisations today share. In fact, it is the purpose of some missions to coalesce the two (cf. Mazzucato 2021).

A common goal jointly decided and clearly communicated across government agencies creates a unified benchmark against which governance performance can be measured and justified. Such a common goal enables governance actors to interpret and evaluate policies more efficiently and allows for the correction of trajectories based on the common goal. The factors observed are:

- the existence of a common goal or mission based on a society's problems and/or commonly defined or accepted values,
- the presence of a (somewhat) institutionalised body or unit that usually formulates or represents the common goal based on the challenges in or necessities of the society,
- the extent to which the common goal is clearly communicated across the industry, policy design, and policy implementation actors, in particular, and society as a whole, in general,
- the existence of mechanisms that allow for the evaluation of the common goal, including information channels to actors in the policy design and implementation spheres that communicate the evaluation result,
- the existence of mechanisms that allow for reflection on both the common goal itself and the approaches taken to implement it,
- and the presence of the possibility to alter the common goal, depending on the impact of existing and implemented policies that are meant to help to achieve the goal.

2.2.2.5 Analysing Public-Administrative Elements

The four public-administrative elements described above capture the activity, capacity, dynamics, and goals of different public organisations in the innovation system. They show what responsibilities agencies take on, how they interact with each other and with other stakeholders in the system and reveal the mechanisms that different public agencies employ (the influence of various public agencies likely differs, which is why they are considered separately in this analysis rather than as a unitary state actor). The four public-administrative elements are summarised in Table 2.3.

Element	Definition	Operationalisation
E1 Centrality and leadership	'Centrality and leadership' refer to the extent to which government organisations are more or less central within the innovation network and the extent to which they exercise leadership over other actors in the system. It investigates how closely connected actors are within the innovation network and whether such centrality corresponds to an active leading role, e.g. through agenda setting, command and control mechanisms, oversight, initiative, funding arrangements, or coordinative activities. Leading and central actors, hence, might be the same but do not have to be.	• centrality in the network • type of relationship with other actors in the system • type of powers actors are endowed with • observed impact of actors • reputation/standing among actors in the system
E2 Capacity and independence	'Capacity and independence' indicate the extent to which government organisations can perform their tasks independently from the government and line ministries and the extent to which the agency has the capacity and capability to do so concerning financial and human resources and knowledge. This includes foresight activities and the flexibility to show discretion to and interpret policies according to their mandate. This applies primarily to executive agencies but also regulatory agencies.	• type of government mandate given to an agency • ability to apply discretion • agency budget and flexibility on spending it • report mechanisms back to the government • interaction arrangement between the agency and others in the system • inclusion of foresight activities
E3 Creative regulatory experimentation	'Creative regulatory experimentation' implies the extent to which a regulatory agency amends existing regulations, creates new regulation or grants (temporary) exemptions and the extent to which the regulator engages with those actors to be regulated. This includes fora for knowledge exchange and mutual learning, both technically and legally, among system stakeholders.	• existence of policy labs, regulatory sandboxes, or similar • approved exemptions from regulations • initiative to amend regulatory frameworks • knowledge exchange between actors about regulation
E4 Common goal-orientation	'Common goal-orientation' signifies the extent to which government organisations (but also other actors in the innovation system) pursue a jointly defined and commonly understood goal that can be achieved (at least in parts) through the implementation of a particular set of socio-technical innovations. The common goal usually represents a consensually designed and purpose-oriented overarching mission, posing as a benchmark regarding socio-economic impact.	• existence of a common goal or mission • articulation of the goal • existence of evaluation mechanisms for the goal • consensual reflection of the goal across actors

Table 2.3: public-administrative elements definitions and operationalisations

2.2.2.5.1 High, Medium, and Low Public-Administrative Influence

The combination of the four elements captures the influence of public agencies on the innovation system. The thesis investigates the impact of each public-administrative element on each TIS function in turn. The analysis highlights which aspects of the innovation system are affected by which part of the public administration and which problems they cause and/or resolve. It also shows how this influence materialises. Based on a 'more-or-less' analytical differentiation (Braun 2015), this influence can be classified as 'high', 'medium', or 'low'.

- 'High' impact (green) implies that the function has been directly and significantly shaped by the public administration, to the extent that without such action, the function would likely not have developed to benefit the advancement of the innovation system. This means that public agencies resolved blocking mechanisms or actively created inducing mechanisms to support the development of the innovation system.
- 'Medium' impact (yellow) signifies that the public administration had some influence on the development of the system function and that this impact was significant to the system's advancement. Yet, without the interference of public agencies, the system function could still have developed, although probably slower, less efficiently, and with less direction towards the common goal.
- 'Low' impact (red) indicates that the function was hardly or not at all influenced by the public administration. A change of behaviour or a lack of public agencies' attention to the respective function would not have altered the innovation system's development and the innovation as such.

This analytic step renders insights into the causal relationship between the role of public administrations and the development of the innovation system. This is useful for (at least) two reasons. As Bergek et al. (2008; 2008) point out, innovation systems can be slowed down or even disabled through mechanisms that prevent the development of individual system functions – so-called 'blocking mechanisms'. In turn, 'inducing mechanisms' can catalyse or enable a system function – and therefore, the entire innovation system (*ibid.*). By analysing the impact of public-administrative elements on system functions, this study shows how public organisations can (intentionally or not) create such blocking or inducing mechanisms in the system. Blocking mechanisms might exist, e.g. due to the predominant, inhibiting regulatory framework, which public agencies could resolve. Simultaneously, (in)action of the public administration might intensify bottlenecks and block further system progress. The second reason this analytic step proves helpful is that it allows us to distinguish which public organisation influences the system, if at all, and which interactions are essential to driving innovation forward. It might be the case, for instance, that a single organisation manages the key actors and actions in the innovation system, whereas in other cases, several organisations cooperate. Combined, the analysis renders Table 2.4, projecting the influence of public agencies on the TIS. Moreover, the analysis indirectly reveals which systemic feedback loops between system functions developed due to the (non-)intervention of public organisations. In sum, well established public-administrative elements support a high quality of TIS functions, and therefore, a well-functioning TIS.

Impact of PA elements … / **… on the TIS functions**	E1: centrality / leadership	E2: capacity / independ.	E3: creative regulatory experiment.	E4: common goal-orientation
F1: knowledge development/diffusion				
F2: entrepreneurial activity/experimentation				
F3: guidance of the search				
F4: market formation				
F5: resource mobilisation				
F6: legitimacy creation				
F7: positive externalities				

Table 2.4: public agency influence matrix template

2.2.3 Foundation III: Policy Coordination Analysis

The third foundation builds on the coordination scholarship within the public administration literature. Policy coordination emerges as the primary challenge in mission-oriented innovation systems. The policy coordination typology for public sector organisations suggested by Bouckaert, Peters, and Verhoest (2010) provides a useful analytic lens, especially to analyse policy arrangements as complex as innovation policy. This typology includes hierarchical, market-based, and network-oriented policy coordination modes (Bouckaert, Peters, and Verhoest 2010). The modes emerge from distinctions based on the purpose and base of interaction, the guidance, control and evaluation of government actions, the role of government as such, the resources needed, and the theoretical base (Bouckaert, Peters, and Verhoest 2010; Kaufmann, Majone, and Ostrom 1986; O'Toole 1997; Peters 1998b; Pierre 2001; Thompson 2003; Thompson et al. 1991). Note that these coordination modes are hardly ever employed in a 'pure' form and are instead often mixed, depending on the policy domain, the stakeholders involved, and the issue at stake. Some misalignments between coordination modes and policy instruments can, therefore, be expected. However, as Bouckaert et al. observe, dominant coordination modes shape the policy implementation practices across countries (*ibid*.). Accordingly, the purpose of this study is not to identify a dominant coordination mode per se but rather to detect shifts in coordination approaches – and their impact on the innovation system – in response to the complexities of mission-orientation and multi-technology innovation (systems).

2.2.3.1 Hierarchical Coordination

Hierarchical policy coordination (Figure 2.1) is based on the authority and the legitimacy to govern on absolute power, i.e. by "overcoming resistance to their expressed desires through the use of the law, budgets, and, if necessary, legitimate coercion" (Bouckaert, Peters, and Verhoest 2010, 37). The government uses top-down command and control mechanisms to direct actors in the system to achieve purposefully created targets, akin to the idea of Weberian bureaucracies (*ibid*.). The emphasis rests "on the division of labour [...] and on rules, procedures, and authority as coordination instruments" (Bouckaert, Peters, and Verhoest 2010, 36). Consequently, coordination between public organisations occurs quasi-automatically by virtue of the entire system being steered by the central government. Manifest coordination instruments in this mode include, but are not limited to, management tools such as strategic planning and evaluation, top-down management, input-oriented financial management, or procedures regarding consultation or review, but also reshuffling of command and control structures (Bouckaert, Peters, and Verhoest 2010, 52).

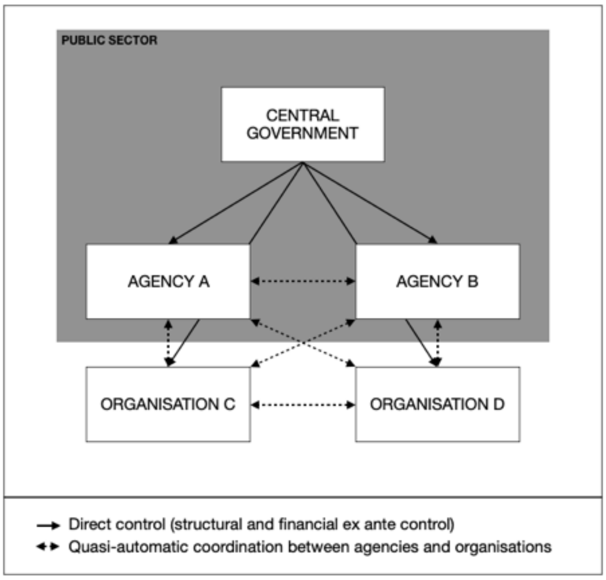

Figure 2.1: simplified schematic graph of hierarchical policy coordination[44]

As Figure 2.1 schematically shows, the government exerts direct control over all stakeholders in the system, such as through structural or financial means, which directly enable or disable organisations to act in a particular way. This includes non-public entities. They interact with each other in a similar, quasi-automatic way, controlled and coordinated by the central government through ex-ante measures. Spontaneous collaborations or any non-defined interaction is mostly absent. Feedback mechanisms, hence, operate directly to the government (if at all) through previously established channels, whereas there is hardly any room to develop novel, non-government supervised feedback loops, even if those might be necessary (cf. Bouckaert, Peters, and Verhoest 2010).

2.2.3.2 Market-Based Coordination

Market-based policy coordination (Figure 2.2) builds on neo-institutional economics. Interaction is structured along exchange and competition between

[44] adapted from Bouckaert, Peters, and Verhoest (2010, 40)

actors and is decided by information gains and relative power, as the 'invisible hand' would suggest (Bouckaert, Peters, and Verhoest 2010, 41). The government in this mode creates markets or, in case they already exist, protects and guides them by procuring goods or services from independent market players or by regulating and/or subsidising market activities (Karo and Kattel 2014). In this mode, supply and demand dynamics structure the interaction between actors, including government ministries and agencies. Manifest coordination instruments include financial budgeting and audit, results-oriented and incentive-based financing, as well as regulated markets and quasi-markets (Bouckaert, Peters, and Verhoest 2010, 52).

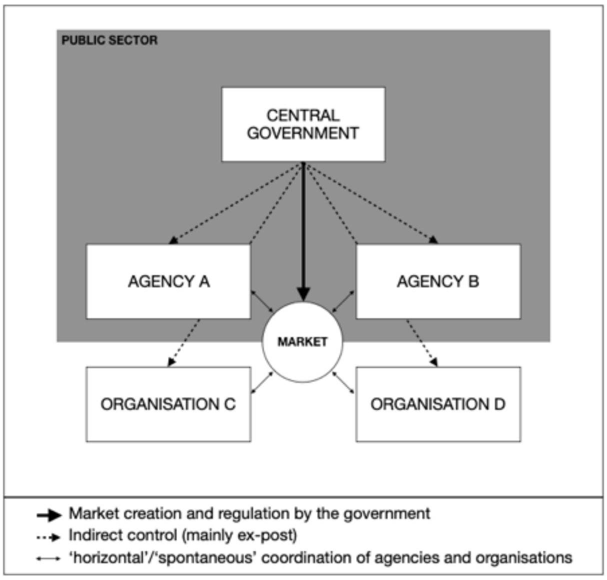

Figure 2.2: simplified schematic graph of market-based policy coordination[45]

As pictured in Figure 2.2, in this coordination mode, the government creates a market to implement a particular service or policy through which the other stakeholders, both public and non-public, then horizontally (and in parts spontaneously) coordinate, i.e. without permanent interference of the government. The central government can either actively participate in this market and/or operate as the regulator of that market (or mandate a government agency to do so). As the government designs the market, it can indirectly also decide about the participation and interaction in the market. Hence, the

[45] adapted from Bouckaert, Peters, and Verhoest (2010, 44)

government also controls the stakeholders that operate in the market. Because of this market-centric design, feedback loops emerge through the market, allowing the government to respond to changes in the market. Feedback loops beyond the market are unlikely (cf. Bouckaert, Peters, and Verhoest 2010).

2.2.3.3 Network-Oriented Coordination

Network-oriented policy coordination (Figure 2.3), in contrast, relies on cooperation, mutual co-optation, trust, and shared goals and values (Bouckaert, Peters, and Verhoest 2010, 44). This implies that collaboration depends mostly on voluntary behaviour and mutual solidarity among stakeholders (Börzel 1998; Kooiman 1993; Powell 1991). It is based on the main ideas of network theory. Networks are "(more or less) stable patterns of cooperative interaction between mutually dependent actors around specific issues of policy (or management)" (Bouckaert, Peters, and Verhoest 2010, 44). This refers to "groups of three or more legally autonomous organisations that work together to achieve not only their own goals but also a collective goal" (Provan and Kenis 2008, 231). Rather than on (market) power, coordination, depends on the legitimacy of actors, negotiation and bargaining, and possibly on mutual co-optation that creates interdependencies (Bouckaert, Peters, and Verhoest 2010). Consequently, coordination occurs through a network of actors, managed and controlled informally by the central government, whereas agencies and other organisations coordinate horizontally and spontaneously among each other (Peters 1998b). Coordination, therefore, relies on the common understanding of context and the issues at stake as well as shared value definitions for potential solutions (Kickert, Klijn, and Koppenjan 1997; Mintzberg 1979). Manifest coordination instruments are mainly structural, such as systems for information exchange, advisory bodies, collective and consensual decision-making, partner organisations, chain management, but also interactive strategic management, result-orientation, and mutual inter-organisational learning (Bouckaert, Peters, and Verhoest 2010, 52).

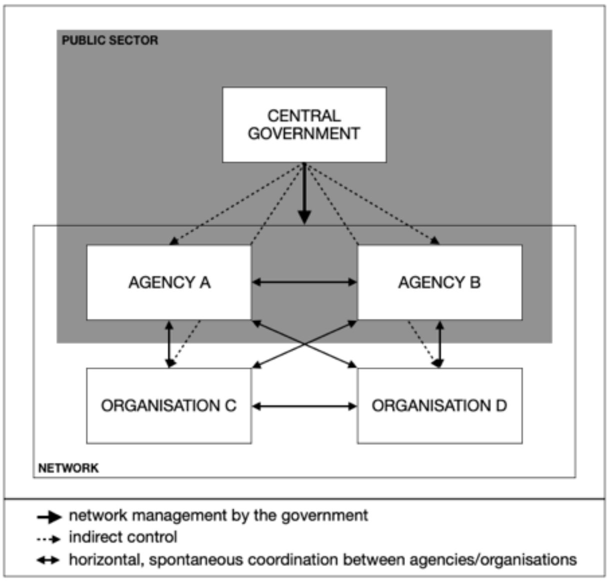

Figure 2.3: simplified graph of network-oriented policy coordination[46]

As Figure 2.3 depicts, the government, instead of controlling actors directly or through a market, creates a purpose-oriented network of public and non-public actors. They coordinate horizontally and spontaneously, on a needs basis, focused on a policy problem. The central government manages the network indirectly and, depending on the specific context and situation, enables the network to grow, allows or even creates new network participants, e.g. intermediaries[47], or supports the network through other means, e.g. financially. Hence, the network is not static and can change over time. Feedback mechanisms develop (spontaneously) within the network. They can reach the government directly or through public agencies, as the central government may be an active participant in the network as well. This means that feedback loops can emerge dynamically, if necessary, e.g. to evaluate or remove a blocking mechanism in the system (cf. Bouckaert, Peters, and Verhoest 2010).

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[46] adapted from Bouckaert, Peters, and Verhoest (2010, 49)

[47] Intermediaries are "actors and platforms that positively influence sustainability transition processes by linking actors and activities, and their related skills and resources, or by connecting transition visions and demands of networks of actors with existing regimes in order to create momentum for socio-technical system change, to create new collaborations within and across niche technologies, ideas and markets, and to disrupt dominant unsustainable socio-technical configurations" (Kivimaa, Boon, et al. 2019, 1072).

2.2.3.4 Analysing Policy Coordination

The typology of policy coordination renders three entirely different modes for interaction across public agencies, on the one hand, and between government organisations and other stakeholders in the innovation system (or the economy), on the other. Investigating a policy implementation system over a certain period regarding a particular policy challenge reveals the government's dominant coordination approach regarding this issue, the mechanisms at use, and the dynamics defining interaction. As mentioned, the TIS boundaries in this study correspond with national borders and policy jurisdictions. Therefore, by combining the analytic approaches, the public-administrative influence on innovation systems can be plotted against the dominant policy coordination mode in the country, answering the following insightful questions:

- Are particular public-administrative influences on the TIS pertaining to a specific policy coordination mode?
- How are the different innovation system functions affected by mode-specific coordination?
- How (if at all) do coordination approaches change over time and throughout the development and growth of the innovation system? Such changes might be a response to dynamics in the innovation system.
- How do changes in coordination patterns resolve blocking mechanisms and accelerate the innovation system's development as a whole?
- How do feedback loops look like that emerge between public agencies and other stakeholders in the system and among government organisations themselves? Notably, the latter shows how information from public agencies who implement policies can be recognised and passed on to their line ministries, and thus eventually to the policy designers.
- For comparative case studies[48] (either across countries, across technologies, across time, or a combination thereof): How do influences of public agencies on innovation systems compare?

[48] Such an analysis would have to follow a specific case selection justification, e.g. a 'most different but similar' system design, where the contexts of different cases varies, yet they still render the same (or a highly similar) outcome.

In sum, the coordination analysis reveals how different coordination modes[49] create a variety of influences and types of feedback mechanisms between policy implementation and policy design. Since the focus of this analytic approach is on innovation systems (where functions, actors, and outcomes interlink), the influence of the different coordination modes on the progress of the innovation system functions – and the innovation system as a whole – varies.

2.2.4 TIS+ in Practice

The TIS+ framework relies on three foundations: the TIS analysis (including a context analysis), the newly introduced public-administrative elements, and the policy coordination analysis. Combined, they render an analytic framework capable of investigating the influence of public sector organisations in innovation systems, detecting changes in coordination modes, and deducing the approach best apt to governing socio-technical innovation systems.

Accordingly, the TIS+ framework can be split into five steps. First, a politico-economic context analysis must define the overarching dynamics in the economy, the structural political arrangements, and the socio-technical trends in which the innovation system is embedded. This may include a network analysis. Second, based on these findings, a classic functional TIS analysis investigates the innovation system at stake, distinguishes the participating actors, and the sophistication with which the innovation system operates. Third, the analysis of the public administration detects the role of public agencies in the system. By evaluating every public-administrative element against each system function, the influence can be derived in detail throughout the innovation system. Fourth, the policy coordination analysis investigates if changes to policy coordination have resolved blocking and/or triggered inducing mechanisms and states which approach is best apt to catering the needs of the innovation system at stake, e.g. of a multi-technology innovation. Fifth, and lastly, the insights can be compared against findings from other countries, technologies, or over time (Table 2.5).

[49] Throughout this thesis the terms 'hierarchical', 'market-based', and 'network-oriented' will be used to refer to these policy coordination modes and to denote the associated characteristics as outlined in this chapter, even if not specified through inverted commas or citations, always referring to Bouckaert, Peters, and Verhoest (2010).

Step	Process	Goal
I	politico-administrative context analysis: using the country as the boundary of the TIS, the context analysis highlights competing/synergetic technologies, the wider sectoral context, defining geographical and political features, and macroeconomic aspects	reveals the context into which the innovation system is embedded and the contextual factors that shape the system and system actors
II	functional technological innovation system analysis: along the functions 'knowledge development/diffusion', 'entrepreneurial activity', 'guidance of the search', 'market formation', 'resource mobilisation', 'legitimacy creation', and 'positive externalities', and taking into account the previous context analysis	reveals the sophistication of the innovation system, outlines its components, actors, and their interaction, shows blocking/inducing mechanisms, indicates feedback loops between functions
III	public-administrative analysis: based on the elements 'centrality and leadership', 'capacity and independence', 'regulatory experimentation', and 'common goal-orientation'; analysing the impact of each administrative element on each TIS system function in turn	reveals how policy is implemented and thus shows the public administration's influence on the innovation system, including on creating/resolving blocking and inducing mechanisms, and highlights the dominant/ central public agencies in the system
IV	policy coordination analysis: relying on the hierarchical, market-based, and network-oriented coordination modes, investigating for practices that adhere to the dominant or alternative coordination modes, especially around challenges emanating from the TIS and associated policies	reveals possible changes of coordination modes and feedback mechanisms, thus explains changes in the interaction of stakeholders linking policy design and implementation, also shows how the various coordination modes affect the TIS in different ways
V	comparison across cases (not for single cases): contrasts trends across jurisdictions or different TIS, possibly featuring different (dominant) coordination arrangements, influences of public agencies on innovation systems, shifts in coordination patterns and influences, approaches to resolving blocking mechanisms, and measures to catalyse inducing mechanisms	reveals similarities or differences across countries or technologies, across countries with diverse mission-oriented policy arrangements, within countries, or across time (depending on the level of analysis)

Table 2.5: 5-step analysis of the TIS+ model (summary)

2.3 Research Design and Methodology

2.3.1 Case Selection

Investigating the public-administrative influence on innovation systems as complex as that of AVs requires a sound understanding of the system's context. This means that any research has to provide the necessary depth to account for political, economic, and social factors that shape both the innovation system and the public administration. Case study research is most apt to deliver these insights (Eisenhardt 1989; Gerring 2004, 2006), as it "can 'close in' on real-life situations and test views directly in relation to phenomena as they unfold in practice" (Flyvbjerg 2006, 235). In this sense, the case study approach and the strategically reflected selection of the cases (Ragin 1992) can support the formation of hypotheses and the building of theories (cf. Flyvbjerg 2006), as is the objective of this predominantly inductive study. Case study research serves particularly well to answer 'how' questions and building a theory thereupon, as in this thesis (Gehman et al. 2018). In other words, when investigating mission-oriented, complex innovation systems, the 'backstage' of the system must be investigated as well, such as the role of public administrations – just as walking through the side streets of London is an essential part of understanding the complexity of the city, which could not be gained by solely visiting the most commonly known sights and attractions (Wittgenstein as quoted in Flyvbjerg 2006). Only case study research provides for the time, scope, and sophistication to figuratively walk the 'back streets' of a complex research question (cf. Labov and Waletzky 1997).

A comparative analysis of the same technology across cases (i.e. countries) can yield beneficial insights about the differences of governance and coordination of/in innovation systems (cf. Sovacool, Axsen, and Sorrell 2018). As outlined above, this thesis focuses on shared, electric, connected AVs as a prime example of multi-technology innovation that emerged from mission-oriented policies. This approach is more valuable than comparing multiple technologies across different countries as the innovation system, the relevant actors, and their interactions would have differed such that a rigorous comparison of public-administrative influences would not have been possible[50] (cf. Peters 1998a). The focus on specific characteristics of cases, technologies, and mechanisms (cf. Flyvbjerg 2006) still allows generalisations regarding governance arrangements for complex technologies. Case studies, after all, "are about something larger than the case itself, even if the resulting generalization is issued in a tentative fashion" (Gerring as quoted in Seawright and Gerring 2008, 294).

[50] A comparative research design focusing on different technologies in one country might yield other insightful conclusions in future studies (cf. section 7.6).

Innovation-related policies and public-administrative practices are usually tied to national borders, rendering country cases the natural study objects for policy analyses. The case selection followed the rationale “to maximize the utility of information from small samples and single cases”, which means that “cases are selected on the basis of expectations about their information content” (Flyvbjerg 2006, 230). Singapore, Estonia, and Sweden fit specific categories to render the most valuable insights possible. They represent highly developed and thriving economies that consistently emerge on top of international innovation rankings (e.g. by the World Economic Forum, INSEAD and the World Intellectual Property Organisation, Bloomberg, or the European Commission)[51] – see below. All three countries formulated missions to achieve sustainable, efficient, and smart public transport solutions in their urban centres. A technology employed to this end are shared AVs, which emerged in all three countries. At the same time, the three countries differ significantly in many other factors. First and foremost, they employ different dominant policy coordination modes. Whereas Singapore follows a mostly hierarchical approach, Estonia’s public administration is primarily market-based, and Sweden established a dominantly network-oriented mode to coordinate activities throughout the public sector. The politico-economic contexts also differ across these countries, including the industrial preconditions regarding vehicle manufacturing and political structures and responsibilities. Altogether, the selection of cases shows significant variation and represents a ‘most different but similar’ research design: The conditions across the countries differ starkly, yet the outcome – a successfully developed AV innovation system – is similar (cf. Seawright and Gerring 2008). Table 2.6 captures the main characteristics and selection criteria for the three case studies.

[51] This type of innovation, competitiveness, complexity, or readiness rankings are not unproblematic. First, definitions and assumptions about ‘innovation’ and innovation-related practices vary across indices. Second, authors employ different methodologies to measure (proxies for) ‘innovation’. This explains the different ranks for countries across indices. Third, the purposes of studies vary, depending on funders and overarching goals. Hence, such indices should not be the sole foundation of or blueprint for policymaking and implementation. The indices are included here to show that the selected cases are outstanding performers across rankings, regardless of the specific methodologies, preferences, or assumptions used. The rankings reveal that the selected cases are generally equipped to cope with complex innovation systems, e.g. AVs.

	Singapore	Estonia	Sweden
Governance structure	single-tier, centralised	multi-level, semi-centralised	multi-level, de-centralised
Current government	centre-right, single party government	centre-right, multi-party coalition government	centre-left/green two-party minority coalition
Policy coordination	hierarchical	market-based	network-oriented
AV industrial prerequisite	relatively weak, no multinational vehicle manufacturer, primarily tier 2 and 3 suppliers	relatively weak, no multinational vehicle manufacturer, no large motor-vehicle supply industry	relatively strong, strong multinational vehicle manufacturers
Gross R&D expenditure	high (1.9% of GDP)	high (1.6% of GDP)	very high (3.4% of GDP)
Business enterprise R&D	medium (1.1% of GDP)	medium (0.9% of GDP)	high (2.4% of GDP)
Innovation agency	no	yes (Enterprise Estonia)	yes (Vinnova)
Population and density	5.7 million, 7953 people/km^2	1.3 million, 30 people/km^2	10.3 million, 25 people/km^2
Geographical context	small land area, single large agglomeration	small land area, concentrated dwelling in two cities, otherwise dispersed	large land area, widely dispersed, not very dense, multiple agglomerations
Dominant challenge	traffic congestion, economic strength, strive for innovativeness, transport system reliability/accessibility	economic development, environmental sustainability, strive for innovativeness	societal welfare and well-being, environmental sustainability, economic strength
Focus mission	efficient, smart, and sustainable urban transport solutions and make Singapore into a smart nation	sustainable transport solutions with modern business models and become an AV testing hub	sustainable mobility solution to make cities more liveable
Technology	shared AV minibuses for first/last mile connectivity to the transport network	shared AV minibuses for first/last mile connectivity to the transport network, also smaller cargo delivery AV	shared AV minibuses for first/last mile connectivity to the transport network, also individual AVs and larger AV buses
Impact	introduction of autonomous minibuses serving specific (sub-urban) areas, university campuses, and tourist sites; testing of truck platooning	introduction of autonomous minibuses in Tallinn's city centre (for testing); invention of AV shuttle bus; mini cargo delivery robots	introduction of self-driving shuttles and buses incorporated into public transport systems; testing of truck platooning and privately-owned AVs

Table 2.6: case study selection characteristics and preliminary observations[52]

[52] Information and data refer to the most current available and is sourced from the OECD (2021), the World Bank (2021), and the Government of Singapore (GovTech Singapore 2021).

2.3.2 Data Collection

Other than through the review of the literature (cf. Gough, Oliver, and Thomas 2012), policy documents (cf. Burnham et al. 2004), and secondary resources, the majority of primary data collection occurred through semi-structured elite and expert interviews (cf. Burnham et al. 2004; Kaiser 2014), for three reasons: First, policy design and implementation offer relatively little scope for quantitative measurements. Similarly, many operationalised TIS parameters cannot be (adequately) measured by quantitative data, especially at this early stage of the TIS. The processes and mechanisms in government organisations forming part of the 'outcome phase' and features pertaining to system functions such as the 'guidance of the search' or 'legitimacy creation' are best understood by collecting qualitative, case-specific information from individuals directly involved. This is especially the case for emerging TIS, where no ample variety of data sources are available (yet). Second, emerging TIS depend heavily on the context in which they are embedded. To account for this context, small n studies of individual cases are more feasible and provide a more sophisticated understanding of the underlying complexities of each innovation system. Semi-structured interviews can cover a relatively large variety of participants while at the same time giving each participant the room to express context-dependent characteristics of the innovation system. Third, the semi-structured approach to conducting interviews allows for coherence across interviews based on the chosen analytic framework (TIS+). Besides, it provides the flexibility to adjust the question catalogue if needed, responding to participants' answers and verifying information gathered in other interviews (triangulation). This approach, thus, accounts for the complexity inherent to socio-technical innovation systems.

Meticulous care has been taken to select interviewees from every functional stage in the TIS, including central government (policymakers), executive and regulatory agencies, innovation organisations or partnerships, industry incumbents, niche innovators, research organisations, intermediaries, topic experts, and others. I invited potential interviewees by email or in person. To obtain information about additional potential participants, I relied on the 'snowballing' technique, asking interviewees if they could suggest anyone else I should talk to regarding this topic (cf. Biernacki and Waldorf 1981; Savaget et al.

2019). This tactic ensured that the range of participants covers representatives from every type of organisation involved in the innovation system at least twice (to enable triangulation of information). In addition, I contacted potential interviewees at meetings, conferences, and workshops that I attended (see appendix). In sum, between February 2019 and May 2020, I conducted 43 semi-structured interviews with a duration of 35-105 min each, the details about which can be found in the appendix.

Upon arranging a date and receiving (written) consent from participants, interviews were held via video calls, phone, or in person[53]. I designed the interview questions based on the TIS functions, the public-administrative elements, and the coordination modes, as the TIS+ framework suggests. The interview followed an 'hourglass tactic' (cf. Dipboye 1994), asking general questions first, following up regarding specific details later on, and ending with open-ended questions. After an 'ice breaker' question about the interviewees' role in their organisation, the first questions tackled the country's innovation system, in general, and the structural aspects that define the AV TIS, in particular. This allowed me to understand overarching dynamics and to gain insights into specific arrangements and mechanisms in the innovation system. The second (main) set of questions focused on the detailed, operationalised parameters of the TIS functions and public-administrative elements (see appendix). During this phase, I also posed questions to cross-reference previous responses about the innovation system. The third and final question set opened up the conversation, referring to previously stated answers, the general goals of implementing AVs, and a future outlook. This last round also allowed for additional triangulation, especially regarding contradicting or unclear responses. Before concluding the interview, I allowed time for any questions by the participants and reaffirmed their consent to use the data provided. Additional questions and minor deviations from the prepared structure allowed grasping previously unknown details. This could be iteratively included as new questions in the following interviews (another 'snowballing' effect) (cf. Kaiser 2014).

[53] I conducted most interviews via video calls. In addition, I attended workshops, conferences, and other events in person (or online, due to the SARS-COV-19 global pandemic; see appendix).

Most interviews were recorded (upon consent) and transcribed, highlighting the most important sections and critical information (transcripts are available upon request). I stored, coded, managed, and analysed the transcripts using the *Nvivo12* software package, building the basis for the empirical chapters of this thesis. All practices, including the recruitment of interview participants and data storage, conformed to the standard ethics and data protection practices at UCL as filed under the research project ethics identification number 12597/003.

2.3.3 Quantitative Data Analysis

Networks are among the most comprehensible ways to investigate and visualise innovation systems. Since this study's primary focus is on coordination mechanisms employed across innovation networks and since the first public-administrative element assesses the centrality of public agencies in the innovation system, a network analysis proves essential. This also serves as a complementary tool to understand the innovation system of each case study.

Networks are defined by the composition of actors, their interaction, and their interaction quality (see above). Network nodes represent actors in the innovation system and refer to organisations rather than individuals, including:

- government actors (prime minister offices, ministries, etc.),
- government agencies (executive and regulatory agencies, etc.),
- industry actors (incumbent firms, niche innovators, suppliers, etc.),
- research organisations (research institutes, universities, etc.),
- intermediaries or hybrid organisations,
- and other, non-defined actors.

The entry points for the network analysis (nodes and edges) were collected over time through desk-based research (official documents, statements, observations, websites, secondary literature, news media, etc.). They were complemented through information gathered in semi-structured interviews. Two nodes are connected through an edge if they work on (collaborate) on the same project/innovation in any form and demonstrate any one or multiple of the following processes:

- the institutionalised flow of information/knowledge intended for the project/innovation,
- the flow of funds intended for the project/innovation,
- or a directive/order specifying how the respective actor ought to behave.

The network analysis describes these relationships between actors and studies the individual actors' distribution across the network, their connection with other actors, the segmentation of actors across the network, and the influence of actors within the network. This analysis relies on the commonly used metrics in (social) network analyses (cf. Carrington, Scott, and Wassermann 2005; L. C. Freeman, White, and Romney 1992; Wassermann and Faust 1994):

- *degree centrality* measures distribution and refers to the number of links per node, distinguishing the most and least connected nodes (cf. Sharma and Surolia 2013),
- *betweenness centrality* describes the extent to which a node is in-between other nodes, measuring the frequency of a node bridging the shortest path between other nodes (cf. Charles Perez and Germon 2016),
- *closeness centrality* defines the average shortest distance between nodes and captures how close any two nodes in a network are (cf. Golbeck 2013),
- *eigenvector centrality* reveals the influence of a node in the network based on the amount of connections to other highly connected and important nodes (cf. Hansen et al. 2020),
- and *hubs* identify nodes with significantly higher node connectivity than other nodes and to some extent aggregate centrality measures (cf. Albert and Barabási 2002).

Note that rather than providing a comprehensive network analysis, the study only analysis non-directional relations that highlight the scope of AV innovation networks in the case studies. Stored in a *Microsoft Excel* file, the data was then analysed and visualised using the *Gephi* software. The visual representation of the network's spatial distribution is based on the 'Force Atlas 2' continuous layout algorithm, a linear-attraction linear-repulsion model with few approximations, as rendered in *Gephi* (cf. Heymann 2015; Jacomy et al. 2014). The network visualisations depict unweighted edges (connections) only. The connections have additionally been confirmed through qualitative research.

2.3.4 Qualitative Data Analysis

This study's findings rely on data gathered through network analyses, semi-structured interviews, events, policy documents, secondary literature, and a substantial amount of desk-based background research. To ascertain the accuracy and validity of this information, i.e. the correct interpretation of results (cf. Alvesson and Sköldberg 2018; Sovacool, Axsen, and Sorrell 2018, 22), I additionally employed an iterative triangulation method. This means gathering data on the same topic from multiple sources and points of view using a variety of methods to increase their overall validity (D. T. Campbell and Fiskel 1959; Denzin 1970; Webb et al. 1966) and to "overcome the weakness of intrinsic biases" (Yeasmin and Rahman 2012, 157). This renders a complete picture of the AV innovation systems – as complete as possible. I began by cross-comparing the data gathered in different interviews. I then compared the interview findings with information in policy documents, media reports, and secondary literature. In case of conflicting information, I attempted the verification by interview partners ('cross-checking') or sought alternative fact-checking forms, e.g. through desk-based research. Therefore, triangulation was iteratively ongoing throughout the research process. For example, this meant that when necessary, I contacted interviewees again to verify information found elsewhere. Hence, for all the data used in this study, I gathered multiple entry points.

Although triangulation is helpful in this respect, Yeasmin and Rahman argue that it "is not an end in itself and not simply a fine-tuning of the research instruments. Rather, it can stimulate to define better and analyse problems in social contexts" (2012, 160). In other words, triangulation is more than a complementing feature to other methods, but rather a method in itself, as it increases the likelihood that researchers fully comprehend social phenomena or issues at stake. Triangulation opens up topics and allows for new questions to be asked, connects data points that previously appeared separated, and spans across epistemological and ontological fringes to open new opportunities for the researcher. Hence, the combination of primarily qualitative and some quantitative methods (the network analysis), paired with triangulation, allowed for a complementary methodological toolbox to broaden and deepen the understanding of the research topic (*ibid.*). It allowed me to build up a rigorous and holistic data portfolio with heightened confidence where the data inputs from different sources converged to improve their internal consistency, enhance the generalisability of the conclusions, and most adequately represent the real world (Jakob as cited in Yeasmin and Rahman 2012, 154).

In conjunction with the triangulation approach, the process-tracing method provides rigour and detail to the analysis (Mahoney 2015; Tansey 2007). Process-tracing enables researchers "to uncover evidence of causal mechanisms at work or to explain outcomes" (George and Bennett 2005, 9), which is the goal of this study concerning the influence of public agencies on innovation systems. This is particularly helpful to ensure near completeness and validity of the data. When tracing processes, gaps in the data become evident and allow follow ups, either through additional interviews, document analysis, or desk-based research. It captures the entire process before conclusions are drawn. In addition, process-tracing exhibits linkages between causes and effects – necessary insights to build a theory or to confirm existing ones (cf. Beach and Pedersen 2019; George and Bennett 2005). Hence, triangulation and process-tracing – and the quantitative analysis – synergetically complement each other, ensuring as complete an understanding of the causalities in the innovation system as possible.

2.4 Limitations

2.4.1 Research Design Limitations

The case study selection comprises three cases where the AV innovation system developed into more or less stable and sophisticated systems (although they are emerging systems, still). It does not include a case where the coordination of this multi-technology example failed and where the system did not develop (there is no 'null case'). Likewise, there is no case where none of the predominant policy coordination modes applies, because to the author's best knowledge, such a case does not exist. Although we could learn from failed cases as well (cf. Flyvbjerg 2006), the objective of this study is to learn from cases where the coordination challenges were resolved and from which we can derive meaningful (policy) recommendations for future cases of similar multi-technology innovations ('best practice'). Besides, by introducing the TIS+

framework, the research project provides an analytic tool that incorporates the role of public administrations in innovation system research. A null case would not have complemented this framework with a significant additional perspective.

The comparative approach with three case studies allows for in-depth analysis of a small n of cases for a specific technology (cf. Peters 1998a). However, the generalisability of such individual case studies is often considered limited (cf. DellaPorta and Keating 2008; Mingers 2006; Sovacool, Axsen, and Sorrell 2018). Nonetheless, the research question's complexity and the investigated technology required an in-depth research focus, which only case study research can provide. As William Beveridge noted, “more discoveries have arisen from intense observation than from statistics applied to large groups” (as quoted in Kuper and Kuper 1985, 95). Still, the comparative design paired with the analytic, primarily qualitative approach and the endeavour of theory development (i.e. extension) allows for some generalisations. This means the study can provide an essential and insightful contribution to the scholarship and practitioners alike (cf. Flyvbjerg 2006; Vennesson 2008), especially in the investigated context of complex, socio-technical innovation systems and the influence of public administration thereupon. Quite likely, examining and comparing the same technology in other countries would add to the validity of the proposed conclusions. Likewise, exploring whether the same or similar observations can be made for other multi-technology solutions would contribute to our knowledge of governing such complex socio-technical innovations further and would strengthen the generalisability of the findings in this thesis. I encourage fellow researcher to undertake such analyses in the future (cf. Chapter 7).

Case selections can be prone to bias, particularly confirmation (interviewer) bias and biases towards the research data revealing desirable outcomes (cf. King, Keohane, and Verba 1994; Peters 1998a; Sovacool, Axsen, and Sorrell 2018). However, the in-depth case study approach paired with the triangulated data collection helps to prevent such biases. The awareness of possible bias can help to reflect consciously on information and question whether causal links could be over-interpreted or caused by other variables (Vennesson 2008). Reflecting on counterfactuals (S. Weber 1996) and alternative theoretical approaches can help in this regard (George and Bennett 2005, 105).

2.4.2 Conceptual Limitations

Although the systems logic was chosen deliberately to understand the interdependencies between stakeholders and their impact on other actors and relationships, systems thinking also has limitations. First, systems hardly capture all underlying dynamics in which the participating actors are embedded. Several scholars have indicated that systems research should thoroughly consider the context of (innovation) systems (Anna Bergek et al. 2015). Through the longitudinal analysis in Chapter 3 and the politico-economic context analyses in the empirical chapters, I attempt to rectify the difficulties emerging from this challenge. Nonetheless, openings remain which could not be covered in the scope of this thesis. This step also contributes to addressing the second conceptual limitation: The 'social construction' of technology, as scholars in the field of 'social studies of technology' and 'science and technology studies' would argue (cf. Bijker, Hughes, and Pinch 2012b), remains under-represented in the systems approach. Yet, systems do capture some social dynamics through specific system actors or relationships between them, as "social processes involved in technological development [respect] the seamless web character of technology and society" (Bijker, Hughes, and Pinch 2012a, 4). In addition to the context and longitudinal analyses, the way in which the public-administrative elements are structured and derived helps to account for these underlying social dynamics (see Chapter 3).

2.4.3 Methodological Limitations

Parts of the framework used in this study relies on (social) network analyses. The process of defining nodes and edges in this network has been outlined above. Still, this comes with a trade-off: Since this study's focus is on public administrations and their influence on innovation systems, the network does not include individuals, even though some individuals (e.g. in Estonia) have been very influential in the innovation system. Simultaneously, while most nodes represent organisations, some also reflect specific AV focused projects or initiatives, which, although institutionalised, are technically not organisations. These have been included as they proved central in the innovation network for the respective case study. Overall, there are limitations concerning the structure of the innovation network. These have been (partially) set off by highlighting each node's specific role clearly in the qualitative analysis of each case. Where individuals have been highly influential, for instance, the organisations they represent have been linked in the network, whereas the individual impact has been highlighted throughout the TIS, public-administrative, and the coordination analyses. Where projects or initiatives have been labelled as network nodes due to their prominence, they have been directly linked to their parent organisation, and this relationship has been evaluated thoroughly. Combined, this process sufficiently justifies the node selections.

Due to the nature of global comparative case study analyses and the resulting language barriers, some resources relevant to this study featured only in Swedish or Estonian. Although relatively good translation software exists, which I used to translate some policy documents, websites, or other sources, it cannot be ascertained that all information was captured in detail and entirely correctly. Whenever possible, I conducted interviews in English or German and relied on policy documents published in English. However, as I have observed, the English translations of official documents provided by the Swedish or Estonian authorities at times only contain an abbreviated version, summaries, or abstracts of the relevant documents. In these cases, in addition to the English document, I reverted to using translation software (i.e. Google Translate) for the original and used a triangulation approach to ascertain the correctness of the data.

Furthermore, innovation policy, especially the underlying technology-specific, entrepreneurial, or funding arrangements, are often considered a competitive advantage by government officials or industry representatives. Especially regarding national innovation strategies or industrial responses to innovation policies, the openness of officials or representatives was at times limited, and information was only reluctantly shared, if at all. This was particularly the case in Singapore, where receiving permission to interview officials was difficult. Cultural aspects perpetuate this challenge. Singapore, for example, considers itself an innovation nation (SG01), outlining the goal to compete against other, similar economies in the region and across the globe and surpassing them in innovativeness and economic growth based on technological innovations.

Combined with a relatively stable, single-party governance system that enforces strict limitations on access to information for non-government officials, officers' readiness in Singaporean ministries or agencies to answer questions, or be available for an interview at all, was limited. For this reason, the process of gathering data in Singapore has taken more time and forced me a) to rely on more junior officers and b) to accept a certain limitation of information. Although all care has been taken to fill the emerged knowledge gaps with information collected through other resources, such as conversations with non-government interviewees, e.g. academics, and utilizing triangulation, some gaps might remain. In case this fact created a hurdle during the data analysis process, or if this inhibited me from deriving meaningful conclusions about a particular process, this is highlighted in the respective chapters. Overall, however, I am confident that the findings of the Singapore case study nonetheless led to insightful and meaningful conclusions.

2.5 Conclusion

This chapter outlined the conceptual and theoretical underpinnings as well as the methodological approaches of this research project. The conceptual basis rests on the systems logic, as the interaction between stakeholders concerning socio-technical innovation and its governance is best captured through a systemic lens. The systems logic manifests itself in the analytic framework that builds on three foundations: First, the TIS approach creates a sophisticated understanding of the innovation system's status and the AV technology. This includes the sound analysis of the political and economic context in which the innovation system is embedded. Second, the introduction of public-administrative elements captures the actual influence of specific public sector organisations on each system function. This novel contribution to the TIS concept links the public administration with the innovation system scholarship. It addresses directly the agency of government organisations in innovation systems that drives innovation (cf. Farla et al. 2012; Kern 2015). Third, the policy coordination analysis based on the hierarchical, market-based, and network-oriented coordination modes reveals changes in coordination approaches as a response to blocking mechanisms that emerged within the innovation system. Combined, the three foundations form the 'TIS+' analytic framework to analyse the development of (multi-technology and socio-technical) innovation in the context of mission-oriented innovation policy – and will be used throughout this thesis.

3 Coordinating Innovation Policy: A Longitudinal Perspective

3.1 Introduction

Implementing 'innovation policy' has proven to be a challenge for governments throughout time (cf. Christopher Freeman 1995; Carlota Perez 2004, 2009; Reinert 2020). Likewise, policy coordination challenges are not new to public administration scholars. This chapter, therefore, analyses how approaches to policy coordination have shaped innovation and innovation policy over time and reveals how innovation policy has been coordinated in the past.

The chapter provides this longitudinal perspective as the foundation for bridging policy implementation and coordination analyses (Bouckaert, Peters, and Verhoest 2010; Karo and Kattel 2010a; Peters 1998b, 2015a, 2018c) with the innovation scholarship (A. Bergek et al. 2008; Anna Bergek et al. 2008; Carlsson and Stankiewicz 1991; Hekkert et al. 2007) – a gap in the literature that this thesis fills conceptually and empirically. The former focuses primarily on administrative practices, policy implementation, and the capacity of the public sector (cf. North 1998; Peters 2019; Radaelli, Dente, and Dossi 2012). "The fact that rules are not just designed but also have to be applied and enforced, often by actors other than the designers, opens up space […] for change to occur in a rule's implementation or enactment" (Mahoney and Thelen 2010, 13). Public organisation, thus, can impact institutions and propel institutional change – which might include themselves (cf. Thelen 2009).

Innovation studies concentrate on feedback loops between actors and their impact, on the influence of specific stakeholders, and on the actual development of technologies (cf. Rosenbloom, Meadowcroft, and Cashore 2019). 'Middle range theories' based on historical institutionalism consider the institutional impact of politico-economic contexts, (political) regimes, and socio-technical innovations over time (cf. e.g. Geels 2002a; Geels and Schot 2007; Turnheim et al. 2015). Similarly, system analyses employ institutional analyses to address the emergence of feedback mechanisms or endogenous and exogenous shocks (cf. e.g. Anna Bergek et al. 2008; Hekkert et al. 2007).

However, none of these dynamics occur in separation. Technology, innovation systems, industrial structures, and institutional change have been closely aligned through the school of thought of evolutionary economics (cf. Abernathy and Utterback 1978; Nelson 1994; Nelson and Nelson 2002). Institutional arrangements embed and define innovation system interdependencies, administrative practices, and public sector organisations (cf. Meadowcroft 2009, 2011; Scrase and Smith 2009). Institutional change can accelerate or slow down dynamics in innovation systems (cf. Anna Bergek et al. 2015; Meadowcroft 2005; Roberts and Geels 2019; A. Smith, Stirling, and Berkhout 2005). Hence, analysing innovation systems without considering the institutional framework in which they are set misses an analytic layer (Meadowcroft 2009, 2011; Scrase and Smith 2009). It is not just policy but also politics and polity (and their activities) that define the institutional arrangements in which innovations occur (cf. Lockwood et al. 2017). "Actors, such as the bureaucracy and the judiciary, charged with implementation, interpretation, and enforcement, have large roles to play in shaping institutional evolution" (Mahoney and Thelen 2010, 13–14), also concerning innovation. "The process of replacing policy ideas then is not dissimilar to the conception that Kuhn (1962) advanced concerning the replacement of scientific paradigms" (Peters, Pierre, and King 2005, 1276). Understanding the institutional embedding of innovation policy and the change or continuity thereof, thus, is paramount to analyse policy coordination.

As established in Chapter 2, the three patterns that capture the principal approaches to coordinating policies are the hierarchical, market-based, and network-oriented modes (cf. Bouckaert, Peters, and Verhoest 2010). They characterise different ways to align policy implementation and design with the purpose and intention of a policy. The hierarchical coordination mode allows the central government to direct actors based on its monopoly of authority and power. Coordination, therefore, occurs top-down. The market-based mode views the government as a market creator or protector based on market-liberal and neo-classical principles. Coordination occurs through that market. The network-oriented mode bases coordination on consensus and trust, as the government enables and manages the network and collaborates with stakeholders. Coordination occurs through that network. As mentioned above, although coordination modes are hardly ever implemented in a 'pure' manner, usually a dominant mode can be identified. This thesis is interested in the transitions from one coordination mode to another, its triggers, and its impact with respect to innovation policy and the advancement of innovation systems.

Approaches to governing innovation, including policy coordination, incrementally evolve (cf. Carlota Perez 2004, 2009). "Change typically consists of marginal adjustments to the complex of rules, norms, and enforcement that constitute the institutional framework" (North 1990, 83). To detect these incremental developments, this chapter provides a longitudinal institutional change analysis of coordination approaches in the context of innovation policy and its implementation. This analysis identifies the points, triggers, and institutional change processes regarding innovation policy, highlights the relevant actors, and emphasises the structural aspects that broadly shaped policy implementation. As any singular institutional change analytic approach would be reductionist and would not do justice to the complexity of this topic, this chapter includes actor-specific, structural, and historical perspectives, building on the complementarity of these approaches (cf. Wegrich 2001).

Institutional dynamics have shaped policy coordination over time. The key elements that emerge from this institutional analysis – power or centrality to lead, capacity and capability to act, legitimacy to enact administrative discretion, and value-driven goal-orientation – are mirrored in the TIS+ analytic framework of this thesis as 'public-administrative elements'. They define institutional change within the TIS, depict the influence of public organisations on innovation, and explain the transition across coordination modes in the context of innovation policy. This ensures that the TIS+ avoids a reductionist approach to institutional change and innovation, as it incorporates multiple factors – actor-specific, structural, and historical – that can contribute to and indeed drive the design and implementation of innovation policy. Hence, this chapter complements the systemic approaches otherwise used in the innovation policy and transitions scholarship (cf. Andrews-Speed 2016) and links the analytic framework introduced in the previous chapter to the empirical observations that follow.

3.1.1 Institutions and Institutional Change

Institutions are "humanly devised constraints that shape human interaction" (North 1990, 3) – also known as 'the rules of the game' (cf. North 1990, 1991; Ostrom 2011; Steinmo 2008). They are the "formal and informal procedures, routines, norms and conventions embedded in the organizational structure of the polity or political economy" (P. A. Hall and Taylor 1996, 938) and represent "enduring regularities" (Crawford and Ostrom 1995, 582). This includes formal, written rules, such as laws and regulations (cf. Streeck and Thelen 2005), but also informal, colloquially accepted operating mechanisms, like behaviours, norms, and values (cf. Crawford and Ostrom 1995; P. A. Hall 1989). Both types of institutions "shape who participates in a given decision and, simultaneously, their strategic behaviour" (Steinmo 2008, 124). Accordingly, institutions can emerge as "organizations and the rules or conventions promulgated by formal organization" (Thelen and Steinmo 1992, 2), shaping society's interaction with the state. Defined by power (P. A. Hall and Taylor 1996), institutions are "relatively enduring features of political and social life […] that cannot be changed easily or instantaneously" (Mahoney and Thelen 2010, 4). How, then, do institutions change?

'Institutional change' implies "the way societies evolve through time" (North 1990, 3). Although change mainly occurs "in subtle and gradual ways over time" (Mahoney and Thelen 2010, 1), such "incremental shifts often add up to fundamental transformations" (Mahoney and Thelen 2010, 2). As institutions are intrinsically interlinked, depend on, and affect each other (cf. Evans 2012; Mahoney and Thelen 2010; Steinmo 2008), changes have knock-on effects. This makes institutional change slow and burdensome – institutions are 'sticky' (Boettke, Coyne, and Leeson 2008). They can even become 'locked-in' if actors resist change and/or prevent it (Foxon 2002; Steinmo 2008; Unruh 2000, 2002). The cross-institutional embeddedness is one reason why institutional change is usually incremental (North 1990). However, sudden changes are also possible, e.g. after crises or critical events.

The common approaches to analyse institutional change focus on actors, structures, and path-dependence[54]. Actor-centric approaches, such as rational choice institutionalism, consider institutional change as the result of single, rational actors' objectives. Accordingly, actors optimise their strategic behaviour based on their (fixed) preferences to maximise the outcome for themselves (P. A. Hall and Taylor 1996; Shepsle and Weingast 1987). 'Politics' becomes the arena where actors resolve "collective action dilemmas" (P. A. Hall and Taylor 1996, 940) because political institutions can reduce transaction costs (cf. Moe 1984; North and Thomas 1973; Weingast and Marshall 1988). Hence, institutions "solve many of the collective action problems that legislatures habitually confront" (P. A. Hall and Taylor 1996, 943). In this light, the power and position of an actor within a system or network becomes a defining characteristic of its influence. Powerful and more central actors are more likely to affect the system than those at the margin and can take a leading role. Likewise, actors with more capabilities and capacity, e.g. in terms of financial means or human resources, obtain more power and are more influential. Although investigating power and capacity through actor-centric approaches is helpful, the approach ignores the structural features that define interactions and feedback loops among actors. Likewise, it only marginally accounts for underlying norms and ideas that shape and drive actors.

This is different in approaches that focus on structures and external factors, such as sociological institutionalism. These consider institutions more broadly (J. L. Campbell 1998) and include "not just formal rules, procedures, or norms, but the symbol systems, cognitive scripts, and moral templates that provide the 'frames of meaning' guiding human action" (P. A. Hall and Taylor 1996, 947). Here, the core of institutions rests on "culturally-specific practices" (P. A. Hall and Taylor 1996, 946) – where culture itself is considered an 'institution' (Zucker 1977). Accordingly, institutional change occurs as a result of enhanced "social legitimacy of the organization or its participants" (P. A. Hall and Taylor 1996, 949), whenever deemed appropriate (J. L. Campbell 1998), and is, thus, a

[54] The analytic approach according to actors, structures, and path-dependency follows Wegrich (2001) (also see Bourdieu 1990; Douglas 1986; North 1990).

response to exogenous factors (DiMaggio and Powell 1983; Fligstein 1996). For this reason, this approach serves well to understand the legitimacy of specific organisations or institutions that may affect change – including their legitimacy to deviate from established practices. It also allows to capture some norms and values that led to the formation of objectives and goals, which catalyse (or inhibit) institutional change, e.g. a policy. Nevertheless, structural approaches only marginally capture the evolvement of institutions over time.

Approaches that focus on historical trajectories and path-dependence, such as historic institutionalism, capture such longitudinal developments (Peters, Pierre, and King 2005). They analyse "the ways in which institutions structure and shape behaviour and outcomes" in politics and society over time (Steinmo 2008, 118). Path-dependence assumes that previous institutional designs shape the future evolvement of institutions as they create a trajectory that limits the options for deviation (North 1990; Pierson 2000, 2004; Pollitt 2008; Thelen 1999; Thelen and Steinmo 1992) – 'history matters' (cf. North 1990) and 'institutions matter' (cf. Lowndes and Roberts 2013)[55]. Change, thus, is either triggered by exogenous factors, called 'punctuated equilibria' (Thelen and Steinmo 1992) or by endogenous factors (Mahoney and Thelen 2010; North and Thomas 1973; Streeck and Thelen 2005). The path-dependent focus suggests that behaviour "depends on the individual, on the context, and on the rules" (Steinmo 2008, 126) and incorporates "the forests as well as the trees" (Pierson and Skocpol, as cited in Steinmo 2008, 135). Accordingly, political and policy processes are seen as a system of interacting parts (Almond and Powell Jr. 1956) which structure collective behaviour (P. A. Hall and Taylor 1996), explaining the relationship between the design of political processes and the behaviour of political actors (Steinmo 2008). Institutions form the arena and the constraints for politics (J. L. Campbell 1998) and enable the formulation and communication of (collective) interests (Lockwood et al. 2017). In this setup, more powerful actors are more likely to shape future institutional trajectories (possibly to their advantage) (cf.

[55] An often cited example highlighting this dynamic is the QWERTY keyboard and its more efficient alternatives, which have nonetheless not managed to replace the initial, type-writer friendly version (Arthur 1989; David 1985; Krasner 1988).

Avelino and Rotmans 2009; also cf. Mitchell, Agle, and Wood 1997)[56]. The capacity and legitimacy of actors, likewise, can be conditioned by past decisions. While longitudinal approaches capture the emergence and development of institutions and, consequently, their influence on policy implementation and/or innovation systems, they often lack an actor-specific lens.

Hence, although there is considerable overlap between these approaches (Pierson 1996; Thelen 1999), the markedly different foci render different analytic insights and implications[57]. Yet, by doing so, each approach also misses aspects that are essential to understanding policy implementation challenges and tensions in innovation systems. "All three varieties of institutionalism, in short, provide answers to what sustains institutions over time as well as compelling accounts of cases in which exogenous shocks or shifts prompt institutional change. What they do not provide is a general model of change" (Mahoney and Thelen 2010, 7). Thus, neither approach by itself is suited to analyse the complexity underlying the transition of coordination modes in the context of innovation policy. In other words, changes of "institutions, ideas, and the environment" must be considered as a "co-evolutionary process" (Steinmo 2008, 133) across actors, structures, and time. Accordingly, to avoid a reductionist approach to institutional change and innovation, this chapter provides a longitudinal study of innovation policy coordination that focuses on actors, structures, and path-dependent elements.

3.2 Innovation Policy Coordination 1945-Today

Since World War II, the objectives of innovation policy have changed decisively, ranging from the single issue-focused 'Manhattan Project' and 'the Moon Landing' to more holistic and systemic approaches as represented by the SDGs and 'mission-driven innovation' (cf. Mazzucato 2013b; Mazzucato, Kattel, and Ryan-Collins 2020; Nelson 1977; Vinnova 2019). Three eras featuring three

[56] Note that the power of a particular actor reflects in itself the result of a pre-existing institutional arrangement – and its potentially path-dependent development.

[57] An in-depth account of institutional change is beyond the scope of this study. A detailed framework to analyse institutional change can be found in Streeck and Thelen (2005) and in Mahoney and Thelen (2010).

different, dominant (although not purely implemented) approaches to coordinating innovation and innovation policy, generally, can be identified. These are defined by the different ways governments and administrations implemented policies and the various challenges and objectives that governments, enterprises, and researchers addressed through socio-technical innovations. The eras range from 1945 to approximately 1990, from 1990 to 2008, and from 2008 to today. The following sections discuss these in turn.

3.2.1 Post-1945: The Hierarchical Era

The immediate era after World War II, beginning in 1945, saw a primarily hierarchical – or policy-led – approach to coordinating innovation policy – in Europe, in North America, and many other parts of the world. This is mainly due to the significant challenges that countries faced after several years of war and war-oriented economic decisions. The aftermath of the War saw economies struggle to revert to structures that are not geared towards weapon manufacturing and wartime economics and instead to diversify across sectors, rebuild economic production, and re-establish and expand trade patterns (cf. Reinert 2020). In this period, science and research clusters shifted priorities from military engagements to research based on the freedom of inquiry. According to leading scientists of the time, this shift would benefit society, enhance well-being, and promote economic growth – as among others argued by the former director of the US National Science Foundation, Vannevar Bush (1945, 10–11):

> "Advances in science when put to practical use mean more jobs, higher wages, shorter hours, more abundant crops, more leisure for recreation, for study, for learning how to live without the deadening drudgery which has been the burden of the common man for ages past. Advances in science will also bring higher standards of living, will lead to the prevention or cure of diseases, will promote conservation of our limited national resources, and will assure means of defense against aggression. […] Without scientific progress no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world."

Conducting curiosity-driven research for 'science's sake' (cf. Brockman 1996; Toulmin 1966) required "five fundamentals": long-term funding arrangements, a broad range of individuals who take science funding decisions, funding for primarily non-governmental research organisations, the self-governance of such research bodies, and complete independence of scientific organisations in terms of methods, nature, and scope of research (Bush 1945, 32–33). During this time, many applied research organisations, such as Germany's Fraunhofer Society, began to shape the innovation landscape.

The reconstruction of economies and research systems during this time required a targeted and strategic approach. Policies in this context were based on propelling economic and scientific activity along a mostly linear understanding of innovation (cf. Narayanamurti and Odumosu 2016; Scherer 1986), similar to the prevailing convictions during and before the War. In other words, science was meant to produce knowledge through basic research, leading to novel ideas and discoveries. Through compounded information and applied research, scientists and later firms would invent new technologies that could be transformed into valuable products and processes. Through investment and scaling, these formed the base for diffusion through commercialisation, which in turn advanced economic activity and increased productivity, to ultimately promote economic growth and societal well-being (Greenhalgh and Rogers 2010). Growth, in turn, would generate revenue and profit, which could be re-invested into the generation of new knowledge and innovation. Then the process starts over, propelling the economy forward and upward (cf. Schumpeter 1912, 1935, 1939). As a result, the 1950s and 1960s featured a swift economic recovery across countries and are often referred to as the time of the *Wirtschaftswunder* (economic miracle). For example, in Germany, this was due to the production of vehicles and machinery, which resulted from strong (industrial) policy initiatives led by the government and enacted by industry (cf. Weiss 1998). The coordination of and cooperation among the government and industry stakeholders was achieved mainly by aligning policy goals as a co-creation process, which resulted in policies that led to economic change (cf. Shonfield 1965). Consequently, technologies such as cars, televisions, and telephones became more mainstream as the purchasing power of the middle class increased, and governments began to settle their war-torn national accounts (cf. Eichengreen 1995; van Hook 2004; Jorgenson 1988).

Given the time and the circumstances after the War, the hierarchical mode of policy coordination – or in some cases (as in Germany) rather the policy-led approach – was suitable to re-build the policy and public-administrative infrastructures and/or to shift the policy focus away from war-time considerations and towards economic recovery and restructuring. As such, the hierarchical mode allowed for consciously designed objectives by the central government, partially in co-production and close alignment with industry stakeholders, which could be implemented directly through active guidance and steering with an immediate effect on industry (cf. Shonfield 1965; Weiss 1998). This is an asset in an arrangement where structures – and institutions – are new and/or not (yet) fully accepted or where routines are not (yet) established. Hence, the central government could operate as a rule-maker and 'supervise' public agencies directly, ascertaining that dependent actors follow pre-set goals. For innovation policy, governments could clear administrative obstacles and enable the flow of funding towards universities or other research centres at the core of the innovation system (cf. Bush 1945). Government organisations could evaluate the innovation landscape and react immediately in case of need, e.g. when a blocking mechanism had been detected.

Towards the end of this first era (1970s/1980s), the actual field of 'innovation policy' as a policy domain began to emerge – at first as a conceptual tool to coordinate other policy domains and to promote and accelerate technological innovation (Sweeney 1985). This resulted from the gradual institutional change regarding science, research, and innovation, over decades. Hence, during this time, the awareness surfaced that innovation is affected by policies from multiple domains and that there is a need to align such policies to innovate successfully. However, at this early stage, the new policy field's coordinative characteristic "failed to materialise" (Kattel and Mazzucato 2018, 4), and its coordinative power remained weak. This is because as the complexity of policy issues grew, the specialisation and thus fragmentation within the public administration also increased. As mentioned above, scholars refer to this phenomenon as the "complexity paradox of modern public policy" (Kattel et al. 2018, 7). It results in the increased need for coordination across public organisations, particularly to create policy-oriented and practice-based linkages across the organisations involved (*ibid*.). This 'paradox' is not unique to innovation policy but is observed across policy domains. It forced stakeholders to attempt alternative approaches to coordinating innovation policies to overcome coordination challenges.

National governments were the central actors in innovation systems during this time, prescribing innovation directions through policies. They were powerful because no other actors in the system had the means, standing, institutional legitimacy, and financial resources to dominantly shape innovation in the post-war setting. Governments were the rule-makers with strong veto powers, not at last due to the post-war funding structures for science (the majority of funds were public) and, therefore, took a leading role to foster innovation activities. DARPA, the US Defense Advanced Research Projects Agency, is a good example (cf. Mazzucato 2013b; Narayanamurti and Odumosu 2016). At the same time, research centres had more independence from government intervention than during wartime (cf. Bush 1945). The War's consequences also reduced the capacity of non-governmental actors, such as firms, which had to be rebuilt, had to re-structure their businesses, and re-connect to suppliers and customers. They could not take a central role in the innovation system immediately after 1945 and were, thus, particularly prone to effects from novel institutional arrangements.

Hence, governments could actively contribute to shaping institutional change in the context of research and science – and thus innovation – by adding layers to institutions, for instance, by creating new research organisations, research practices, funding arrangements, or general science strategies. Governments changed existing institutions and re-oriented them towards the new, post-war common goal: economic recovery. This 'layering' strategy of institutional change (Mahoney and Thelen 2010) implies that laws and norms were added on top of old rules[58], which opened new possibilities for innovation.

In sum, this first era reveals gradual institutional change regarding innovation, away from the war-time logic and towards curiosity-driven research that yields a positive impact on society. Innovation policy during this time was predominantly coordinated hierarchically or policy-led, as public organisations

[58] Some institutions that shaped war practices were not maintained post-1945 and disappeared.

and targeted policies maintained a central role in innovation systems. As power rested with the state, both during and immediately after the War, its central role was hardly challenged. However, the independence of research organisations, and later also firms, increased their role in innovation systems and led to an acceleration of innovative activity in the latter part of this era, which was shaped by the norms and values pertaining to re-building and re-gaining economic strength, jointly with industry actors. The hierarchical mode to coordinate (innovation) policy was best apt to deliver these goals.

3.2.2 Post-1990: The Market-Based Era

The post-1990 era, after the fall of the Iron Curtain and the end of the Cold War, saw changes to innovation policy coordination. Governments established a more market-based approach to governance, in general – not just for innovation (policy). The transition towards market-based approaches occurred incrementally over time, starting already during the late 1970s and 1980s, whereas some countries or regions have adopted changes sooner, others later. This time's overarching theme resulted from the competition of politico-economic systems between the 'East', led by the Soviet Union, and the 'West', led by the US and Western Europe. The capitalist, American influence was labelled the 'Washington Consensus' – a tribute to the location of the largest international organisations representing this approach (The World Bank and the International Monetary Fund, in addition to one of the largest donors to these organisations: the US Government) (cf. Rodrik 2006; J. Williamson 1993).

The core tenets of the 'Washington Consensus' included a generally more market-oriented approach to conducting politics and implementing policies. This implied a new structure to public administrations that emphasised the treatment of citizens as customers and the running of government akin to private sector companies. This form of 'New Public Management' (NPM) drove the liberalisation (and privatization) of markets, deregulation, decentralisation, and the evaluation of public sector performance through measurement (Dunleavy and Hood 1994; Pollitt and Bouckaert 2011; M. Robinson 2015). NPM was first implemented in countries where these ideas originated (e.g. the UK, Australia, New Zealand, US), but after 1990 also in Eastern European countries, such as Estonia and the other Baltic states (cf. Bohle and Greskovits 2009), as well as economies in East Asia (except China) and in the Global South (cf. O. E. Hughes 2003). There, the influence of the aforementioned organisations based in Washington D.C. and their structural adjustment programmes continue to shape economic dynamics until today (cf. Dooley, Frankel, and Easterly 2013; Rodrik 1990). In general, thus, liberal approaches prevailed during this era and shaped, by definition, 'the retreating state' (cf. Nederhand, Bekkers, and Voorberg 2016).

Countries that experienced significant regime changes, including a politico-constitutional and economic re-orientation towards democratic and (neo-) liberal structures, e.g. Estonia or other countries in Eastern Europe, saw a particularly strong shift towards the ideals and ideas embodied by the dominant international organisations and institutions (Bohle and Greskovits 2007a, 2007b, 2009, 2012; Karo and Logga 2016). Attempts to expedite economic development through 'leap-frogging' nurtured the role of the private sector and market dynamics (cf. Burlamaqui and Kattel 2016; Dosi et al. 1988; Chris Freeman and Soete 1997), which consequently also affected their role in innovation (systems), ultimately shaping largely market-oriented approaches in these countries. Generally, the context – and, therefore, the dynamics – in which innovation occurs in low and middle-income countries may differ, however (cf. Chataway, Hanlin, and Kaplinsky 2014; Watkins et al. 2014).

The focus on market dynamics and the establishment of market structures in state institutions and practices replaced some of the previous decades' command-and-control practices. Market dynamics allowed for results to be spontaneously created due to market-based interaction. The market-based coordination approach manifested itself in mechanisms defined by 'the invisible hand', i.e. the interplay between supply and demand. This includes government organisations that consume or provide a particular service (or even a specific good). Accordingly, profits or losses were used as a tool to evaluate the work of public administrations, e.g. through performance-based budgeting (cf. Bouckaert and van Dooren 2009; Pollitt 2006). For innovation policy, this meant, for instance, an increase in private sector participation, such as private research institutes, less state-centred innovation activities, the expectation of government funding to yield returns, and the installation of incentives rather than directives for private firms. In this light, governments used their role as market creators to procure knowledge development activities through research organisations or purchase innovations and generate demand for a technology (cf. Lember, Kalvet, and Kattel 2010; Sarapuu and Lember 2015).

In terms of innovation practices, this time of *laissez-faire* politics incentivised the private sector to take up innovative activities. More private entrepreneurs, therefore, invested in new technologies and RD&D efforts. Simultaneously, although many government-financed programmes shifted, changed, or ceased, the general support for basic research, also for applied programmes, continued. This showed, for instance, in the US healthcare sector, where "public investments in innovation have been critical for sustaining high levels of risk-taking and innovation across different stages of the business cycle" (Mazzucato and Semieniuk 2017, 31). This one-sided 'stigmatisation' often considered the private sector as the (sole) hub for innovation, even though the public sector still played a vital role in promoting, financing, and in parts implementing innovative products or processes (Mazzucato 2013b, 2021). At the intersection of these dynamics, innovation agencies began to emerge during this time (e.g. *Vinnova* in Sweden in 2001 or Enterprise Estonia in 2000). These contributed significantly to creating and implementing innovation-related policies and new visions about innovation and industrial policy, particularly in catching-up economies like Estonia (cf. Burlamaqui and Kattel 2016; Karo and Kattel 2010a; Tiits et al. 2008).

In this era, the role of the Internet and digital services fundamentally changed the practices of industrial and entrepreneurial activities. This 'digital layer' complexified innovation processes by adding additional possibilities, such as the sourcing of knowledge from a broader spectrum of actors, the acceleration of practices, improved logistics and product management, enhanced marketing and scaling options, as well as new forms of collaboration, just to name a few (cf. Brynjolfsson and McAfee 2014). Generally, the Internet and digitalisation led to efficiency improvements (European Environment Agency 2019). However, the Internet also imposed obligations and responsibilities for manufacturers, consumers, and policy professionals alike, e.g. regulation, cybersecurity, data privacy, and interconnectivity. With regard to the coordination of innovation, the heightened significance of the Internet, digitalised communication, and digitalisation further increased the number of stakeholders involved in innovation systems – also geographically (cf. Binz, Truffer, and Coenen 2014; Pietrobelli and Rabellotti 2009).

The transition of innovation policy coordination practices between the post-1945 era and the post-1990 era mainly occurred through 'displacement', i.e. existing institutions were replaced by new ones (cf. Mahoney and Thelen 2010). In the market-based coordination mode, the government has significantly fewer (veto) powers compared to the hierarchical coordination structure because other actors play a central role (e.g. firms) – the underlying market dynamics 'automated' many interdependencies and actor relationships, to some extent including coordination. Institutional change, thus, emerged alongside economic incentives and market opportunities. Old rules were no longer fit for purpose in this new, dynamic, market-based arrangement and were consequently removed; newly designed rules and institutions replaced them. Pressures from international partners, the increasingly globalised world, and international organisations further contributed to this shift (cf. Reinert 2020).

Innovation in this era emerged to enhance economic opportunities and improve competitive advantages through novel products and services. Public organisations participated in this innovation process through procurement, public-private partnerships, or other demand-side stimuli (cf. Lember, Kalvet, and Kattel 2011) – in other words, government-initiated markets through which stakeholders were coordinated. Governments, thus, were one group of actors among many in innovation systems. Similarly, fragmentation and departmentalisation caused different public agencies to interact through market principles, e.g. by bargaining for influence and power, by 'consuming' each other's services, and by refraining from non-beneficial interactions (cf. Bouckaert, Peters, and Verhoest 2010).

This means that market dynamics, and therefore private companies, took centre stage, rather than government organisations. At the same time, this transition increased the capacity of private firms, which also took over some tasks previously enacted by government organisations (cf. market liberalisation, e.g. in the electricity or transport sectors). The shift also increased private sector independence, selling services to the government rather than relying on funding support. Firms expanded their networks, improved business relationships (around the world), and therefore sourced products and knowledge from collaborators (or competitors) globally (cf. Reinert 2020). However, the increased globalisation and simultaneous market liberalisations required governments to devise rules in the form of regulations to 'guide' the private sector. The legitimate interference into these markets by governments emerged as a challenge – which it remains today (cf. Mattli and Woods 2009; Vogel 2007, 2010; Vogel and Kagan 2004). The underlying norms and values focused on taking advantage of new opportunities, primarily of economic nature, but also pertaining to technological possibilities.

In sum, the second era, approximately classified as the post-1990 era, reveals a gradual institutional change of coordination approaches towards the market-based mode, heavily influenced by the 'Washington Consensus'. This also implies a shift of innovation activities towards the private sector, although with governments still involved as funders and enablers. Public organisations had a less central role during this time, as power shifted away from the government towards industry players and as the increased capacity and capability of the private sector rendered it more independent. This required, in turn, a redefined approach by governments to structure private sector behaviour through novel rules and regulations. For innovation, this shift meant that an increasing number of firms pursued emerging opportunities and, therefore, accelerated and expanded innovative activities. The increased marketisation also led to market-based rationales emerging within the public sector. Organisations, such as executive agencies, became more market-driven, working more independently and sourcing capacity from private stakeholders. The market-based coordination mode was at the time apt to accommodate the changes in the wider economy and to provide opportunities for economic growth without a dominating (central) government – a strong underlying rationale at the time.

3.2.3 Post-2008: The Emerging Network-Oriented Era

The contemporary era, starting approximately after the global financial crisis of 2008 and the Euro crisis in the years thereafter triggered further changes to innovation policy and policy coordination. Generally, this era sees the inclusion of increasingly more actors in economic processes, in general, and innovation processes, in particular. As problems and challenges are becoming more complex, they become more extensive in scope and/or are considered from a more global perspective, such as climate change, digitalisation, or socio-economic development (cf. Reid et al. 2010). This means that challenges themselves, but also solutions to these challenges, become highly interrelated. Changes to one part of a system can affect actors, economies, and societies in another part. Consequently, the attempted solutions tend to be more system-oriented and focus on cross-cutting and overarching approaches rather than on a single technology or sector. This increased focus on problem-oriented policies to address 'wicked problems' causes the type of stakeholders in innovation systems to diversify across industrial sectors, geographical spaces, and policy domains. Good examples concerning this mindset are the Millennium Development Goals and their successors, the SDGs (Sachs 2012; United Nations 2000, 2015). Mission-oriented approaches that target holistic (economic) transformations have recently regained traction (Ghazinoory et al. 2019, 2020; Göpel 2016; Mazzucato 2013b, 2016, 2018a, 2021; Mazzucato, Kattel, and Ryan-Collins 2020; Mazzucato and Semieniuk 2017; Pyka 2017a).

Innovation in this era has taken another leap. With the ever-increasing importance of digital technologies and the goal to transform our economies to achieve the SDGs, entrepreneurs and innovators face the tasks of incorporating technological and social change into new artefacts and processes (cf. Sachs et al. 2019; UNDP 2018). Behavioural modification and the reconfiguration of consumer behaviour, as well as the formation of new services, became as much of a target for innovation as technical advancements before. Therefore, research programmes and communities, as much as industry actors, link the technical with the social dimension of innovation, referring to socio-technical innovations (cf. Berkhout, Smith, and Stirling 2004). This includes, but is not limited to the circular economy, the sharing economy, the gig economy, and the platform economy (Frenken and Schor 2017; Kirchherr, Reike, and Hekkert 2017; De Stefano 2016), all of which describe new business models and a new type of products based on novel behavioural trends. The availability of vast amounts of data associated with these innovations initiated the transition towards new paradigms, posing new challenges also for governments and public administrations, e.g. in terms of privacy protection and data regulation, cybersecurity, and most recently, misinformation and social media interaction (cf. Brynjolfsson and McAfee 2014). In other words, the opportunities inherent to digitalisation are an extenuation of the trends of the previous era but paired with AI, automation, big data, and high-speed interconnectedness in a time of unprecedented global challenges, offer both greater potential and heightened risks – economically, politically, and socially.

Innovation hereby occurs more frequently through collaborations – many firms practise open innovation (Chesbrough 2003a, 2006) – but also through diversified value chains, closer cooperation with universities, and through government initiatives. Principles such as autonomy of researchers about funding allocations, technology transfer, learning-by-doing, international collaboration, adaptive learning, and stable financial support form the foundation for innovation (Chan et al. 2017). Regional agglomerations propel such initiatives, for example, in the Silicon Valley in the USA. Purpose-created organisations or intermediaries foster networks that incorporate stakeholders with diverse perspectives, knowledge, and skills. Governments incentivise industry and research organisations to cooperate, e.g. through competitions such as the X-Prize. Even international organisations and transnational government organisations, such as the EU, regularly release purpose-oriented funds across sectors and organisations, such as supporting a 'European Green Deal' and the transition to a cleaner, carbon-neutral economy (European Commission 2020a).

The growing number of stakeholders in these complex innovation systems required amendments to innovation governance. As a result, we are beginning to see elements of network-oriented policy coordination. The network-oriented approach can accommodate the multitude of actors and allows for improved cooperation to achieve purposefully designed goals that are based on missions or joint visions to cater a larger problem or challenge. Governments can enable the growth of these networks by managing the network actors, contributing knowledge or funds, advising actors with regard to policy and regulatory questions, and facilitating, e.g. through agenda-setting, the creation of adequate fora, or the formation of topic-specific intermediaries. As this dynamic is mainly built on trust and loyalty within the network, public agencies gain from being members of such innovation networks, for example, by learning about new technical developments. Stakeholders, thus, have a more equal standing within the network compared to the hierarchical or market-based approaches. Since network-oriented policy coordination is based on shared values and consensus, governments have some but no overwhelming power in innovation systems.

Institutional change from market-based coordination approaches to the network-oriented mode results mostly from 'conversion': Institutions are re-purposed due to the new overarching mission or goal (cf. Mahoney and Thelen 2010). This can include the mandate to respond to global challenges like climate change, global trends, or specific local needs. Actors thrive due to the freedom to choose partners, trajectories, and networks based on a particular challenge. "Institutional challengers capture resource by acting as opportunists who re-deploy the prevailing rules for their own purposes" (Mahoney and Thelen 2010, 29). Generally, this is an efficient approach, as the old institutional structures must not be abandoned entirely but can be re-structured. This means that neither firms nor governments take sole leadership in innovation systems. Instead, power is more equally distributed across multiple actors. Actors are independent because they represent a component of the innovation system without which the system may fail. The most central organisations are purpose-built intermediaries, such as institutionalised interest group associations.

Within governance apparatuses, this era begins to see increased cooperation, where public organisations work across policy domains based on a particular problem or challenge. The UK revealed this initiative, e.g. during the Blair government, in the form of joined-up and whole-of-government cooperation. The legitimacy for governments to influence innovation results from other actors' needs in the system that either require financial support, access to resources, or changes to existing policy frameworks. This represents a form of public-private collaboration. The focus – and the underlying value proposition – rests on improving society's well-being, including economically, as the SDGs and the contemporarily dominant climate change discourse demonstrate.

In sum, the third era reveals a trend towards network-oriented coordination in the context of innovation policy. This results from a gradual institutional change in response to increasingly complex, global challenges and the increasing number of stakeholders in innovation systems. Hence, we are beginning to observe this shift regarding specific policy areas or topics where networks already exist or can quickly be established. The network-oriented coordination approach is suitable to mitigate some of the issues public agencies face when governing increasingly global challenges as well as socio-technical solutions that are meant to address them. This implies a more cooperative and collaborative approach to innovation across industry, academia, and government with an increased (although not exclusive) focus on social well-being.

3.2.4 Discussion: Institutional Change of Coordination

The general policy coordination approaches for innovation and innovation policy have shifted over time from the primarily hierarchical mode after World War II to the market-based approach post-1990. Since 2008, network-oriented coordination approaches have taken hold in specific policy domains and/or issue areas. These shifts have in common that they respond to the pressing challenges of the time and the corresponding needs in innovation systems, where central governments at first led innovation efforts and then retreated to give space to the private industry. Today, networked approaches seem a better fit to tackle contemporary innovation challenges.

The transition from war-time hierarchical coordination to post-war, recovery-focused coordination, which also followed the mostly hierarchical coordination pattern, emerged through ‘layering’. The same (government) actors remained at the centre of innovation systems, coordinating policies through top-down measures and supply-side measures. Yet, the structures that support them and the norms that guided them changed from wartime to (economic) recovery rationales – still conditioned by the path-dependent effects of the War, however. Innovation occurred mostly in (applied) research organisations and private firms in response to policy-led rationales. Over time, motivated by potential economic gains and growth, innovation moved increasingly into the private sector, paving the way for the second era that emerged in the 1970s and 1980s.

The shift from hierarchical coordination approaches to the market-based mode was driven by economic incentives and the interests of private firms. New private sector actors took centre stage in a new structural environment, shaped by market dynamics which replaced old rules. Governments still funded and facilitated innovation efforts and remained part of the market through procurement and partnership programmes, i.e. through demand-side policies. In public agencies, this became visible in the form of NPM. For coordination, this meant that the market quasi-automatically coordinated governance activities. Hence, this transition can be best described as ‘displacement’.

After the financial crisis of 2008, a transition from market-based to network-oriented policy coordination began to emerge, which we still observe today. This shift continues to be shaped by the increased complexity of innovation systems and wicked, global challenges. The number of actors in innovation systems surged rapidly, rendering a more inclusive approach to governance essential. As institutions remained structurally in place, the rules according to which stakeholders interacted changed. Due to this institutional ‘conversion’, governments hold no longer a central, powerful position but instead form an active part of the emerging networks. These are predominantly shaped by public and private purpose-built organisations that drive the cause and direction of innovation. Intermediaries coordinate innovation and governance activities through increased collaboration based on mutual trust.

Hence, on the one hand, the transitions from one policy coordination mode to another occurred in response to the issues that actors attempted to resolve through innovations: re-building the economy, strengthening the private sector, reducing government inefficiency, tackling wicked problems, etc. These are exogenous factors that triggered an institutional change of policy coordination practices. On the other hand, these shifts were also a response to the challenges emerging within public organisations due to the particular nature of new technologies. As innovations became more socio-technical and broadened their impact on society, they required novel forms of regulation, addressed a larger number of stakeholders that had to be managed, and invoked new governance ideas. These are primarily endogenous factors that emerged from within public sector organisations. Combined, these effects triggered transitions of coordination practices in the context of innovation policy.

Today, as a response to increasingly complex challenges, we often observe all three policy coordination modes – across jurisdictions, policy domains, and issue areas. Simultaneously, in many countries, past experiences and path-dependent arrangements continue to define the way policies are designed, implemented, and coordinated. Institutional change concerning policy coordination remains 'sticky', as some of the cases discussed in the following chapters show. Many countries, including those at the core of this study, reveal a combination of policy coordination modes rather than a pure arrangement.

3.3 Implications of Changing Coordination Modes

As strategies for (innovation) policy coordination changed over time, responding to exogenous and endogenous factors, the influence of public organisations on innovation systems changed alongside. Throughout the transitions from one coordination mode to another, four defining features emerged that characterise this impact of public administrations: power, capabilities, legitimacy, and norms/values. These can be directly linked to institutional change. They are also reflected as public-administrative elements in the analytic framework of this thesis, the TIS+. This section discusses the implications of changing coordination modes in public administrations on innovation, innovation policy, and policy implementation.

3.3.1 Implications for Innovation (Policy)

3.3.1.1 The Hierarchical Coordination Mode

Innovation policy that is coordinated hierarchically provides the central government with the *power* to guide actors involved in the policy implementation process. It means that it can, for example, instruct government organisations to promote some, but not other technologies, be flexible with some, but not other regulations, or provide funding to some, yet not to other organisations. Feedback loops in the hierarchical coordination model are (mostly) linear, which means that information exchange and policy evaluation occurs top-down via the central government, for instance, via inspection reports or supervision arrangements. This means that the government can be relatively responsive and has the *capacity*, for example, to resolve blocking mechanisms in innovation systems related to regulation, lack of knowledge and expertise, or lack of funding. Accordingly, the decision power rests with a single authority and is then passed on along the chain of command, reducing friction and confrontation within the innovation system. Nevertheless, this may prolong response times because the alternative, more direct channels of information flow are not established. The central government can add or supplement existing institutions in this scenario. In that case, “change agents must work within the system to achieve their goals” because the strong position of the government and its high *legitimacy* “makes it difficult for opposition actors to openly break or even bend the rules of an institution” (Mahoney and Thelen 2010, 29).

Misaligned regulation for a new, complex technology is a good example of governments’ influence on innovation systems. Hierarchical policy coordination would imply that changes to or discretionary interpretations of existing regulations can only be initiated or approved by the central government. In this case, supplementary regulations, exemptions, or entirely new legal frameworks would have to be passed by the government and/or a legislator before the public administration can act upon it, even if the relevant government agency may be better equipped to evaluate technologies. Alternatively, the government could specifically instruct an agency to act accordingly. The hierarchical approach assumes a pre-defined chain of command and information flow through which the executive agency, topic experts, or innovators themselves inform the government. In case this is not possible, the government would rely on past experiences or, possibly, on ‘the best guess’. This could create further challenges.

3.3.1.2 The Market-Based Coordination Mode

In policy coordination arrangements employing a market-based approach, the central government has less direct *power* over stakeholders in the innovation system. Instead, it indirectly influences and coordinates the market through which other stakeholders interact. The government also steps in to counter possibly market failures (cf. Mazzucato 2016). Accordingly, system actors, including public agencies, are more *independent* and coordinate their behaviour through the market horizontally, i.e. between them and without intermediation by the government. Likewise, feedback loops also emerge via the market. For example, if tasks have not been fulfilled to the satisfaction of either partner of market-based agreements, they can seek new partners for future projects. The entire market dynamic occurs in the framework of existing legislation. A change thereof would, in most cases, still have to pass through government and legislation processes. Besides, the government can itself become a market player, e.g. through public-private partnerships or public procurement, which may also spur innovation (Edquist and Zabala-Iturriagagoitia 2012). This represents a reorientation of *norms* for interaction. The government can still initiate institutional change through policies, for instance, to replace old with new institutional arrangements, rules, or organisational practices.

As discussed above, one reason to do so could be the accommodation of novel multi-technology innovations into existing regulatory frameworks. Regulations would change if the participating stakeholders expect a benefit, e.g. their market position (firms) or their power position and influence (government). The direction of change is usually subject to bargaining between organisations – both public and private. Change is less likely if a public agency would risk its performance record, particular funds, or legitimacy. At times, public agencies may transfer jurisdictions to other agencies to increase their effectiveness and improve performance.

3.3.1.3 The Network-Oriented Coordination Mode

The network-oriented coordination approach implies that the government creates, enables, and takes part in policy and innovation networks. The government, thus, has less *power*, only indirect control over other system actors, and can only shape the direction into which the network develops to a limited extent. Other stakeholders remain *independent* as they interact across the network, horizontally and spontaneously, without the government controlling or mandating them. Feedback loops can emerge between actors without the involvement of the government. This renders feedback generation, evaluation, and the flow of knowledge dynamic and flexible – particularly with regard to novel, complex innovations – as only directly affected actors have to be included in the respective feedback mechanisms. Therefore, feedback loops are shorter, more efficient, more adaptive, and more targeted and can lead to institutional change based on conversion (cf. Mahoney and Thelen 2010). Accordingly, *norms*, rules or policies remain formally unchanged, but are enacted and implemented differently, such that they fit the new circumstances (cf. Thelen 2003). This means that actors respond to the opportunity that the institutional design (i.e. the network) provides. Hence, the network-oriented approach is generally open to institutional change as most actors would not prevent such if it benefits the system (cf. Mahoney and Thelen 2010).

If regulatory frameworks have to change to accommodate a novel, complex technology, the network-oriented coordination mode enables the flexibility and adaptability needed to find the best-suited solution for the innovation system's stakeholders. Regulatory obstacles can be removed by interpreting the regulatory framework more 'creatively' and by "actively exploit[ing] the inherent ambiguities of the institutions" (Mahoney and Thelen 2010, 17) – for the benefit of network actors or a particular socio-technical innovation. As such, the network-oriented mode allows for collaboration between stakeholders on a need basis, e.g. filling knowledge gaps. Changing institutional arrangements in this way rests on trust, shared values, and a common problem analysis, which might be slower to build but could yield a reciprocally beneficial outcome for the innovation system as a whole.

3.3.2 Implications for Policy Implementation

Implementing purposeful and intentional institutional change by public sector organisations depends on their power, capacity and capabilities, legitimacy, and the underlying norms/values that guide their actions. These characteristics feature in the TIS+ framework of this thesis as public-administrative elements.

3.3.2.1 Power

First, "the focus on the role of power structures and power relations is a key to analyse institutional change" (Wegrich 2001, 11). The concept of 'power' includes a broad scope of definitions, including strategic, critical, and radical views (Foucault 1977, 1980; Lukes 1974; Machiavelli 1532)[59]. The original Weberian view defines power as follows: "Within a social relationship, power means any chance, (no matter whereon this chance is based) to carry through one's own will (even against resistance)" (Wallimann, Tatsis, and Zito 1977, 234; original: Weber 1925, 28, see also Weber 1947). In other words, it is "the ability to those who possess power to bring about the outcomes they desire" (Salancik and Pfeffer 1974, 3). Power is, therefore, of transient nature, meaning that actors can gain (more) or lose power (Mitchell, Agle, and Wood 1997)[60]. Avelino and Rotmans conceptualise power in the context of (sustainability) transitions not simply as power 'over' (someone) or power 'to' (act), but also as a dynamic, where actors have more or less of different types of power (Avelino and Rotmans 2009). Thus, the focus in this study is on defining "how relations of power *can be* [...] by understanding how, why, and when they change" (Avelino and Rotmans 2009, 564). The more contemporary accounts serve as a good foundation for understanding 'power' for this thesis' purpose.

In the context of policy implementation, power defines the position of actors within the (innovation) network, including an actor's centrality and/or its ability to take on a leading role in the network. In turn, the chance to interact with other stakeholders, but also the opportunities that emanate from such interaction, are defined by an actor's power (cf. Avelino and Rotmans 2009; Mitchell, Agle, and Wood 1997). In other words, power yields an actor's more central/leading (or less central/following) behaviour within the network. The speed, direction, and extent of institutional change in the context of policy coordination in networks are associated with the power and position of an organisation in that network. Hence, power can enable public organisations to shape the innovation system

[59] The depth of the discussions concerning 'power' exceeds the scope of this thesis.
[60] Mitchell et al. discuss the role of power in stakeholder interactions, emphasising that different types of stakeholders employ power differently, and are, thus, also in different positions to change relationships, organisations, and outcomes (Mitchell, Agle, and Wood 1997).

from a central position. Accommodating this might require a transition of coordination modes, for instance, to incorporate elements from hierarchical structures. For this purpose, the TIS+ framework considers the 'centrality and leadership' of public organisations as a proxy for power.

3.3.2.2 Capacity

Second, the institutional capacities of an organisation, i.e. their capabilities and competences, define the extent to which it can impact institutional change. Although, generally, definitions for these concepts diverge across the scholarly literature (Wu, Ramesh, and Howlett 2018), most commonly 'capability' refers to the resources available to individuals, organisations, and the broader system as a whole that are required to fulfil a particular task (*ibid.*). This includes, but is not limited to, the workforce and financial means available to an organisation (*ibid.*). Competence, in turn, manifests the skills level within an organisation, describing whether it is "functionally adequate or having sufficient knowledge, strength, and skill" (Vincent 2008). This includes analytic, operational, and political skills and defines the extent to which an organisation (or individual) is prepared to fulfil a particular task (Wu, Ramesh, and Howlett 2018). Combined, as mentioned above, skills and resources, i.e. competences and capabilities to achieve a specific task, define an organisation's capacity (cf. Karo and Kattel 2018a; Painter and Pierre 2005b; Peters 2018a; Wu, Ramesh, and Howlett 2015, 2018).

The institutional arrangement of policy coordination also defines the capacity of public administrations. Policy implementation, in general, depends on the extent to which public organisations are trained, prepared, and structured, but also to what extent they are endowed with resources of knowledge, workforce, and finance. The capacity of public agencies comes to play particularly in innovation systems of new, complex technologies: It defines how they encounter new challenges, interact with new stakeholders (e.g. new start-ups), handle new policies, or feed their experience back to the policy designer. Consequently, capabilities, competence, and, thus, capacity shape how an organisation can initiate change. Public sector organisations can influence innovation systems the more so if they are independent of ministries and the central government.

However, as independent organisations, they must possess the capabilities and the competences to undertake specific actions, including knowledge, skills, workforce, financial resources, etc. Accommodating independence and capacity might require the transition of coordination modes. For this reason, the TIS+ framework includes the ‘capacity and independence’ aspect as a proxy for the capability and competence of public organisations.

3.3.2.3 Legitimacy

Third, the extent to which an organisation can implement, change, or interpret a policy is furthermore defined by a public organisation's legitimacy. ‘Legitimacy’ refers to the democratic legitimation and legality of an organisation – whether or not it is allowed and mandated to fulfil a particular task – but also includes the extent to which other actors in the network accept the organisation (cf. Bekkers et al. 2016; Klijn and Edelenbos 2012; Klijn and Koppenjan 2016; Papadopoulos 2000). Legitimacy also “reflects the perception that the production of information and technology has been respectful of stakeholder’s divergent values and beliefs, unbiased in its conduct, and fair in its treatment of opposing views and interests” (Cash et al. 2003, 8086). Policy implementing agencies need to show this aspect of legitimacy to fulfil their role within society – as a representative of the state. For this reason, in turn, legitimacy also defines the influence of an organisation (cf. Mitchell, Agle, and Wood 1997), e.g. concerning its freedom to interpret policies flexibly, to enact discretion, or to delegate tasks to other actors (both public or private). Note that inaction, i.e. the decision not to pursue a particular change, not to interpret a policy in a specific way, or not to show flexibility when implementing a policy, equally depends on the organisation’s legitimacy (i.e. its legitimacy not to do something).

A public organisation’s legitimacy defines the scope of its (in)actions when implementing a policy and institutional change. This means that if an organisation is considered trustworthy, has a positive reputation, is deemed important, and contributes markedly to society's well-being or structure, its influence on institutional arrangements can be more prominent. In turn, public organisations with less legitimacy are more closely bound to their mandates and their line ministry's instructions. Moreover, an organisation's legitimacy shapes the creation and reception of feedback loops. Whereas an organisation with higher legitimacy can form more influential feedback loops and is more likely to be heard, it is also less likely to be receptive to change resulting from feedback (due to institutional stickiness and path-dependence). The reverse is true for younger and smaller public organisations. Hence, the more legitimacy a public sector organisation has, the more creatively it can interpret and experiment when implementing policies. This includes the discretionary implementation of mandates for executive agencies but also the interpretation of regulations for regulatory agencies (or executive agencies that also have regulatory responsibilities), such as through exemptions. Accommodating this might require a change of coordination modes, which is more feasible if public agencies have more legitimacy. For this purpose, the TIS+ framework contains the 'creative regulation and experimentation' element as a proxy for legitimacy to detect public sector organisations' influence on innovation systems.

3.3.2.4 Norms/Values

Fourth, the underlying values, norms, ideas, and purposes inherent to public organisations shape their institutional change approach. Norms and ideas can also shape attitudes to change, both regarding the organisation (institution) itself and its impact. It includes, but is not limited to, the basic tenets of the governance structures that align the organisation with other institutions in the governance system but can also refer to the ideas behind the formation of the organisation and the associated problem it is meant to solve. Today, this is often embodied by visions or missions towards which the organisation supports or works. Missions, as discussed previously, "indicate a clear direction […] with ambitious innovation actions, […] are delivered through multiple top-down and bottom-up activities, and co-created via cross-disciplinary, cross-sectoral and multi-level relationships" (Vinnova 2019). This means that they span "several stages of the innovation cycle [… and] cross various policy fields" (OECD as quoted in Wesseling et al. 2020). Such missions can lead to the accumulation and surge of efforts towards achieving this overarching goal across government organisations

– and can even include private sector organisations. The joint understanding of this common goal, hence, can lead to better-coordinated actions.

Although public administrations' primary objective is the implementation of policy, they are usually considered a part of the government apparatus just like other actors, e.g. those responsible for policy design. Therefore, they are, to some extent, likewise expected to represent the motives and strategies for which executive government actors stand – who might have, for example, campaigned along a specific idea or value. In the context of (mission-oriented) innovation systems, elected officials and often also the society expect the public administration to enact missions. Public organisations are more likely to impact innovation systems and/or impact institutional change if the underlying values and goals align with the government's overarching missions. On top of that, institutional change is more likely if several (or all) actors related to a particular institution (see 'embeddedness' above) simultaneously attempt to initiate a change. This is especially the case if the proposed changes are fundamental, e.g. breaking out of a path-dependent trajectory. If stakeholders are aligned along a common goal or mission, this becomes easier. Therefore, institutional change also depends on the presence, awareness, and acceptance of a joint mission across government organisations – a 'common goal-orientation'. Accommodating new norms, such as addressing a complex challenge through mission-orientation, might require a change of coordination modes, which becomes more feasible to enact if such norms are aligned across public organisations. For this reason, the TIS+ framework considers the 'common goal-orientation' element as a proxy for underlying norms and values in the public administration.

3.4 Conclusion

The longitudinal analysis in this chapter revealed that approaches to policy coordination in the context of innovation policy have changed throughout time. Governments amended their coordination strategies in response to actor preferences, the policy issues they had to govern, structural constraints, and path-dependent pre-conditions. Institutional arrangements define the implementation of innovation policy and, crucially, the extent to which policy coordination can change. In turn, the behaviour and role of public administrations in innovation systems – their power, capacity, legitimacy, and the norms and values that guide their goals – can trigger institutional change. Hence, institutional change in the innovation policy context occurred due to both exogenous and endogenous factors. Therefore, institutional analyses should consider actor-specific, structural, and path-dependent perspectives to avoid reductionist conclusions.

The combined institutional analysis in this chapter rendered four key characteristics of public sector organisations that define their ability to change institutions. These align with the public-administrative elements introduced in the previous chapter and form an integral and novel part of the 'TIS+' model in this thesis: 'centrality and leadership', 'capacity and independence', 'creative regulatory experimentation', and 'common goal-orientation'. The TIS+, hence, combines different angles: the actor-focused policy perspective, a structural system-oriented lens, as well as historic and institutional analyses. The framework highlights the complementarity of these approaches to answer complex policy questions and, thus, forms the ideal foundation for this thesis.

The institutional change factors and public-administrative elements link as follows: Power refers directly to an organisation's position in the network and reflects to what extent an organisation can take on a leadership role. This feature, hence, corresponds to the first public-administrative element in the 'TIS+' framework ('centrality and leadership'). Note that this might not have to be the largest or most central organisation. Instead, smaller organisations can also take on leading roles in the network – yet they must have the power to do so. The capabilities and competences, i.e. the capacity required for institutional change, are likewise reflected in the analytic framework as element two, the 'capacity and independence' of (public) organisations. The third element, 'creative regulatory experimentation', consequently, corresponds to the legitimacy aspect discussed above, as it depends on this institutional factor whether or not an organisation, such as a regulatory or executive agency, can (re)interpret a policy more freely, adapt it, or change it altogether. Lastly, the underlying values that align public sector organisations towards a unified attempt for institutional change feature in the analytic framework as 'common goal-orientation'. Hence, all four aspects that are found to be relevant for public-administrative organisations to initiate institutional change are also included in the framework to analyse their impact on innovation (systems).

The remainder of this thesis investigates the transition across coordination modes and the associated institutional change comparatively in three case studies in the contemporary contexts of Singapore, Estonia, and Sweden. The respective chapters explore the changes in coordination modes for innovation policy and innovation systems by focusing on the example of AVs.

4 Autonomous Vehicles in Singapore: Hierarchical Coordination

4.1 Case Introduction

This chapter explores the governance arrangements for the technological innovation system of AVs in Singapore until 2020. Generally, "Singapore is subject to a very top-down approach when it comes to policymaking" (SG04), mainly featuring a hierarchical approach to policy coordination, where top-down command-and-control measures dominate. Regarding innovation and transport policy, the public administration also follows this hierarchical approach (SG03, SG04). However, as the innovation system developed, features of network-oriented coordination have been increasingly incorporated. This is a consequence of the challenges that emerged from governing the complex network of actors underlying the multi-technology challenge associated with AVs. The regulatory framework, which was not fit to govern AVs, the actor-network that includes numerous stakeholders across the public and private sectors, and the need for improved information exchange across organisations required a more collaborative approach. This approach features purpose-built cooperation fora, a central 'one-stop shop' for manufacturers and developers, and the orientation towards common goals and visions to resolve Singapore's transport challenges. In this arrangement, the government emerged as an enabler of the AV innovation system. As a result, Singapore today features a hybrid hierarchical-network mode of policy coordination for AV innovation.

The dominant hierarchical policy coordination mode in Singapore results from the politico-economic context in the country (Section 4.2). The single-tier structure, paired with a strong presence of the main political party, and a dedicated strategy to make Singapore one of the world's most competitive economies, leads the government to maintain a decisive role across policy domains. Singapore's statutory boards, i.e. governance agencies, who implement policies, are equipped with strong mandates. Singapore does not feature a solid industrial landscape regarding motorised vehicles. Instead, the government actively pushes innovation in high-tech and service sectors through government-funded programmes, RD&D support, or direct engagement with novel technologies. In the case of AVs, the Land Transport Authority (LTA) – an executive and regulatory agency responsible for transport-related matters – maintains a central role in the AV innovation system. The LTA is a statutory board, i.e. a "corporatized autonomous entity [where] the top managers are assigned with considerable autonomy in financial, personnel, and other operational matters" (Haque 2009, 10). Among others, the LTA's engagement with the AV innovation system through pilot studies and partnerships led to the system developing in a sophisticated way, despite its early stage (Section 4.3).

According to public administration theory, we would expect that the government controls actors in the innovation system for AVs through state intervention, top-down rules, authority, and power, with the aim to steer the system in the direction desired by the government. However, whereas the government's role is strong, it also emerges as a network participant and enabler of the innovation system. The LTA runs AV pilots together with industry partners, initiated a regulatory sandbox to allow experimentation, and created an inter-governmental committee to exchange experience and analyse the development of AVs. The LTA also became the central point of contact for manufacturers. The 'learning by doing' strategy coalesces the interests of manufacturers and researchers with the government's intention to advance road safety, transport efficiency, and implement mobility solutions rapidly. These are network-oriented features, which Singapore's government incorporated into its governance arrangement for AVs, complementing the hierarchical approach, to facilitate and enable the growth of the innovation system (Section 4.4).

The case study reveals that the hierarchical coordination mode alone is insufficient to govern complex multi-technology innovations, such as AVs. Coordination mechanisms associated with the network-oriented mode can complement existing approaches to resolve stumbling blocks emanating from the complexity of such innovations. They accommodate the multitude of stakeholders, represent multiple interests, and allow for cross-organisational learning, both among government organisations and between government and industry. This means that policy coordination modes can change[61], depending on the subject matter, the policy domain, and the challenges that emanate from there. Singapore's AV innovation system emerges as a hybrid form of policy coordination between the hierarchical and network-oriented modes, which induced the innovation system to advance to its current state.

4.2 Context and Background of AV Innovation in Singapore

4.2.1 Structure, Actors, Interaction: Politico-Economic Overview

The politico-economic structure and the role and interaction of the different stakeholders in Singapore's innovation eco-system define the AV innovation system's output. Politically, the Republic of Singapore features a single-tier government structure and inherited a Westminster-like governance model – a relic of British rule – yet transformed the model into a unicameral system, where the 'People's Action Party' has been the dominant political actor since independence from Malaysia in 1965 (Singh 2017), including for shaping Singapore's economic development (Haque 2009). Opposition parties play only a minor role[62] (Mutalib 2003). To maintain its status and influence, the People's Action Party recruits promising individuals through a meritocratic cadre system, forming an elite group within the party, which offers a pool of talented junior politicians to fill essential posts throughout the government apparatus (Chee 1985). As such, the party significantly influences state agencies or even state enterprises, the media, and other organisations associated with the state or the party[63] (Singh 2017). Continuous economic success additionally preserves the incumbent party's power[64].

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[61] Policy coordination modes are hardly implemented in a pure fashion. "The majority of the coordination practices are considered unstable, flexible and changing" (Lægreid et al. 2014, 14). Dominant modes exist, however. In constantly advancing innovation systems such shifts may continue in the future.

[62] Three Prime Ministers have governed Singapore: Lee Kuan Yew (1990-2004), Goh Chok Tong (2004-2010), and Lee Hsien Loong (since 2010), all members of the People's Action Party.

[63] A wider discussion of these factors and the influence of the People's Action Party is beyond the scope of this thesis, but can be found in Singh (2017), Mauzy & Milne (2002), or Mutalib (2003).

[64] This phenomenon is known as the 'pro-government bias' (Oliver and Ostwald 2018).

Singapore's public administration, equally based on the UK model, likewise relies on a meritocratic system as a determinant for promotion and positions of leadership (Quah 1996; Singh 2017), expecting to attract the 'best and brightest' for roles of responsibility in both the party and the government (cf. Low 1998; Quah 1996). The "administrative system has been characterized by political neutrality, permanent tenure, centralized structure, [and] loyalty based attitude" (Haque 2009, 6). Singh describes this system as follows (2017, 42):

> "Singapore's civil service is concerned with efficiency, implementation, coordination, planning, and optimising the policy process, while political leaders are mainly concerned with the effectiveness, ideology, changes, and optimising the outcomes that can benefit and legitimise them politically. […] The reality is that the civil service, due to its close relationship and interdependency with the political leadership and government structure, finds it difficult to maintain a truly natural position. It generally takes on either: (a) a subservient role, (b) a representative role, or (c) a combination of the two."

In practice, as a government official explains, "a lot of what makes this system work has to do with the close relationships between people. It is a unique HR system; the government knows its people. The layers of senior management know each other. This means they just call each other when they have a problem, and everybody knows this" (SG02).

Singapore's 'Statutory Boards' are government agencies "for greater managerial autonomy and operational flexibility" (Haque 2009, 10) that have the responsibility to autonomously "perform specific functions" (Tan 1974, 102). They are created through legal acts of parliament, which, in turn, define their rights and powers in statutes (Quah 2010) and are overseen by and report to a ministry, yet do not form part of the civil service (cf. Haque 2002). Financially, they are dependent on the government and their respective line ministry, as their budget need ministerial approval and as they remain accountable to the government's audit office (Ow 1976). Their purpose is to improve the implementation of primarily national development policies, lower the burden on the civil service, increase its administrative performance, and offer talented Singaporeans a government-related job market to favourable conditions (similar to the private sector) (Quah 2010). Among others, statutory boards maintain the infrastructure and essential services such as housing and urban planning, ensure environmental sustainability, regulate transport and traffic, and promote economic activity and innovation (*ibid*.). Examples, particularly relevant to the topic of this chapter, include the LTA overseen by the Ministry of Transport, Enterprise Singapore and the Jurong Town Corporation (JTC) overseen by the Ministry of Trade and Industry, and the Government Technology Office (GovTech) attached to the Prime Minister's Office (PMO).

The Singaporean economy with 6 million inhabitants has been growing rapidly since its independence. Due to its lack of natural resources and its geopolitically strategic location, Singapore emerged as a trading nation (GovTech Singapore 2020; Maritime and Port Authority of Singapore 2020). In recent decades the country grew into a stable service economy (forming 70% of GDP), featuring, among others, strong financial, insurance, IT, and retail sectors (Oatley 2012). Singapore ranks third globally in terms of per capita GDP (by purchasing power parity) (Department of Statistics Singapore 2020). Among others, the economic growth led to significant investments into the country's infrastructure, including the expansion of the island, broadband, and public transport, but also the road network, roadside technologies such as smart traffic lights and signage, and vehicle-to-vehicle/vehicle-to-infrastructure communication (cf. Schwab 2019) – all relevant technologies for AVs. The Autonomous Vehicles Readiness Index (AVRI), accordingly, ranks Singapore second in the sub-category 'infrastructure' (as well as second overall) (KPMG 2019), pointing towards its lucrative infrastructure set-up for AV development.

In terms of vehicle manufacturing, Singapore does not boast a large industry. There is no significant industrial history of car or truck manufacturing, other than a few suppliers and several large but foreign firms that produce vehicle parts (software/hardware) on the island[65]. In addition, Singapore employs a strict car ownership regime – the vehicle quota system – where customers require a

[65] A useful indicator for the production capacity of an economy is its 'product space', representing "the relatedness of over 800 goods" (Harvard University Growth Lab 2020b). Countries usually expand their economic activity towards products in the vicinity of existing capabilities or skills, thus following a certain path-dependence "based on the connectedness of its knowhow" (*ibid.*). Based on this indicator, given the low density of vehicle manufacturing in Singapore, a development into this direction would not be expected.

government permission to purchase a motorised vehicle and must pay multitudes of the original sales price due to a government levy (Diao 2019; Huiling and Goh 2017; Yuan 2018). Experts nonetheless label Singapore as a frontrunner regarding AVs and, as mentioned, place the country among the readiest to implement AVs on a larger scale (KPMG 2019).

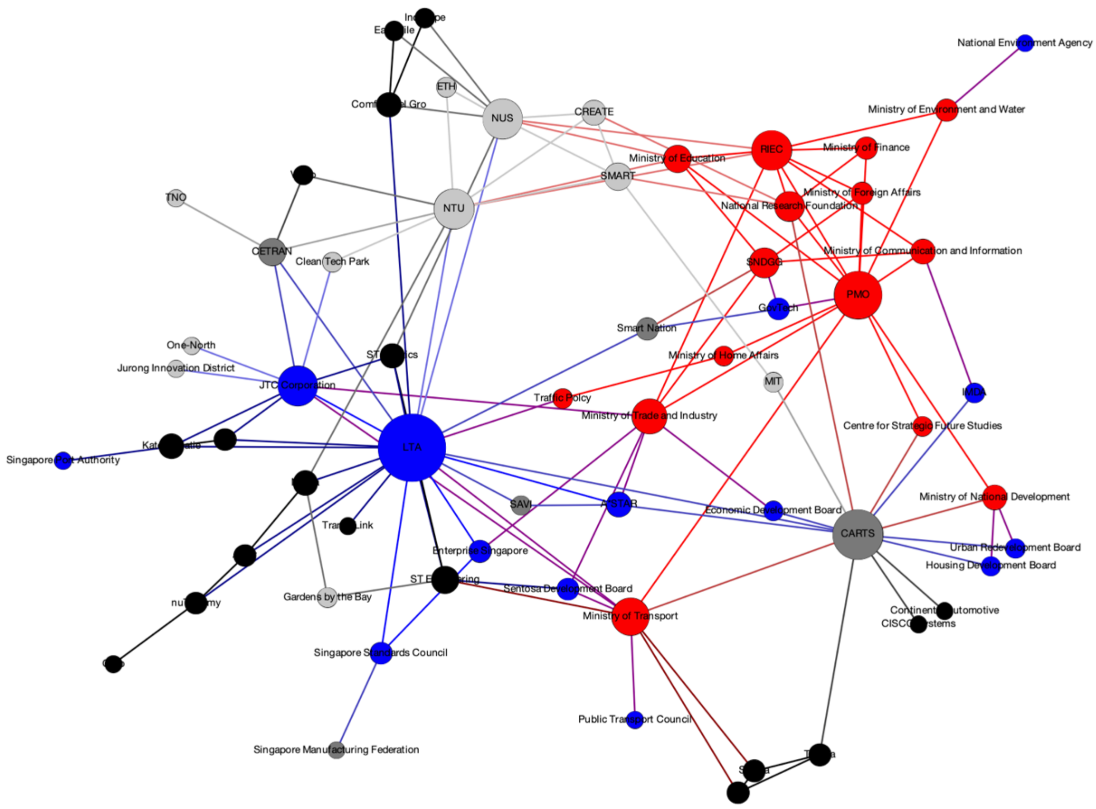

Figure 4.1: Singaporean AV innovation network visualisation[66]

Turning to the specific actors within the AV innovation system, and as shown in Figure 4.1, the AV actor-network for Singapore reveals a relatively highly connected network without many isolated nodes. The nodes representing ministries and the PMO (red) cluster mainly towards the upper right side of the network visualisation. Numerous government agencies (blue) perform central roles within the network, in particular the LTA. It is the by far most connected node (in terms of degree and centrality measures; see Table 4.1). The majority of interaction in the network occurs through or with the LTA. The analysis reveals

[66] A larger node size implies a higher degree; red: government, blue: government agencies, black: private sector firms, dark grey: intermediaries, light grey: other including research organisations.

that the LTA forms the most influential node, measured by eigenvector centrality. All other nodes are significantly less central, with the second-highest ranking node in terms of eigen centrality only achieving about half of the LTA's score. Other central organisations are the Committee of Autonomous Road Transport for Singapore (CARTS), the PMO, and the Ministry of Transport[67]. They score highly across all centrality metrics. Knowledge development organisations, such as the Singaporean universities, are neither central to the network nor isolated. They form direct links to the LTA, on the one hand, and to companies who conduct AV trials, on the other. This means they contribute to knowledge formation and diffusion and have a linking function in the network. The number of private sector actors in the network is limited, as the manufacturing and production sector for AV remains small (vehicles of international manufacturers are used instead). An increasing number of AV start-ups emerged at the fringe of the network, however.

Metric	**Highest**	**2nd Highest**	**3rd Highest**
Degree	21 (LTA)	14 (CARTS)	13 (PMO)
Eigenvector centrality	1.000 (LTA)	0.5453 (PMO)	0.5330 (RIEC)
Betweenness centrality	0.4639 (LTA)	0.2440 (CARTS)	0.1458 (Ministry of Transport)
Closeness centrality	0.5688 (LTA)	0.4882 (Ministry of Transport)	0.4769 (CARTS)
Hubs	0.4423 (LTA)	0.2370 (PMO)	0.2338 (JTC)

Table 4.1: network metrics for Singapore's AV innovation network

The network analysis reveals that Singapore's AV innovation network is relatively small, with a total number of 63 nodes and 125 edges. Government agencies in the form of statutory boards hold a central position in the network, especially the LTA, but also the JTC and A*STAR (Singapore's Science and Technology Agency). These public sector organisations are also the most influential nodes as they are involved in most node interactions, especially regarding AV trials and research projects. This suggests a coordination structure where government organisations play a central role and maintain influence – as

[67] A complete list of actors in Singapore's AV innovation system can be found in the appendix.

expected in a hierarchical coordination approach. However, highly connected purpose-built organisations such as the intermediary 'CARTS' as well as the large number of linkages between public organisations overall hint towards increased cooperation among organisations. These are features customarily attributed to the network-oriented coordination mode. Hence, the observations in the network analysis trigger the re-iteration of one of the research questions this thesis asks: What is the role and influence of public agencies in complex innovation systems?

4.2.2 Singapore's Politico-Administrative Coordination: the Hierarchical Mode

Singapore's approach to coordinating innovation policy, in line with other policy domains in the country, is predominantly based on what Bouckaert, Peters, and Verhoest (2010) refer to as the 'hierarchical model' (see Figure 4.2). Accordingly, the interaction of politico-administrative actors is based on Weber's bureaucratic theory "with its emphasis on the division of labour […] and on rules, procedures, and authority as coordination instruments" (Bouckaert, Peters, and Verhoest 2010, 36). Principally, this means that the legitimacy to govern is based on power, i.e. by "overcoming resistance to their expressed desires through the use of the law, budgets, and, if absolutely necessary, legitimate coercion" (Bouckaert, Peters, and Verhoest 2010, 37). In this model, coordination occurs mainly hierarchically between the central government and other organisations. Consequently, the interaction among public organisations is coordinated quasi-automatically. This does not mean, however, that the central government precisely defines every action. Nor is it the case that only government organisations enact government policy. Other non-governmental actors (e.g. firms, R&D facilities, etc.) can also fulfil government-defined functions on its behalf. In other words, statutory boards that govern a particular policy domain (e.g. the LTA) or area of the city (e.g. the JTC) inevitably cooperate with other stakeholders in the innovation network under this hierarchical regime.

In the hierarchical coordination mode, the government and government ministries are the most central actors who design (innovation) policies. The top-down routine not only defines the design of policies, however, but also their implementation, their supervision, and their evaluation (SG04). These tasks rest mainly with statutory boards. In practice, this means that the government purposefully designs policies or projects before they are passed on to either statutory boards or other actors in the innovation system for implementation. In conjunction with the single-tier governance structure, this process allows the government to align policies along a commonly devised objective or mission. As a result, the hierarchical structure supports the notion that an employee of GovTech emphasises: "If the government wants something done, it will get done" (SG02). In other words, common goals can be disseminated across governance organisations rapidly and directly due to the hierarchical structure. For example, the government and the directors of statutory boards jointly consider housing policies, urban development, infrastructure projects, public transport, vehicle regulations, environmental sustainability aspects, or digitalisation issues (SG06). This step resembles a feature of network-oriented policy coordination.

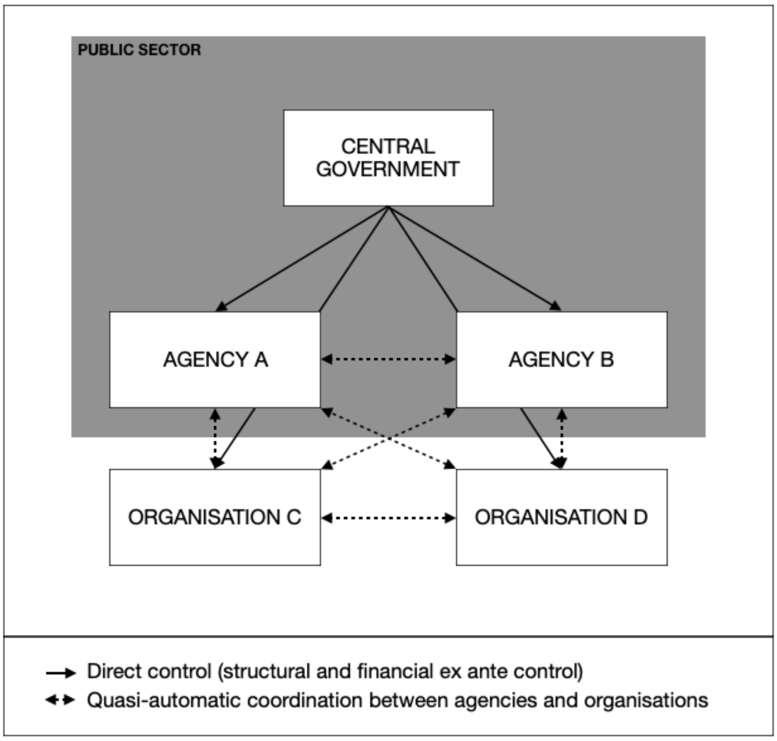

Figure 4.2: hierarchical coordination model[68]

[68] adapted from Bouckaert, Peters, and Verhoest (2010, 40)

This also means that the party-political influence of the People's Action Party is discernible in both policy design and implementation. Personal networks span across party and organisational domains, which enhances mutual trust, public servants often rotate across governance organisations which improves cross-organisational communication, and the cadre system with the presidential fellowship programme ascertain a continuous high quality of staffing in leadership positions.

Concerning innovation, the government can be seen as the undisputed rule-maker who defines interactions between the other actors in the innovation system through programmes, rules, or targets (SG02, SG04, SG06). Accordingly, the innovation system in Singapore is steered by the government through its hierarchical policy coordination approach. This dynamic is emphasised and in parts catalysed by the political and financial dependence of innovation system stakeholders from the government, as is the case for statutory boards (by constitutional arrangement) as well as many research facilities or state-owned enterprises (by funding arrangement).

In the case of AVs, companies running pilot projects require permits which they obtain from the LTA, the executive agency also responsible for transport regulation. Thus, most aspects regarding AVs are in the hands of a single agency, the LTA, which enables improved alignment and the minimisation of time lag during the permit process, but also allows for experimentation with regulations (see below). Firms have a significant advantage as they only have to deal with one government agency instead of several different ones. The LTA can impose restrictions to ascertain that safety and security requirements are met. It has an unambiguous mandate covering all aspects of road transport, traffic, infrastructure, and maintenance. Although they are a separate organisation (a statutory board), they are overseen by the Ministry of Transport, limiting the scope of the LTA through command-and-control mechanisms and budgeting. The LTA is an organisation with a remarkable capacity and over 5000 well-trained employees (as generally observed throughout Singapore's public sector), recruited via the government's meritocratic cadre system (SG04). The LTA also closely collaborates with research organisations and the private sector to source adequate knowledge.

4.2.3 Innovation and Innovation Policy in Singapore

Singapore's government maintains a central and vital role throughout the country's innovation ecosystem. The central government (such as ministries) and public agencies (such as statutory boards) are directly or indirectly involved in Singapore's innovation systems. This also applies to AVs. Due to Singapore's single-tier government structure, many traditionally split tasks across multiple levels of governance (i.e. in larger countries) are concentrated in only a few organisations. The PMO as the primary representative of executive power is responsible for the innovation policy portfolio. It is supported, among others, by two statutory boards: the Government Technology Agency ('GovTech') and the National Research Foundation (NRF). By virtue of its policy domain, the Ministry of Trade and Industry is also preoccupied with innovation and serves as the line ministry of several innovation-related statutory boards, e.g. 'Enterprise Singapore' or the 'Economic Development Board'. The Ministry of Transport is responsible for innovation in the transportation industry, the Ministry of Information and Communication for internet-related technologies. The AV innovation system includes all of these stakeholders (see appendix).

Complementing the government, Singapore's Agency for Science Technology and Research (A*STAR), the Smart Nation Singapore Programme (SNS), and the NRF are three central actors in Singapore's innovation eco-system and also shape the innovation system of AVs. A*STAR is a statutory board under the Ministry of Trade and Industry with the mission to "advance science and develop innovative technology to further economic growth and improve lives" (Agency for Science Technology and Research Singapore 2020). A*STAR connects academic and commercial endeavours regarding RD&D activities by collaborating with large, multi-national corporations as well as with smaller Singaporean firms and even start-ups (*ibid*.). The agency's overarching vision, to make Singapore "a global leader in science, technology, and open innovation", is embodied in three missions regarding healthcare, sustainability, and urban living for the benefit of Singapore's community (*ibid*.). A*STAR hosts and funds various technology centres, research clusters, a graduate academy, a research accelerator, as well as a commercialisation and technology transfer office (*ibid*.).

The SNS initiative launched in 2014 and pushed the development of 'smart technologies', e.g. AVs. The idea of an innovative, 'smart nation' has become a part of Singapore's self-image (SG11). The government-initiated programme funds the development of 'smart' technologies across the pillars 'digital economy', 'digital government', and 'digital society' (mainly) through procurement (Smart Nation Singapore 2020c). This includes the digitalisation of Singapore's public transportation and infrastructure (*ibid*.). SNS funded several autonomous shuttles and autonomous minibus trials (e.g. in 2019) and plans to continue this engagement. The Smart Nation and Digital Government Office oversees this programme, which is implemented by GovTech (Prime Minister's Office Singapore 2017). Both are responsible to the PMO (*ibid*.).

The NRF was set up in 2006 as a department of the PMO and is responsible for the overarching direction of RD&D in Singapore. It advises the PMO on science and innovation-related policies (National Research Foundation Singapore 2019). Its mission is to "transform Singapore into a vibrant R&D hub that contributes towards a knowledge-intensive, innovative, and entrepreneurial economy and make[s] Singapore a magnet for excellence in science and innovation" (*ibid*.). For this purpose, the NRF funds individual ideas and projects as well as research programmes for AI and cybersecurity, among others. The NRF hosts the 'Campus for Research Excellence and Technological Enterprise' (CREATE), which offers space for (international) university collaborations, among others AV tests.

Furthermore, Singapore's universities contribute directly to Singapore's innovation eco-system. This refers above all to the National University of Singapore (NUS) and Nanyang Technical University of Singapore (NTU), which build the backbone of the country's academic research and training environment[69]. At rapidly expanding campuses in Singapore's West with almost 70,000 students combined, NUS and NTU offer a broad range of courses and host various international research centres (Nanyang Technological University Singapore 2020; National University of Singapore 2020). Smaller universities and many private organisations offer additional degree and research

[69] NUS and NTU are the only Singaporean universities included in international university rankings. For 2020, THE ranks NUS as 25th and NTU 48th globally (Times Higher Education 2020), whereas QS ranks both universities jointly as 11th globally and best in Asia (QS 2020).

programmes, shaping the country's technology-intensive skills base. See Appendix 1 for a list of actors involved in Singapore's AV innovation eco-system.

Numerous international innovation indices[70] confirm Singapore's innovative strengths (see Table 4.2). They highlight the "enabling environment" (Schwab 2019, 506) for economic activity based on its institutions, its infrastructure, its macroeconomic stability, and its public sector performance (Quah 1996). The Global Innovation Index[71] portrays Singapore's 'institutions' (global rank: 1), but also its 'human capital and research' (global rank: 5), and the country's 'business' and 'market sophistication' (global rank: 4 and 5, respectively) as fundamental strengths (Dutta, Lanvin, and Wunsch-Vincent 2019).

Index	**Index Scope**	**2017**	**2018**	**2019**	**2020**
Global Innovation Index[72]	global	7	5	8	8
Bloomberg Innovation Index[73]	global	6	3	6	3
Global Competitiveness Index[74]	global	3	2	1	-
Economic Complexity Index[75]	global	5	5	-	-
R&D Investment Index[76]	OECD	18	20	-	-
AV Readiness Index[77]	selected countries	-	2	2	1

Table 4.2: Singapore's rankings in innovation-related indices 2017-2020

[70] Countries rank differently across these indices as definitions and assumptions about 'innovation' and innovation-related practices vary across studies and because different methodologies to measure 'innovation' render different results. Moreover, the purposes and funding arrangements of these studies vary (also see Section 2.3.1).

[71] The 'Global Innovation Index' lists 'institutions', 'human capital and research', 'infrastructure', 'market sophistication', 'business sophistication', 'knowledge and technology output', and 'creative outputs' as proxies for the ability to innovate (Dutta, Lanvin, and Wunsch-Vincent 2019). Each indicator consists of a range of sub-indicators.

[72] The 'Global Innovation Index' by Cornell University, INSEAD, and the World Intellectual Property Organisation measures overall innovation-related parameters (Dutta, Lanvin, and Wunsch-Vincent 2017, 2018, 2019, 2020).

[73] The 'Bloomberg Innovation Index' gathers general innovation-related metrics (Bloomberg 2017, 2018, 2019, 2020).

[74] The 'Global Competitiveness Index' by the World Economic Forum annually measures the competitiveness of global economies, which can be considered a proxy for innovation (Schwab 2017, 2018, 2019).

[75] The 'Economic Complexity Index' emerged from the 'Atlas of Economic Complexity' and measures the sophistication of economic activities across countries based on the knowledge intensity of products and services as well as the relatedness of such products and services(Harvard University Growth Lab 2020a).

[76] The 'R&D Investment Index' measures the share of GDP invested into R&D activities (OECD 2020).

[77] The 'AV Readiness Index' by KPMG assesses the physical, knowledge, political, and economic infrastructures across countries with regard to AVs (KPMG 2017, 2018, 2019, 2020).

Overall, Singapore today is one of the most innovative and competitive economies globally, not just technologically, but particularly concerning services – a trait that is characteristic of the country's economy. The state in the form of the government and the associated statutory boards plays a central role in the country's innovation system. Whereas the PMO and the ministries remain responsible for policy design, the statutory boards hold a strong position when implementing policies. Due to their central role in the network, they also act as a coordinator between research centres and universities, international enterprises and start-ups, as well as between other government organisations. What does this mean for the AV innovation system? The following section explores Singapore's AV innovation system in detail.

4.3 Technological Innovation System Analysis for AVs in Singapore

The TIS analysis for AVs in Singapore reveals an early yet mostly established innovation system. It shows that hierarchical dynamics are key to the system's foundation but also hints that network-oriented characteristics are responsible for resolving some of the roadblocks that emerged in the early phase of the TIS. The government and the statutory boards are the primary enablers for the cooperative features of this hybrid approach.

4.3.1 Function 1: Knowledge Development and Diffusion

Even without any large-scale vehicle manufacturing in Singapore, the 'knowledge development' concerning AVs is strong. Primarily, this is a result of the RD&D activities by Singapore's universities (SG06). Both NUS and NTU successfully developed components, software, and pilot projects for AVs and, together with external partners, implemented AV tests (Huiling and Goh 2017; Nanyang Technological University Singapore 2019; Smart Nation Singapore 2020a). NUS considers AVs a "promising mobility solution" and ascertains that "the knowledge and experience gained from this trial [at NUS] will bring us closer to the day when autonomous vehicles become a common safe mode of transport and, with citizens who are comfortable with embracing new technologies, we can then further entrench Singapore's standing as a smart nation" (Yu 2019a). Three organisations promote AV-related research at universities: the Centre of Excellence for Testing and Research of Autonomous Vehicles at NTU (CETRAN), the Singapore-MIT Alliance for Research and Technology (SMART), and the LTA.

CETRAN was founded after the successful first AV pilot in August 2016 by the LTA, the JTC, and NTU. Based at 'Cleantech Park' in the Jurong Innovation District, it hosts a testing circuit (on private grounds), simulating real traffic and city conditions typical to Singapore in a 'living lab' (Nanyang Technological University Singapore 2019). CETRAN also launched a virtual testing environment, where traffic simulations and future mobility models complement the AV pilots (Smart Nation Singapore 2020b). The AV testing and research at CETRAN are meant to inform policymakers regarding the user experience, human-vehicle interaction, and the perception of AVs in a novel urban environment (SG06). CETRAN attracts international AV manufacturers, software programmers, and industry partners, e.g. Germany's BMW (CETRAN 2021).

SMART was founded in 2007 by MIT and the NRF. Based at CREATE, it supports research collaborations between international and Singapore-based research organisations, like NUS and NTU. CREATE also hosts researchers from the Swiss Federal Institute of Technology Zurich (ETH) and the Technical University of Munich (Smart Nation Singapore 2020b). Thus, through CREATE, the building of "knowledge about AVs involves quite a bit of transfer from foreign-based start-ups" (SG11). SMART dedicates its research efforts and resources to components of AV-related technologies. The 'Future Urban Mobility Interdisciplinary Research Group' within SMART "aims to develop […] a new paradigm for the planning, design, and operation of future urban passenger and freight transportation systems that enhance sustainability and societal well-being" (Singapore-MIT Alliance for Research and Technology 2019). SMART ran an AV trial in One-North in 2016.

To foster AV knowledge diffusion in the government, the Ministry of Transport and the LTA took several measures. Among others, they formed the Committee of Autonomous Road Transport Systems (CARTS)[78]. It is attached to the Ministry

[78] CARTS will be discussed in further detail in section 4.3.3.

of Transport but includes leaders and representatives from other public organisations, private firms, and research centres. CARTS exemplifies how Singapore's public service builds ties with globally leading universities and firms to source knowledge and expertise about emerging technologies to inform government action (SG02). For the same reason, groups of civil servants regularly participate in (overseas) study trips to learn about technologies, innovation, and practices in foreign public-administrative systems (SG02). In addition, the LTA seeks input from other countries (both actively and passively) to learn about AV standards and regulation (SG08), e.g. through connections in Sweden. The LTA also requests manufacturers and developers to send feedback concerning their AV tests and overall experience in the country (SG07, SG08). This serves to improve the process and to expand knowledge about AVs in the agency further. Thus, "the government does try its best to stimulate knowledge sharing among the public and private entities" (SG11).

Overall, the 'knowledge development/diffusion' for AVs across Singapore occurs through multifaceted channels. Some are purpose-built (e.g. CETRAN, CARTS), others emerge organically and complementarily to existing mechanisms (e.g. university spin-offs, SMART). The LTA maintains a strong position and controls the development of knowledge channels, as it is involved in most efforts as a funder or direct stakeholder. This effort shows how "Singapore seeks to provide fertile ground and testbeds for local firms to learn and search for options during their exploratory stage" (Wong et al. 2018, 59). As a result, AV knowledge emanates primarily from universities and smaller firms. The government learns from interaction with these organisations. Hence, the 'knowledge development and diffusion' function reveals that a hierarchical structure pushed for the emergence of an AV knowledge cluster, complemented by network-oriented features promoting cooperation and inter-organisational learning.

4.3.2 Function 2: Entrepreneurial Activity

The 'entrepreneurial activity and experimentation' regarding AVs in Singapore increased substantially since the first pilots occurred in 2015. Numerous enterprises settled in Singapore, testing and producing parts and software for AVs, including smaller firms such as Movita, and larger corporations, like Bosch, Volvo, and Continental (SG07). Much of this 'entrepreneurial activity' occurred in the purpose-designed innovation districts at Sentosa and Jurong, where NUS and NTU are located as well. NUS is testing an AV in One-North (Jurong) jointly with a large, local public transport company, ComfortDelGro. NuTonomy[79], a university spin-off that produces AV software, in cooperation with Delphi, began trialling a 'mobility on demand' service with autonomous minibuses at CETRAN. Besides, NTU and ST Kinetics started an autonomous bus trial. Further testing occurs in surrounding areas and will expand even further in the near future, e.g. as part of the official public transport network connecting living districts to the main train lines (Land Transport Authority Singapore 2017a). The agglomeration of stakeholders in the One-North district enables collaboration between local universities and entrepreneurs, funders, international firms, and the government. The government actively stimulated the engagement of firms willing to test their innovations by supporting trials financially in conjunction with research projects (as discussed above) or by making trials lucrative for international firms.

Table 4.3 shows a list of AV trials in Singapore.

Year	Location	Operator	Vehicle	Status
2015	One-North	A*STAR Institute for Infocomm Research	self-developed	completed
2015	One-North	NUS / SMART	various	ongoing
2016	One-North	nuTonomy	various	ongoing
2017	West Coast Highway	Ministry of Transport / PSA / Toyota / Scania	various	completed
2017	Jurong Island	Katoen Natie / VDL	various trucks	ongoing
2017	Gardens by the Bay	Gardens by the Bay / ST Engineering	EZ10 by EasyMile	ongoing
2017	NTU Campus	NTU	Navya 'Arma'	ongoing
2019	NUS Kent Ridge Campus	ComfortDelGro / NUS	EZ10 by EasyMile	ongoing
2019	NTU Smart Campus / SMRT bus depot	NTU / LTA / Volvo Buses	Volvo 7900 e-bus	ongoing
2020	Jurong Island / NUS	LTA / ST Kinetics	ST autonomous bus	planned

Table 4.3: AV pilots completed, ongoing, or planned in Singapore

[79] NuTononmy, a spin-off company of the SMART initiative led by MIT, was later purchased by Delphi, which then turned into Aptiv (Aptiv 2020). Aptiv continues to be an active stakeholder in the Singaporean AV innovation system.

To enable and incentivise 'entrepreneurial activity', the government took various measures. This includes creating innovation districts in specific geographical areas, establishing a regulatory sandbox, passing amendments to existing legislation, expanding the test areas for AVs and providing subsidies and tax incentives (see below) (SG02). Similarly, the Ministry of Transport actively invited new business models that incorporate the AV technology (SG02). These measures signal to entrepreneurs and innovators that the government generally supports the development of the technology, in this case, AVs. The government's rationale was based on the 'smart nation narrative' and the realisation that the complexity of the AV technology surmounts the existing potential in the country such that Singapore would not be able to match the rapidly unfolding international dynamics in this sector (SG04). In response, new companies (start-ups) formed, existing firms expanded their portfolio, and multinational corporations entered the Singaporean innovation system. Many firms also approached the LTA and the Ministry of Transport, expressing their views and needs regarding government support (SG04). Thus, "Singapore has been relatively efficient and successful in bringing in some of the best AV companies across the world to launch their AV trials in the city-state" (SG11).

Overall, 'entrepreneurial activity' for AVs has markedly increased in Singapore, mainly due to research partnerships and small firms focusing on AV components. Singapore's government creates an enabling environment for such activities through focused and targeted top-down policy design and implementation, particularly through LTA involvement (SG06). The government, hence, "fuels" AVs and AV entrepreneurship (Roy 2019) – mirroring the hierarchical approach from Singapore's public-administrative model. However, network-oriented features supplement this hierarchical approach. This includes, but is not limited to, the public-private sector collaboration, the responsiveness of the government to private sector needs, and the regulatory and financial support. The orientation towards shared goals, e.g. making Singapore the leader in smart technology innovation and relieving some of the transport-related bottlenecks, aligns public and private sector interests and fosters new, collaborative business models. The government and the LTA, hereby, are network participants and enablers rather than top-down controllers.

4.3.3 Function 3: Guidance of the Search

Singapore's government guides the search for innovative solutions in the space of urban infrastructure, transportation, and mobility actively. This includes AVs, which are considered as "efficient, environmentally friendly, time-saving and stress free [and] could transform our lifestyles" (Ministry of Transport Singapore 2020). The government responds directly to several challenges concerning a growing and ageing population, a labour shortage, the expansion of town centres within a limited land area, and consequently, a stark increase in the demand for efficient and clean public transportation (Land Transport Authority Singapore 2020b; Quek 2017). The transport challenges have also been a major topic in recent elections (SG02, SG04). The key strategies to achieve a sustainable transport system focus on reducing private means of transport, the increase of public transport use, and the encouragement of cycling and walking (Quek 2017). By 2030, public transport use is meant to have increased from 67% today to >80% (Future Agenda 2020). Moreover, the Ministry of Transport emphasises that "a combination of new technology, new business models and forward-thinking regulation is needed to meet our needs. And AVs will play their part in this" (Ministry of Transport Singapore 2020). Accordingly, the value proposition for AVs includes an increase in productivity and road safety, the optimisation of road capacity, new mobility concepts, and additional R&D value add (Quek 2017).

In mid-2014, the government established CARTS, a committee attached to the Ministry of Transport. Its task is "to steer the strategic direction of AV-enabled land mobility concepts" (Ministry of Transport Singapore 2014). CARTS members meet twice a year, closed to the public. The committee operates as a consultative forum, chaired by the Minister of Transport. Members include representatives from the government, the private sector, and research organisations, both domestic and international[80]. CARTS, jointly with the LTA and A*STAR, launched the 'Smart Autonomous Vehicle Initiative' (SAVI), which

[80] Members include the chief executives of the Land Transport Authority (LTA), the Housing Development Board (HDB), and the Urban Redevelopment Authority (URA), the deputy Minister of National Development, the managing directors of A*STAR, the Economic Development Board (EDB), and the Infocomm Development Authority (IMDA), as well as professors of Singaporean and international universities and representatives of private firms, including Cisco, Toyota, and Continental. A full list of members can be found via the Ministry of Transport (2014).

serves to propel RD&D into the technical aspects of autonomous driving, e.g. by promoting further relevant infrastructure improvements (Ministry of Transport Singapore 2020). Hence, CARTS brings together most major stakeholders involved in the AV innovation system and allows the government and the LTA to understand what companies need to progress in their technological innovation endeavours regarding AVs (SG07).

CARTS enabled the testing of AVs on public roads and advocated for incorporating AVs into Singapore's public transport system, namely through pilot projects in the Jurong Innovation District, Punggol, and Tengah. CARTS members aimed at including the private industry, research organisations, and government organisations in these pilots to establish "the key requirements and enablers needed for the successful pilot deployment" (Land Transport Authority Singapore 2017a). In 2015, the LTA launched a first call seeking "proposals on how AV technology can be harnessed" (Land Transport Authority Singapore 2015). CARTS emphasised a holistic approach beyond the technology, including infrastructure requirements, business models, system management and operation, and optimal usage and deployment models (*ibid*.). The chairman of CARTS explained that "the pilot deployment will take us into the next phase of the roadmap set out by CARTS for the deployment of AVs in Singapore when we begin to progressively deploy AVs as a form of public transport in our towns. Safety and accessibility will be our top priorities" (*ibid*.). The first AV pilots, hence, were a result of a strong government push and the consequential cooperation across the industry, government, and academia. Simply put, "getting AVs on the road is a government initiative" (SG06; similarly also SG04).

To further promote AV testing, the LTA expanded the AV testbed on public roads. In several steps, the testing area grew from 6km to 12km road space in September 2016, then to a total of 67 km in June 2017, including the Sentosa and Jurong islands, the innovation district One-North in Singapore's Southwest (Toh 2019), as well as 'Cleantech City' around the NTU campus (Land Transport Authority Singapore 2017b). In October 2019, test grounds expanded further, covering almost 1000 km of road space across half of Singapore (Toh 2019). This allows "robust testing" across the entire range of road and traffic conditions[81] (Yu 2019b) (see Figure 4.3). The 'expansion strategy' embodies the government's responsiveness to the needs of private firms. The LTA CEO explained that "we want to create an open platform in One-North, where the industry, research institutions, and the authorities can jointly conduct Proof-of-Concept trials, to provide the basis for future deployment in other sites" (Land Transport Authority Singapore 2015). The LTA itself has announced its intention to initiate a further large scale AV pilot in the early 2020s, further bolstering its interest in the technology (Yu 2019b).

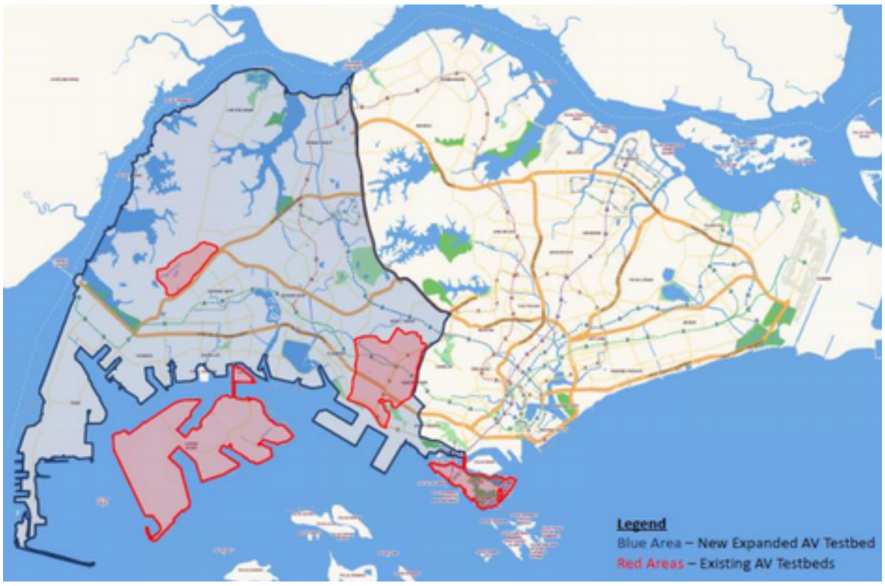

Figure 4.3: map of Singapore's old (red) and new (blue) AV test areas[82]

According to the Ministry of Transport, AVs are meant to form a part of the public transport network in Singapore, substantiating the 'walk-cycle-ride' strategy that prioritises public, active, and shared transport modes, as the 'Land Transport Master Plan 2040' indicates (Land Transport Authority Singapore 2020c, 2020b). The city's expansion strategy foresees pre-defined corridors connected by road and rail that bring the suburbs closer to the existing city centre (Diao 2019). As quoted in Diao (2019, 327), the integrated and automated approach to last-mile transportation designed to be

[81] Testing remains subject to prior LTA approval, vehicles must pass a strict safety assessment (Yu 2019b) and continue to be required to have a safety driver on board (Toh 2019).
[82] Source: Yu (2019b)

> "smart, inclusive, and green helps Singapore's transport system to achieve greater efficiency to support economic development, retain affordability to enhance social equity, and mitigate transport emissions and pollution to improve environmental quality, thus achieving a sustainable transport system".

The master plan, hence, guides the general transport development in which AVs are embedded in Singapore and serves as an indicator for entrepreneurs.

Moreover, the government guided the AV innovation system through regulation, particularly by introducing a regulatory sandbox in 2017 (Singapore Government 2017a, 2017b). The sandbox enabled the transport regulator, the LTA, "to create and amend rules governing autonomous mobility activities in the city-state" (Yu 2019b). Two years later, the government introduced national AV standards primarily regarding passengers' safety and security in and outside of the vehicle (Land Transport Authority Singapore 2019). These form a guideline for manufacturers and developers intending to bring their vehicles to Singapore. This amendment to the existing regulation, the Road Traffic Act, is known as 'Technical Reference 68' or 'TR68' (Singapore Standards Council 2019). It refines regulations for AVs regarding data protection and cybersecurity (cf. Lago and Trueman 2019). Overlapping policy domains were taken into account by the policy design[83].

Furthermore, Singaporean officials promote the AV technology avidly through remarkably consistent and positive rhetoric, stressing in nearly identical wording the potential of AVs as a solution to some of Singapore's mobility challenges – they emphasise the mission. Accordingly, AVs can make Singapore's roads safer, smooth the city's traffic situation, make transportation more environmentally friendly, and offer additional mobility options to the elderly and disabled (Yu 2019b). The following examples illustrate this narrative:

> "AV shuttles could radically transform mobility by enabling more efficient dynamically-routed or on-demand forms of shared transport and have greater potential for realising the promise [of] full autonomy".
> – *Senior Minister of State for Transport, Janil Puthucheary* (Yu 2019b)

[83] See section 4.4.3 below for further details on 'regulatory experimentation' regarding AVs.

> "With the ability to self-drive, AVs have the potential to optimise road capacity by moving in a compact, systematic manner. They can also provide greater connectivity for first and last-mile travel and facilitate the efficient sharing of vehicles."
> – *LTA Chief Executive, Chew Men Leong* (Land Transport Authority Singapore 2015)

> "AV technology can greatly enhance the accessibility and connectivity of our public transport system, particularly for the elderly, families with young children, and the less mobile. Through the pilot deployment, we can gain insights into how we can design infrastructure, organize services and formulate regulations to better facilitate the safe use of AVs in Singapore."
> – *Minister for Infrastructure and Minister for Transport, Khaw Boon Wan* (Land Transport Authority Singapore 2017a)

> "Deploying AVs for shared transport will help enhance our first- and last-mile commute and bring greater mobility to the elderly and other commuters who may have difficulties in taking public transport today."
> – *LTA Chief Technology Officer, Lam Wee Shann* (Land Transport Authority Singapore 2017b)

> "These shuttles, trucks, buses could quite significantly transform mobility in Singapore, enabling more efficient, dynamically routed or on-demand form of shared transport."
> – *Senior Minister of State for Transport, Janil Puthucheary* (Toh 2019)

Hence, the joint narrative emphasises that AVs are a means to an end, rather than an end in themselves, to resolve mobility challenges. The consistency behind such remarks highlights the direction in which the government hopes to see the AV innovation system develop. It also reasserts the government's support to entrepreneurs (see above) and increases the technology's legitimacy (see below). "A lot depends on rhetoric concerning innovation", states a member of GovTech, and adds that "the government is really behind this, making sure that everybody knows what they want to see" (SG02). Aligning this narrative across different governance organisations reveals a joint vision about Singapore's future, generally, and about the core mobility challenges, in particular. Such collaborative and consensus-oriented features are common in network-based governance coordination modes rather than in hierarchical modes.

In an overarching manner, "establishing a dynamic innovation hub that supports high-tech manufacturing and R&D had become a national development agenda" (Mok 2015, 92). This goal, ultimately strengthening Singapore's competitiveness, also motivated AV development (*ibid*.).

Overall, the government actively guides and advocates for the innovation and implementation of AVs in Singapore (SG10, SG11). It attempts to create an environment beneficial to this endeavour by engaging with all stakeholders in the innovation system (SG07, SG10). "The government is very proactive in thinking about the future of mobility. It is seriously investigating the possibilities as well as preparing for a regulatory environment that will facilitate a future that is autonomous" (KPMG 2019, 15). The government is "very determined and pro-tech" that actively requests technological solutions from companies, making it "a question of 'when' rather than 'if'" AVs will roam Singapore's roads (SG07). This indicates a strong and authoritative role of the central government. However, "a hierarchical structure as we typically know from Singapore", as the former Head of the Futures Strategy Unit at the Ministry of Transport explains, "is not possible in these circumstances [...] as command-and-control measures don't work here", adding that "the case of autonomous transport and the particular field of AVs is different" (SG04). Instead, network-oriented coordination features such as collaboration among public agencies and aligned goals and policies to avoid overlap are critical to remove blocking mechanisms and enable AV innovation. Here, "network governance by the Ministry of Transport and the LTA helped" (SG04). In this sense, Singapore's governance organisations deliver "a unified and orchestrated effort, eager to push the technology forward, and the conductor is the government" (SG10).

4.3.4 Function 4: Market Formation

The AV TIS in Singapore is still in its maturing phase. Consequently, a large-scale institutionalised and dynamic market does not (yet) exist. However, as a global front-runner in the AV technology (KPMG 2019), Singapore attracts investment and firms from within the country and abroad. Their activity concentrates on small and medium-sized shuttle buses as well as autonomous freight transporters. This can be explained by the relatively high entry barriers for AV manufacturing, the tight individual car ownership regime in Singapore, and its central role in global trade. Companies such as ST Engineering, for example, focus on autonomous cargo vehicles for Singapore's harbour and Changi Airport (SG10). In other words, shuttles and autonomous trucks are the most likely AVs to be implemented in Singapore (SG10).

Companies increasingly trial the commercial feasibility that could sustain the AVs. In July 2019, Singapore's local transport provider 'ComfortDelGro', in cooperation with NUS, launched a one-year, fixed-route autonomous shuttle pilot (Yu 2019b). The goal is to explore how a business case could look like for AVs that are incorporated into the existing public transport system.

In addition, the government's urban planning initiatives provide indirect opportunities for a future AV market. Due to Singapore's limited size and demographic context, the government plans to expand the city towards the island's outer parts (Land Transport Authority Singapore 2020a, 2020c). Mobility solutions to cater for this development have been outlined in the 'Transport Master Plan 2014 for Singapore' (Land Transport Authority Singapore 2020c). AVs feature as a possible solution. In fact, "the government plans new neighbourhoods based on AVs" (SG06). Hence, the government could be a commercial partner in the future for AV firms (Wong et al. 2018).

Overall, the AV market in Singapore remains in a very early stage. Yet, given the local context and prerequisites, a market could form with the support of the government. The Ministry of Transport and the LTA actively encourage firms to settle in the country, invest, and test their technologies and business models. This strategy follows a top-down 'master plan' that emerged from the government's overarching goals. In the future, Singapore's government could coordinate AV implementation through market-based mechanisms or network-oriented features, e.g. by creating joint projects and purpose-built organisations or by procuring AV services. This remains to be seen.

4.3.5 Function 5: Resource Mobilisation

As the innovation system is still in its early stages, resources mobilisation occurs primarily to support the basic development of the technology and components, such as software, as well as AV pilots. Financial resources emerge from the private sector, but also directly and indirectly from the government. The Minister of State for Transport declared in October 2019 that significant investments are underway regarding AVs (Toh 2019), refraining from citing precise amounts. The LTA, specifically, has been supporting AV trials financially (SG07). The NRF and its associated programmes, like SNS or CETRAN, provided additional (public) funds. For the fiscal year 2017, the government supported 'smart' initiatives, including AVs, via SNS with SGD 3.5 billion (GBP 1.85 billion) through procurement rather than direct subsidies or grants (GovTech Singapore 2017). The government, hence, "is the major entity that funds the innovation and implementation of AVs in Singapore" (SG11).

Figure 4.4: autonomous bus by Volvo, NTU, and the LTA[84]

Further financial resources emerged from international firms through collaboration projects with local research organisations or companies. Volvo, for instance, launched an AV pilot with a sizeable autonomous bus (fitting 80

[84] Photo: Nanyang Technological University Singapore (2019)

passengers; see Figure 4.4) – a novum globally – and tested the vehicle at CETRAN (Nanyang Technological University Singapore 2019; Yu 2019c). Volvo chose to pilot this unique bus in Singapore because “the journey towards full autonomy is undoubtedly a complex one, and our valued partnership with the NTU and LTA is critical in realizing this vision”, as the President of Volvo Buses explained (Nanyang Technological University Singapore 2019), indicating a clear affinity to Singapore as a feasible and useful test ground. Other firms investing and developing AV technologies in Singapore include, but are not limited to, the Japanese car manufacturer Toyota, the German car part supplier Continental, and the US-based ICT conglomerate CISCO (Hwei 2014). These foreign investment arrangements have partially been enabled through public-private partnerships upon the initiation of Singapore’s government (SG11).

In terms of knowledge resources, numerous basic research and training programmes (e.g. at Singapore’s universities) contain themes and projects that are beneficial for the AV sector, both in terms of product development as well as skills and knowledge training. This includes the technical development of sub-components whose immediate target purpose is another than AVs but are still used in these vehicles, such as sensor technology, GPS mapping, or 5G connectivity (SG07).

Overall, both private and public resources contribute to the development of the AV innovation system. Singapore’s government remains a principal funder which in turn also incentivises private investments (SG03). Government investment in innovation-related activities is generally high in Singapore (SG09) and is likely to increase further, particularly for AVs (SG10). The involved public organisations work in close cooperation with private firms and academic organisations to enable the innovation system to emerge further.

4.3.6 Function 6: Legitimacy Creation

Legitimacy for the AV technology is created through various public and private efforts in Singapore, helping the technology become accepted. The government's above-mentioned initiatives to promote AVs also support the ‘creation of legitimacy’ for the technology, mainly because trust towards Singapore's government is high, even during challenging times (Edelman 2019). The rhetoric by government officials, above all the PMO, stresses the different use cases for AVs (SG04) and highlight the associated benefits to tackle Singapore's transport challenges (cf. Haller 2020). Symptomatic for this approach is the government's AV information website, where the Ministry of Transport highlights benefits for residents, especially for vulnerable groups, families, and children (Ministry of Transport Singapore 2020). The website also emphasises passenger safety in AVs (Yu 2019b) – a beacon to gain trust and legitimacy. The government enforces transparency about the measures and policies taken regarding AVs (Yu 2019b). This includes public 'hands on' access to AV pilots (Ministry of Transport Singapore 2020). The government also conducted public consultations about AVs and formed its vision by incorporating society's feedback (SG04).

The LTA, as the executive and regulatory agency for transport-related matters, maintains a reputable, credible, and highly respected role in Singapore (SG07). The Chief Innovation and Technology Officer at the LTA stated that AV testing is "aligned with Singapore's aim to roll out autonomous vehicles to improve accessibility and connectivity for local commuters" (Yu 2019c), strengthening the need for AVs. In its communications about AVs, the LTA permanently stresses that safety remains the top priority for conducting AV trials. In previous statements, the LTA noted that automated transport technologies are not new to the country, as several commuter train lines (the MRT) and the light rail transit already use driverless technologies. This also facilitates understanding and accepting the new technology among the public (Land Transport Authority Singapore 2020d). The LTA continues to plans community engagement programmes regarding AVs (Toh 2019).

AVs have also provoked criticism in the past. Singapore's government and the LTA handle such instances with openness and transparency, not to thwart legitimacy for AVs. In October 2016, after a non-fatal road accident involving AVs, the LTA announced a new partnership with NTU to test autonomous buses more rigorously. This sent a clear signal to both society and industry that the government continues to support the technology only under a strict safety imperative (Yu 2016). Similarly, in 2018 issues concerning camera blind spots of AVs emerged. The LTA's Director for Technology and Industry Development declared immediately that the government would continue to support the technology nonetheless, due to the benefits for individuals and the country as a whole (Land Transport Authority Singapore 2018). He reiterated that "public safety is always the top priority" and highlighted the rigour of existing safety and security procedures (Land Transport Authority Singapore 2018). NTU's Chief of Staff, who is also Vice President of Research, spoke in a similar voice, contributing to 'legitimacy creation' as a representative of a highly esteemed academic and research institution, carrying both saliency and credibility.

The existing AV pilots also promote 'legitimacy creation'. Observing AVs roaming the roads or even riding on an AV stimulates interest and fosters an understanding of the technology (SG11). Many firms incorporate user feedback into their analysis, as ComfortDelGro's group CEO explains: "This passenger service trial provides us with an opportunity to observe how passengers respond to an autonomous vehicle. The operational experience gained will also be invaluable as we prepare for a future where autonomous and artificial intelligence becomes an integral part of our daily commute" (Yu 2019a).

In addition to government and industry efforts, there is a cultural-cognitive element that supports the 'creation of legitimacy' for emerging technologies, in general, and for AVs, in particular. Singaporeans consider themselves as front-runners regarding innovativeness and modern technologies – "it is part of our genes" (SG01). The Nutonomy co-founder states that "people are happy to try out the shuttle buses" (SG07). This attitude is rooted in two separate but related aspects: First, Singapore aims to be the most modern, most competitive, best performing, and most advanced nation in South-East Asia (SG01). This effort becomes particularly visible regarding economic and industrial policies supporting and attracting leading firms, but also technological innovation (cf. Research Innovation and Enterprise Secretariat Singapore 2016). Second, the dogma of 'the best and brightest' is intrinsic to Singapore's socio-economic structure. The meritocratic principle first promoted by Singapore's founding Prime Minister, Lee Kuan Yew, today dominates Singapore's education system, its company culture, and, as discussed above, also its public administration (Quah 2010, 2018) – "it is omnipresent" (SG02). The idea of Singapore as an innovator at the technological frontier is deeply enshrined into the country's cultural-cognitive identity, which quasi-automatically legitimises new technologies such as AVs (cf. Quah 2018; Smart Nation Singapore 2020c). The active promotion of AVs by senior officials paired with the narrative of necessity, the public funding by SNS and NRF (and others), the international cooperation, and the successful AV pilots all enhance trust and lead Singaporean's to trust the technology (SG07, SG09, Smart Nation Singapore 2020a).

Overall, many different actors support the 'legitimacy creation' for AVs in Singapore. The government promotes AVs through policy decisions, explicit rhetoric, and a top-down (hierarchical) approach to establish AVs as a part of the transport system. At the same time, the existing AV trials and research projects allow citizens to experience vehicles first-hand. However, the main factor creating legitimacy is the trust citizens place in the government and its decision to support the technology. In addition, the self-perception of Singaporeans as an innovation nation contributes to AV legitimacy. Legitimacy, therefore, emerges also due to mutual co-optation between the government, industry, and research organisations based on shared goals to establish AVs as a viable alternative to existing mobility solutions. This replaces the initially authoritative relationship between the government and its agencies, on the one hand, and the private sector, on the other. Mutual co-optation, cooperation, and shared goals are features of a network mode of policy coordination and implementation.

4.3.7 Function 7: Positive Externalities

'Positive externalities' can only be determined to a limited extent due to the early stage of the AV innovation system and the lack of large-scale AV deployment to this date. In terms of immediate impact, the development of AVs in Singapore increases the knowledge base about the technology (and related technologies). This can mainly be felt at universities and research centres.

Indirectly, assuming the development and diffusion of the AV technology continue as projected, several indicators suggest positive spill-over effects in the future. First, integrated AVs in the transport system can bring the quickly expanding sub-urban areas closer to Singapore's city centre, as they improve first-/last-mile connectivity to commuter train lines. This can particularly improve access to mobility for citizens of vulnerable groups. Second, shared AVs can increase the efficiency of the transportation network. The smart operation of AVs can reduce road space needed for vehicles, can eliminate the need for parking lots and other vehicle infrastructure, and can decrease the overall number of registered cars. This can lead to less traffic congestion and lower pollution levels – a key concern of many residents and the government (SG04). Third, and as a consequence, shared AVs reduce greenhouse gas emission and improve the environmental impact of the transport system. The government continuously stresses these potential positive impacts of AVs (SG04).

Uncertainty regarding the future trajectory of AVs continues, however[85]. This may affect the potential impact of (positive) externalities. Although some of the advantages outlined above may not emerge, the knowledge and skills gains, as well as the economic activity associated with companies developing and testing AVs in Singapore, can still prove beneficial. The projected externalities rely on an interwoven and densely linked system of actors across the transport sector, technology developers, policymakers and implementers, businesses, and society. The cooperation among these actors to let 'positive externalities' materialise will likely rely on network-oriented approaches across sectors and domains.

4.3.8 Functional Analysis Conclusion

In conclusion, the AV TIS in Singapore, irrespective of its early stage, reveals significant sophistication, especially across functions 1-3, but also regarding function 6. 'Knowledge development' (F1) centres around the two leading universities, NUS and NTU, but is to a large extent also transferred from abroad. Many non-AV research projects, e.g. regarding AI, still benefit the AV innovation system. Smaller firms, university spin-offs, and start-ups contribute to knowledge diffusion through their 'entrepreneurial activity' (F2). Several larger, multinational companies like Volvo and Toyota also test AVs in Singapore. The government and the statutory boards actively support AV innovation by 'guiding

[85] This refers primarily to scenario-uncertainty and variability-related uncertainty (Petersen et al. 2013), as the direction of the AV trajectory overall, but also of essential sub-technologies, is not yet clearly defined. This is due to unknown developments of component parts, policies, or socio-economic parameters that could skew the trajectory of AVs into a different direction.

the search' (F3) through policies and enabling 'regulatory experimentation'. The LTA maintains the physical and, through funding, also the research infrastructure necessary for AVs. This explains, in part, the number of AV pilots in the country. The market for AVs is still small due to the early stage of the innovation system. For now, testing is the priority. However, various transport providers, like ComfortDelGro, are beginning to tap into that market, planning to integrate AV into the transport system (F4). The technology's potential attracts financial and human resources (F5), primarily from the government – channelled via the NRF through programmes such as SNS – but also from private investors. The government's advocacy for AVs increases their 'legitimacy' (F6), which has catalytic effects in an innovation-prone country like Singapore. 'Positive externalities' (F7) are difficult to distinguish at this stage, but the government does not hesitate to continuously outline the potential positive effects for Singapore's society and economy. Hence, given the testbed expansion, continued investments, and the government's ongoing interest, the AV TIS is rapidly growing. Autonomous shuttles could be integrated into the regular transport network within the coming five years (SG05, SG07, SG10).

The Singaporean state is the central actor in the AV TIS. In particular the LTA, but also the Ministry of Transport, serve as central coordinators of innovation activities across all seven system functions. They guide, fund, advertise, signal, legitimise, and regulate the emerging AV sector's activities. This pattern follows largely a hierarchical policy coordination structure. However, several functions also yield a more cooperative approach of government agencies, especially the LTA, complementing the hierarchical structure where necessary with network-oriented features. This includes the close alignment of mission-driven goals and narratives across government organisations, inter-organisational efforts to advise the Ministry on AV-related matters through CARTS, and the partial transfer of jurisdictions to the LTA, forming a 'one-stop shop' for AV companies. It also shows regarding the joint evaluation of policy impacts, the mission-focused funding arrangements of SNS, as well as the formation of a regulatory sandbox and a new legal framework (TR68) which removed regulatory uncertainty. The former head of the futures and strategy unit at the Ministry of Transport explains that the complex technology crossing policy domains "makes cooperation across the government necessary" (SG04). As a result, Singapore's government organisations became network participants rather than top-down rule-makers. The LTA maintains the role as the lead organisation in the network (cf. Provan and Kenis 2008).

Hence, the functional TIS analysis suggests that hierarchical and network-oriented administrative mechanisms shape Singapore's AV innovation system. How do public agencies implement policies, remove blocking mechanisms, and shape the innovation system in such a scenario? The following section will discover this in detail.

4.4 Coordinating AV Innovation: the Hierarchy-Network Hybrid Mode

The innovation system for AVs in Singapore principally reflects a hierarchical approach but also features network-oriented coordination characteristics – rendering a hybrid model. This is a result of the complexity inherent to multi-technology innovation, as embodied by AVs. The government, particularly the LTA, is a central actor in the innovation system, partly funds AV-related projects, creates legitimacy for the technology, amends legislation to accommodate AVs, and coordinates activities surrounding the technology. Purpose-built intermediary organisations, such as CARTS, SAVI, and SNS, contribute to advising the government and promoting collaboration for AVs. The following section analyses how the coordination of the public administration in Singapore contributed to this outcome by discussing the impact of each politico-administrative element (E1-4) on the TIS functions (F1-7) in turn.

4.4.1 Element 1: Centrality and Leadership

The 'centrality and leadership' of public organisations significantly shapes the 'guidance of the search' (F3) for AVs, revealing a high influence. The government, particularly the PMO, the LTA, and the Ministry of Transport through its 'Futures and Strategy Unit', began to promote and advertise the AV technology early on by emphasising its potential to resolve some of Singapore's most pressing transport-related problems. In doing so, the government invites developers and researchers, as well as investors and manufacturers to the country. The responsibility for AVs rests with the LTA, the executive and regulatory agency for transport. “Singapore […] leads a specific measure on having a single government organization that deals with AVs, which improves AV coordination and reduces confusion around who does what” (KPMG 2019, 10).

The LTA employs powerful rhetoric to support and push AVs (a selection of relevant statements has been included above). The Minister of Transport but also the CEO of the LTA repeatedly stress the benefits associated with AVs and the positive impact on everyday life, e.g. regarding accessibility and inclusivity, environmental sustainability, traffic safety, but also reliability and (cost) efficiency (Yu 2016, 2019b, 2019c). Across the media, government publications, and public appearances, the LTA also highlights the projected ‘positive externalities’ (F7), including increased competitiveness, global leadership, and improved skill levels among the workforce (Huiling and Goh 2017; Land Transport Authority Singapore 2015, 2017b; Ministry of Transport Singapore 2014, 2020). The centrality of the agency ensures that these remarks are heard.

The Ministry of Transport’s ‘Future and Strategy Unit’ scrutinises press statements and public remarks by senior officials before these are delivered. “Sometimes it is just about adding a paragraph or two to a Minister’s speech or a sentence here or there to a press release”, the former director of the Ministry of Transport’s strategy unit explains (SG04). She adds: “It is all about public acceptance […] and the government is determined to make this happen” (*ibid.*). Hence, the vocal and practical support of the Ministry and the LTA also has a high influence on creating legitimacy for AVs (F6). The LTA’s central and leading position in the innovation system and its role as executive and regulatory agency renders it the key signalling organisation regarding AVs.

In more practical terms, the LTA as an executive agency initiated and funded some of the early AV pilot programmes through a call for projects, bringing together research organisations (e.g. NTU and NUS) with the private sector, therefore, stimulating ‘entrepreneurial activity’ (F2). To liaise between stakeholders and to incentivise ‘knowledge development and diffusion’ (F1), the LTA relied on existing institutions, such as the NRF or SNS, on the one hand, and created new intermediaries and arenas for knowledge exchange, like CETRAN, CARTS, and SAVI, on the other. The LTA leadership reassures investors, entrepreneurs, and knowledge creators that Singapore is likely to be a profitable future market, possibly with the government as a key customer (F4). This approach 'tilted' the playing field and reduced risk. As transport regulator, the LTA enabled AV pilots by expanding testing grounds, flexibly applying regulations, and preparing amendments to existing legislation. The LTA was able to do so because of its central position in the innovation system, where it can immediately react to feedback and where executive actions have a direct effect.

For 'knowledge development and diffusion' and 'entrepreneurial activity', the lack of a pre-existing industrial landscape for vehicle manufacturing was an obstacle, initially blocking the development of the innovation system (SG05, SG07). Industrial networks between the research sector and industry, as well as value chains within the industry, did not exist. The LTA resolved this stumbling block by arranging, incentivising, and (partially) funding joint projects with international vehicle manufacturers and suppliers, such as Volvo, Toyota, and Continental (SG04, SG07). The LTA emerged as a network enabler.

The government is a pivotal contributor to funds for AVs (F5). Although large proportions emerge from the private sector, funding arrangements via the NRF and SNS support the development of AVs (cf. Hoang 2015), revealing an overall medium influence on the function. The leading efforts by the two key public organisations in the transport space may also support the formation of markets (F4), as it reduces uncertainties related to potential governance interference and regulation. Otherwise, 'centrality and leadership' are less influential concerning these two system functions.

In sum, the 'centrality and leadership' of Singapore's public administration, primarily the LTA, but also the Ministry of Transport, supported the growth of the AV innovation system, especially in its earliest phase. "They were a significant driver to get these things underway because they would be the ones who then go and negotiate with companies, talk to stakeholders, try to marry them with the use cases" (SG04). 'Knowledge formation and diffusion' and early 'entrepreneurial activities' directly resulted from the LTA's vivid advocacy for AVs. This also elevates the technology's legitimacy as a viable solution to some of Singapore's transport challenges. Although the LTA coordinated efforts centrally, it rather emerged as a network participant and enabler than as a mere controller. Its central position allowed the LTA to detect blocking mechanisms immediately and address them, e.g. concerning regulatory uncertainty. Cooperation emerged among public and private stakeholders, including universities and international firms, through CARTS and other purpose-built units. These enabling and collaborative practices diverge from the dominant hierarchical structure in Singapore. Hence, the 'centrality and leadership' reveal both hierarchical and network-oriented coordination approaches to AV governance.

4.4.2 Element 2: Capacity and Independence

The 'capacity and independence' of public organisations in Singapore's AV innovation system affected its development less strongly overall. On the one hand, the LTA is a statutory board and thus, by definition, independent from its line ministry, the Ministry of Transport. On the other hand, the goals and interests of the LTA and the Ministry, as well as the hierarchical oversight arrangement, reveal that the LTA is less independent than the constitutional structure suggests. Concerning capacity, the LTA indicates a strong position. The high skill level of its employees and the organisation's capabilities, in general, allow for direct engagement with firms and research organisations (cf. Quah 2010, 2018). The LTA has specialised units with significant technological understanding (SG08).

The LTA requires the technical capacity to understand the technical aspects of AVs to pass the safety and security assessments attached to the testing permit process. This also applies to decisions about amendments to transport infrastructure, for which the LTA is responsible. These must not thwart the operation of AVs (SG08). Parts of the knowledge and expertise inside the LTA results from CARTS (SG04). Although only a consultative forum, CARTS also feeds information from industry stakeholders and experts back to the LTA and the Ministry of Transport, enabling a link between policy implementation and policy design. Besides, "information and feedback flow into the Ministry of Transport and the LTA from firms directly" (SG04).

Public employees can switch positions within the public sector relatively frequently (SG02, SG04). This may include switches into and from the private sector or academia. Often public employees continue to work on the same (or similar) issues and therefore gain expertise and knowledge about these issues from different perspectives (SG02). Hence, specific governance-related knowledge can flow directly between government, industry, and academia. This practice increases the understanding of guidelines, regulations, and laws and enables smoother coordination across these organisations. Additionally, given the country's small size, it is not unlikely that employees build their own network of colleagues in the civil service and across statutory boards over time. “It is a lot easier when we can just pick up the phone or drop them an email to clarify something” (SG04), a former Ministry of Transport employee admits. This phenomenon valuably adds to the capacity of public organisations. Additionally, foresight activities and knowledge from Singapore’s Risk Assessment and Horizon Scanning system generally “facilitates inter-agency collaboration and pulls together all potentially relevant information from within government as well as from external sources to enable effective information- and perspective sharing across government” (Habegger 2010, 55), in turn contributing to learning and information diffusion across public agencies (SG04). Combined, these aspects highly influence the ‘guidance of the search’ for AVs (F3).

Moreover, the LTA became a ‘one-stop shop’ for manufacturers and operators – a single agency that handles all matters regarding AVs on the state’s behalf. This only works because of the capacity (and centrality) of the LTA. It reduces uncertainties, waiting times, and the risk of misinformation (SG06). In turn, this facilitates processes for the private sector and enhances ‘entrepreneurial activity’ (F2). To enable this, the PMO and the Ministry of Transport transferred some responsibilities to the LTA, relieving other statutory boards, such as the JTC and the HDB, from some of their tasks that might have interfered with the innovation system otherwise, e.g. regarding infrastructure decisions. Hence, the position of the LTA is a result of cooperation among government organisations – characteristics intrinsic to network-oriented coordination mode.

The ‘capacity and independence’ of public organisations are of medium relevance for ‘knowledge development’ (F1), ‘resource mobilisation’ (F5), and ‘legitimation’ (F6). Although the government pushes for ‘knowledge development’, incentivises investments (including its own), and advocates for

AVs, it is other organisations, i.e. research centres, where AV knowledge mainly emerges, and it is the firms and industry stakeholders, particularly from abroad who (for now) invest, in addition to the government. Likewise, it is not the LTA's capacity or the Ministry of Transport that pushes these three system functions, but rather their central role, reinforcing their advocating statements.

The remaining two system functions, 'market formation' (F4) and 'positive externalities' (F7), are only slightly affected by the independence and capacity of public organisations. As described above, the government's effort and signalling promote market activity, mainly because the Singaporean state itself looks like a potential customer for AVs. Similarly, although externalities seem promising for the future, they are not yet distinguishable.

In sum, the 'capacity and independence' of Singapore's public authorities shape the interaction of the LTA and the Ministry of Transport with other stakeholders in the system primarily through the capacity aspect, less so through independence. This affects primarily 'entrepreneurial activities' and the 'guidance of the search', but to some extent also 'knowledge development', 'resource mobilisation', and 'legitimation'. In terms of capacity, network-oriented features complement the hierarchical structure. "It was quite a deliberate strategy to learn together with the private sector. […] It was about trying to find a way of putting things together that would also enable mutual learning, which is why there are a lot of pilots" (SG04). The underlying characteristics of this practice – consensus, shared values, inter-organisational learning, trust, and cooperation – are inherent to network approaches of policy coordination. The LTA participates in the system as a stakeholder, e.g. in CARTS, to learn from other stakeholders. This shows that no purely hierarchical structure is in place.

4.4.3 Element 3: Creative Regulatory Experimentation

'Regulatory experimentation' and flexibility by the transport regulator, the LTA, emerged as a fundamental enabler for developing Singapore's AV innovation system. It influenced mostly 'entrepreneurial activities' (F2) and the 'guidance of the search' (F3) functions.

Initially, AVs fell in between regulatory frameworks and caused uncertainty regarding the testing and commercialising of AVs (SG07). For this reason, in 2017, the LTA created a regulatory sandbox, i.e. the option of testing AVs free from the existing regulatory framework and instead following a set of AV-specific rules substantiating Singapore's Road Traffic Act (cf. Haller 2020; Lago and Trueman 2019). The sandbox implies that "tentative regulations are set to govern AVs, but these are not hard and fast rules, in the sense that they are flexible for amendments based on changing circumstances and new incidents that are developing along the way" (SG11). The sandbox prescribes a three-level test at CETRAN prior to the pilot on public roads. The first phase tests the AV on public roads within a limited perimeter. The second phase expands the perimeter. Phase three removes the safety driver to test the vehicle's responsiveness in (staged) emergency situations – a phase that no applicant has passed yet (SG08). The LTA had made an effort to process permit applications for AV pilots swiftly. Still, the sandbox turned the previously employed exemption model into a more transparent and streamlined process, which took only a few weeks (SG08).

The sandbox model results from "heavy government support" (SG10) and strong engagement of the LTA with industry stakeholders and research centres. Manufacturers and operators provided feedback about their pilots as well as the permit process and also expressed their needs regarding further amendments. This process stimulated inter-organisational learning between public organisations, industry actors, and research centres. On the one hand, policies and regulations could be immediately evaluated through informal mechanisms rather than lengthy formal processes (e.g. by reporting in CARTS meetings) (SG10). In other words, "the government is also learning how to best regulate AV at the moment" in a spirit of "learning by doing" (SG11). On the other hand, knowledge about the legal/regulatory aspects of AVs and the formalities required to obtain a permit flowed from the government to the industry, and the LTA could outline its expectations (SG10). Through these efforts, the LTA could make sure that permit applications are likely to be accepted and closely guide the direction of search (F3) and development of the AV innovation system as a whole. Hence, instead of controlling the regulations top-down, the government participated in the innovation network directly and enabled a beneficial relationship between the regulator and the regulated. The permanent amendment of vehicle regulations to the Road Traffic Act in the form of TR68 (Singapore Standards Council 2019), which embeds new standards for AVs into the legal framework for road transport (Roy 2019), resulted from this process.

TR68 was jointly developed by policymakers, executive and regulatory agencies, researchers, and industry experts under the guidance of the Singapore Standards Council's 'Manufacturing Standards Committee' (Land Transport Authority Singapore 2019). TR68 received widespread support and applause:

> "The joint development of TR68 reflects the close collaboration between the AV industry and government as well as research institutions."
> – *Permanent Secretary of Transport and Chairman of CARTS* (Land Transport Authority Singapore 2019)

> "TR68 provides a strong foundation that will ensure interoperability of data and cybersecurity that are necessary for the deployment of AVs. […] As the AV technology is new, it is encouraging to see local and international experts from the industry, government agencies and academia working together to develop this technical reference together with the Singapore Standards Council, Enterprise Singapore, and LTA."
> – *Director General of the Quality and Excellence Group at Enterprise Singapore* (Land Transport Authority Singapore 2019)

> "It is much welcomed by the industry as it provides autonomous vehicle developers like ST Engineering with clear guidelines that are benchmarked against international standards. This will ensure a smooth transition from the development to the operationalisation of autonomous vehicles in Singapore."
> – *Chief Robotics Engineer and Vice President of the Robotics Business Group at ST Engineering* (Land Transport Authority Singapore 2019)

> "We are happy to have contributed to creating TR68 as it will facilitate the commercialisation of autonomous vehicles in Singapore."
> – *Chief Operating Officer of Aptiv Autonomous Mobility* (Land Transport Authority Singapore 2019)

> "As a partner in nation-building, the SMF is pleased to be a key partner in the development of this set of technical references."
> – *President of the Singapore Manufacturing Federation* (Land Transport Authority Singapore 2019)

Both initiatives, the regulatory sandbox and TR68, triggered increased 'entrepreneurial activity' (F2), "enticing private companies" (SG11), as they removed the uncertainty pertaining to regulatory misalignments – the central blocking mechanisms for firms (and research organisations). Permanently enabling AV pilots triggered an additional 'mobilisation of financial resources' (F5), particularly from the private sector, going beyond the funding acquired from the NRF or associated programs (National Research Foundation Singapore 2016; Research Innovation and Enterprise Secretariat Singapore 2016).

'Creative regulation' influenced 'knowledge development' (F1) to a medium extent. Although the amended regulatory framework reassured the research centres and their immediate private sector collaborators that it would be possible to test AVs in Singapore, it hardly changed the direction, pace, or content of research organisations (SG08). However, the regulations and the safety standards define how developers must construct their vehicles from a safety and security perspective, including the availability of manual controls for a safety driver. Similarly, the 'creation of legitimacy' (F6) received an additional push from TR68 and the regulatory sandbox. They signalled to citizens that the government is 'in control' of the technology, ensuring society's safety and security (SG04). Furthermore, TR68 provided senior officials with additional opportunities to appear in public, praising AVs' safety and future potential.

The experimentation with regulation hardly influenced 'market formation' (F4). It merely means that due to the established regulatory framework, firms can begin to scout the (future) market for AVs, above all for public transportation and last-mile services. The formation of such markets is at a very early stage, however, but could also induce further 'positive externalities' (F7), e.g. skills, competitiveness, or other (economic) knock-on effects and might set a precedence for similar innovations in the future.

In sum, 'regulatory experimentation' and flexibility is at the core of enabling the AV innovation system in Singapore. Initially, the central, powerful role of the LTA, an executive agency and a regulator at the same time, indicated the attempt to establish a hierarchical policy coordination approach. However, the further development of the innovation system, in addition, reveals strong network-oriented features. The regulatory sandbox increased 'entrepreneurial activity' and interest from investors and induced inter-organisational learning across private and public sectors. Hence, the regulatory amendment, TR68, results from cooperation among system stakeholders focusing on a shared goal: the successful acceleration of the AV innovation system. The LTA enabled this development by removing regulatory barriers and uncertainties.

4.4.4 Element 4: Common Goal-Orientation

Common goals influence actors in the AV innovation system and are discernible throughout the system. The overarching narrative utilised by senior officials across Singapore's governance organisations demonstrates shared values and a joint mission to resolve the country's transport needs by improving public transport and reducing individual car ownership. Shared AVs are considered as a contribution to that goal (SG07, SG08) – "access instead of ownership is the rationale" (SG08) (see also Mahbubani 2015). Associated common goals include increased accessibility for the elderly and disabled, improved traffic safety, lower congestion, enhanced reliability and cost-efficiency of transportation providers, less pollution, and better environmental sustainability (Huiling and Goh 2017; Lam 2020; Land Transport Authority Singapore 2015, 2017b; Ministry of Transport Singapore 2014, 2020). Hence, "there is a value system behind these goals" (SG06). Many of the transport system topics took centre stage in the most recent parliamentary election campaign (SG04). In addition, the "AV technology is pushed as this aligns with the overarching goals of the Singapore government to transform Singapore into a smart nation" (SG11). This, in turn, can strengthen Singapore's economy and enhance the well-being of Singaporeans.

Common goals guide government organisations when making decisions regarding AVs (F3). The government's vision is omnipresent, not just across public sector organisations but also in other committees and organisations that are part of the innovation system, such as CARTS, SAVI, CETRAN, and CREATE. The press releases and strategies published by the LTA and the Ministry of Transport reiterate these goals. Senior officials of the LTA or the Ministry of Transport regularly emphasise the common goals underlying the AV efforts the country pursues, which in turn strengthens the legitimacy (F6) of the technology. These consciously designed missions rest on the joint analysis of the predominant challenges Singapore faces by the LTA, the Ministry of Transport, the PMO, and other public organisations – generally an approach associated with network-oriented coordination. Likewise, the way these visions are implemented is typical in network-oriented coordination modes: through cooperation and the creation of purpose-built collaborative organisations, like CARTS and SAVI.

Common goals have a medium influence on the 'development and diffusion of knowledge' (F1) for AVs. They proliferate across research organisations and developers and guide possible trajectories and use cases of AVs. However, they are too high level to alter the technical development of AVs (SG07) substantially. Concerning 'entrepreneurial activity' (F2), the awareness about common goals has contributed to lowering resistance, doubt, and risk aversion of investors and entrepreneurs, as trust in the technology and the government to support it rises. 'Positive externalities' (F7) are at this point only presumptive. However, common goals that focus on the growth of the Singaporean economy and the establishment of Singapore as an innovative smart nation could yield benefits for adjacent sectors, where automation could replace labour intensive and health-threatening jobs undertaken by humans (SG10).

Otherwise, for 'market formation' (F4) and 'resource mobilisation' (F5), the influence of common goals among government organisations is low. Although common goals also exist among industry stakeholders, they are overshadowed by the usual incentives and pressures that market dynamics impose.

In sum, the orientation towards common goals provides a unifying rationale to develop AVs. The government promotes these goals and, therefore, accelerates some system functions. The PMO, the Ministry of Transport, and the LTA have aligned goals. At the same time, goals among businesses and, to some extent, also research centres differ. Nonetheless, the formulation of overarching goals based on shared values and the joint analysis of challenges is a feature of network-oriented coordination.

4.4.5 Public-Administrative Influence: Synthesis

Across many policy areas, Singapore employs a top-down, hierarchical mode of policy coordination. However, in the context of AV governance – an example of multi-technology innovation – network-oriented features complement the dominant, hierarchical structures. These address a set of blocking mechanisms in the innovation system that hierarchical mechanisms struggle to resolve, particularly pertaining to regulation and cross-agency collaboration. Singapore's government "wants AVs to achieve last-mile connectivity within the existing transport network" (SG06) yet realised that "command and control mechanisms won't work here" (SG04). In CARTS, representatives from government, industry, and research organisations advised the Ministry of Transport and the LTA, contributed to inter-organisational learning, and advocated for a regulatory sandbox and a common standard enshrined in TR68. This incentivised entrepreneurs and investors but also guided researchers and manufacturers when developing further components of AVs.Table 4.4 summarises the influence of Singapore's public administration on the seven TIS functions as the "main actor that drives AV innovation" (SG11).

The LTA particularly maintains its central position and is the focal point in the innovation system. The LTA also participates in the innovation system by co-running trials, passing permit applications, and actively exchanging knowledge and experiences about the technology and the regulatory framework, e.g. through CARTS. This way, the LTA can respond quickly to the needs of innovators and entrepreneurs, who in turn advance the AV technology towards the objectives proposed by the government (SG04). This results in a fruitful collaboration between organisations. Thus, the LTA's active role resolves uncertainties and incentivises the innovation system's growth and acceleration. These measures represent network-oriented features, with the LTA as network manager and enabler at its core, rather than in a position as top-down controller. The LTA "is by far the most important governance agency when it comes to transportation [...] and the reason why innovation in mobility works so well in Singapore" (Lam 2020). As a result, the LTA's and the government's engagement with innovators and entrepreneurs of AVs represents a hybrid form of policy coordination, following a mixed hierarchy-network model.

Impact of PA elements ... / **... on the TIS functions**	E1: centrality / leadership	E2: capacity / independ.	E3: creative regulatory experiment.	E4: common goal-orientation
F1: knowledge development/diffusion	high	medium	low	medium
F2: entrepreneurial activity/experimentation	high	high	high	medium
F3: guidance of the search	high	high	high	high
F4: market formation	low	low	low	low
F5: resource mobilisation	medium	medium	high	low
F6: legitimacy creation	high	medium	medium	high
F7: positive externalities	low	low	low	medium

Table 4.4: analysis of public-administrative elements in Singapore's AV TIS

As Figure 4.5 demonstrates, the central government, together with core agencies, form the network relevant to coordinate the policies which affect the AV innovation system. Although the government controls some organisations directly (e.g. in Singapore's case, the LTA), others are simply part of the network and are coordinated quasi-automatically by virtue of being a part of the network. Spontaneous coordination between organisation can also emerge, as the network enables this, e.g. by forming joint projects. In Singapore, this applies to research organisations and some private firms. All actors are interested in maintaining and expanding the network. Hence, although the government has a powerful network position, it *is* part of the network rather than controlling it through top-down mechanisms.

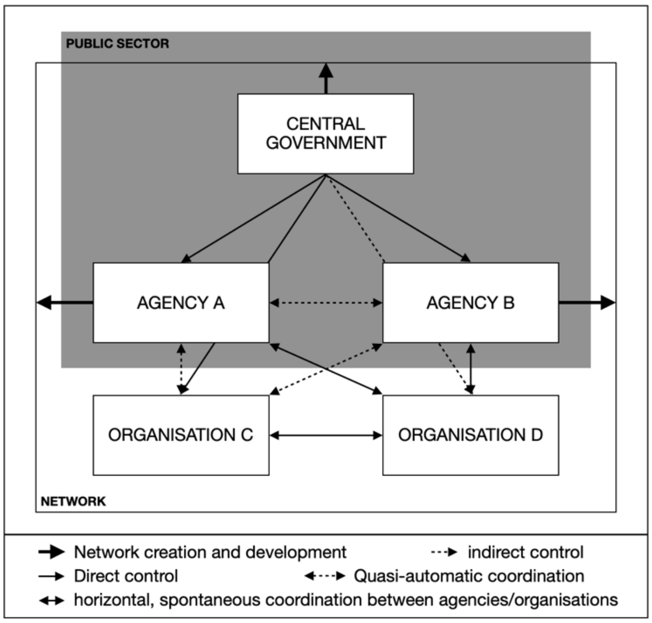

Figure 4.5: hybrid hierarchy-network coordination model[86]

The Singaporean case shows that a purely hierarchical system is not fit for purpose to govern multi-technology challenges, such as AVs. Although some hierarchical structures are maintained across the public sector, stumbling blocks such as regulatory uncertainty and the lack of inter-organisational learning were removed through network-oriented features. Thus, Singapore's public administration governing AVs forms a hierarchy-network hybrid, i.e. a collaborative innovation network that is by and large led by public organisations.

4.5 Case Conclusion

This first case study explored the governance arrangements of the AV innovation system in Singapore and determined the public-administrative influence on that system. The functional TIS analysis revealed a sophisticated innovation system, especially regarding 'knowledge development', 'entrepreneurial activity', 'guidance of the search', 'legitimation', and in parts also 'resource mobilisation'. Numerous RD&D projects and AV pilots are ongoing, the activities of entrepreneurs and investors are expanding, and the government is actively pursuing a transport strategy that includes AVs. However, as the

[86] adapted from Bouckaert, Peters, and Verhoest (2010)

innovation system is still in an early stage, the remaining functions are yet to emerge fully.

The coordination analysis showed that the hierarchical mode commonly observed in Singapore strongly shapes the innovation system. Yet, to remove systemic blocking mechanisms pretraining to regulatory uncertainty and inter-organisational learning, the government resorted to network-oriented mechanisms. This includes the purpose-built CARTS, the creation of a regulatory sandbox and a vehicle standard (TR68), the continuous collaboration between government agencies, and the purposeful design of a common strategy for AVs. The network elements are apt to incorporate the large number of stakeholders across government organisations directly or indirectly governing the AVs, such as the EDB, the HDB, SNS, NRF, or JTC. The measures can also better take into account stakeholders beyond the public sector.

In this arrangement, the Singaporean government emerged as a network participant, enabler, and manager rather than a network controller or market creator. The LTA, at the centre of the innovation network, but also its parent ministry, the Ministry of Transport, advocate and push the AV technology – financially, rhetorically, and symbolically. The LTA is the single point of contact for firms, revealing a partial transfer of jurisdiction to the LTA – another network-oriented characteristic. Consequently, the AV TIS has advanced rapidly, and the city-state remains one of the most active places concerning testing, development, and promotion of AVs as a means of enhancing mobility and public transport in an efficient, reliable, and environmentally more sustainable manner.

Hence, the case study concludes that the hierarchical approach to innovation and policy coordination can be fruitful. However, due to the technical and socio-political complexity and the inherent regulatory challenges, socio-technical innovation systems featuring multi-technology innovations benefit from complementary elements common in the network-oriented mode. Singapore's hybrid hierarchy-network policy coordination approach yields an accelerated advancement of the AV innovation system and a successfully growing AV sector.

Following this analysis of the hierarchical coordination mode governing multi-technology challenges in Singapore, the next chapter turns to the market-based approach, as employed regarding Estonia's AV innovation system.

5 Autonomous Vehicles in Estonia: Market-Based Coordination

5.1 Case Introduction

This chapter investigates the governance arrangements for the technological innovation system of AVs in Estonia, as developed until 2020. The innovation system emerged as a result of market dynamics, similar to other sectors in the country, mirroring the mostly market-based Estonian politico-administrative structures. Generally, governance organisations are relatively independent and coordinate their activities through supply and demand mechanisms. However, as the AV innovation system develops, policy coordination incrementally incorporates elements of a network-oriented coordination model. This results from the complex nature of the AV technology, a prime example of multi-technology innovation. The quickly expanding actor-network, the required administrative and regulatory modifications, and the emerging knowledge space benefit from cooperation rather than market-based competition. The government and its associated agencies hereby emerge as innovation enablers rather than as creators of markets, as they jointly forge common goals around the new technology. As a result, Estonia today features a hybrid market-network approach of policy coordination in the AV innovation system.

The initial market-based coordination approach followed Estonia's post-Soviet politico-economic trajectory, which continues to shape the public-administrative apparatus (Section 5.2). As such, the government provided the initial push for the emerging AV market, in line with the country's self-perception and international reputation as an innovation and start-up hub. In the first AV projects, such as the pilot in Tallinn (in 2017), the central and local governments were crucial stakeholders – as initiators and advisors. Projects were run by companies that provided the technology, paid for RD&D, and operated the vehicles. As interest in the technology and the innovation network grew, the government increasingly stepped back, yet the significance of (executive and regulatory) government agencies increased. Hence, across the early stages of the innovation system, various government actors, e.g. the Government Offices and the Ministry of Economic Affairs and Communication, emerged as advocates of an emerging market for a new technology (Section 5.3).

According to public administration theory, we would expect a further withdrawal of the government and a coordination approach based on competition and 'invisible' market mechanisms. The government would retract to become an independent purchaser of goods. Yet, in the Estonian case of AVs, we observe instead that the government continues to participate actively in the network. The responsible ministries and the regulator participate in projects and contribute to information exchanges, rather than merely procuring services. As a result, emerging challenges, e.g. AV regulation, are approached through collaboration and consensus-seeking between the private and public sectors. Although firms still carry the core burden concerning knowledge and 'market formation' as well as regarding 'resource mobilisation', public agencies directly shape the direction in which the technology develops, based on a common goal: a more efficient, accessible, and sustainable transport system. In doing so, the government also contributes to legitimising the technology. Throughout the more advanced stages of the innovation system, hence, the government and government agencies emerge as network enablers, which contribute directly to the further growth of the network, directly and indirectly promoting the majority of the system functions (Section 5.4).

The case study reveals that multi-technology innovation systems are challenging to govern through market-based coordination approaches alone. Instead, some of the core characteristics of the market-based approach, such as the competition for (financial) resources, profit and loss as a means of evaluating success, or regulations that are designed for existing rather than novel technologies, are inhibiting rather than promoting innovation. Throughout the development of the AV innovation system, network-oriented features began to complement the market-based structures, which are more apt to counter the challenges that emerged within the system and emphatically induce innovation, rendering the government an (indirect) innovation enabler. Estonia today features a hybrid market-network approach to coordinating policies for AVs.

5.2 Context and Background of AV Innovation in Estonia

5.2.1 Structure, Actors, Interaction: Politico-Economic Overview

The politico-economic context and the role of the different actors in Estonia's innovation eco-system condition to a large extent the innovation output, especially regarding AVs. Estonia's unicameral parliamentary system (Riigikogu 1992, 1993) is defined by "multiparty democracy, pluralism, and market economics" (European Bank for Reconstruction and Development 2016, 3). The dominant governance structures are on the national level, with comparatively weaker structures on the local levels (Raagmaa, Kalvet, and Kasesalu 2014). Compared to the other two Baltic states, the political system, parties, and common alliances are well established, less in flux, and widely accepted (Auers 2015; Duvold, Berglund, and Ekman 2020). The eleven ministries form an extremely stable structure in Estonia's political landscape. Their responsible policy domains are usually not amended, regardless of potential changes of government or party coalitions across electoral cycles (EE02). Ministries, which mostly design policies, oversee state agencies responsible for policy implementation pertaining to their policy domain (Sarapuu 2011, 2012). The Ministry of Finance maintains a unique role to direct policy through the budget process (Riigiportaal 2019). Matters pertaining to transportation fall within the Ministry of Economic Affairs and Communication, which also oversees the Road Administration[87], the executive government agency responsible for transport-related policies, and the agency tasked with regulating AVs (Maanteeamet 2020).

The institutional capacity and practices across government organisations since independence in 1991 have grown to align with international standards. Yet, "especially in terms of strategy formulation, design of policy instruments, and policy learning activities" (Polt et al. 2007, 41), trust in politics, politicians, and parties continues to be a problem in Estonia (Ekman, Berglund, and Duvold 2015; Ekman, Duvold, and Berglund 2014). The lack of trust in combination with

[87] The Road Administration is an executive government agency implementing transport policies. It is also responsible for AV permits and tasked with regulating AV safety and security. It is, therefore, at times referred to as 'the regulator' in this thesis.

state interventions failing to address private sector needs de-legitimises the public sector in its relationship with a "fragmented private sector with diverging interests and mistrust towards the public sector" (Karo and Kattel 2014, 96).

Estonia's economic context continues to be shaped by the consequences of the country's independence from the Soviet Union in 1991 (Bohle and Greskovits 2012; Havas et al. 2015; Karo and Kattel 2010b; Karo and Lember 2016; Lember and Kalvet 2014; Suurna and Kattel 2010). The turn towards a market-liberal model and the resulting macroeconomic stabilisation efforts can be considered an antidote to the constraints under which the country previously operated (Karo and Logga 2016; Tiits et al. 2008). The government initiated reforms to pass assets and decision-making powers on to the private sector, to reduce taxes, to stabilise prices, to attract foreign direct investment, and to join the 'Western' trading blocks, such as the EU, the World Trade Organisation, as well as the defence organisation NATO (Lember and Kalvet 2014). These policies align with the political and economic convictions of the time (i.e. the 'Washington Consensus') and are associated with administrative processes defined by 'New Public Management' (Kattel, Kalvet, and Randma-Liiv 2010; Randma-Liiv 2008). Since 2003 FDI has increased immensely (Karo and Logga 2016), as Estonia "became the Baltic frontrunner in terms of economic performance and enacting reforms" (Auers 2015, 180). Estonia is often referred to as the "ideal type liberal market economy" (Karo and Lember 2016, 3) in Central and Eastern Europe, outperforming "the other Baltic states in economic and institutional terms" (Duvold, Berglund, and Ekman 2020, 194). Combined with a continuously low public debt to GDP ratio (European Bank for Reconstruction and Development 2016), this approach explains why Estonia emerged among the most competitive post-Soviet economies, enjoying a positive reputation among international investors (Evenett and Hoekman 2005; Schwab 2019).

Estonia's economy developed across a large variety of goods and services (cf. Harvard University Growth Lab 2020a). The vehicle manufacturing sector and its supply chain remain small in Estonia, with only a few transport and transport-related companies manufacturing in the country (0.06% of global market share) (*ibid*.). Although Estonia features a liberal market economy, larger corporate structures remain relatively poorly developed (Auers 2015; Raudla and Kattel

2011; Thorhallsson and Kattel 2013). The vast majority of private firms (around 99%) are small and medium-sized companies, nearly 90% of which are microenterprises (Kallaste, Kalantaridis, and Venesaar 2018). Estonia, primarily a service economy, grew into a hub for start-ups and technophile entrepreneurs, featuring a comparatively large number of relatively young firms with expertise and business models built on digital innovation and IT (e-Estonia 2017; Heller 2017; Mets 2017, 2018). "Start-ups are growing quickly in Estonia […] a lot of innovation is happening there, [and] this is driven by entrepreneurs" (EE08). As a response, the public administration is primarily guided by the rationale "how can we help them, not stand in the way" (EE08). The country's universities and other educational facilities, but also the government's economic and investment strategies cater for these firms, aiming to attract more economic activity, e.g. through e-residence offers and easy to open businesses[88] with promises to little bureaucracy and red-tape (Kattel and Stamenov 2017; World Bank 2019).

As a result of this economic success, Estonia's infrastructure received a significant boost, catalysing growth and stability. Large amounts of foreign direct investment went towards improving the road network, ports, and Tallinn's airport. To date, much of these improvements centre in and around Tallinn, the country's major agglomeration. Similarly, the telecommunication infrastructure was upgraded across the country, providing a relatively dense coverage with above-average broadband connections compared to other OECD countries (Statista 2020) – a fundamental necessity for the reliability and security of AVs.

Turning to the specific actors within the AV innovation system, as depicted in Figure 5.1, the AV actor-network in Estonia is relatively highly connected without many isolated nodes. The nodes representing government ministries and the Prime Minister's Office (red) cluster to one side of the network diagram and are highly connected but relatively distant to other actors in the network – only a few connections mainly to government agencies, research organisations, or intermediaries remain[89]. Government agencies (blue) form a relatively central

[88] The most recent 'Ease of Doing Business' report ranks Estonia 18th globally, 7th in Europe, and 2nd in Eastern Europe, whereby "a high ease of doing business ranking means the regulatory environment is more conducive to the starting and operation of a local firm" (World Bank 2019).
[89] The municipalities of Tallinn, Tartu, etc. are an exception, as they maintain connections to many pilot projects if these take place within their city limits.

hub in the network, although mostly because the Road Administration (one of the most central nodes) is involved in every single AV pilot due to its role as regulator and assessor of the permit process. Otherwise, most connections (edges) within the network emerged between firms and intermediaries, between firms and research organisations, or among firms themselves.

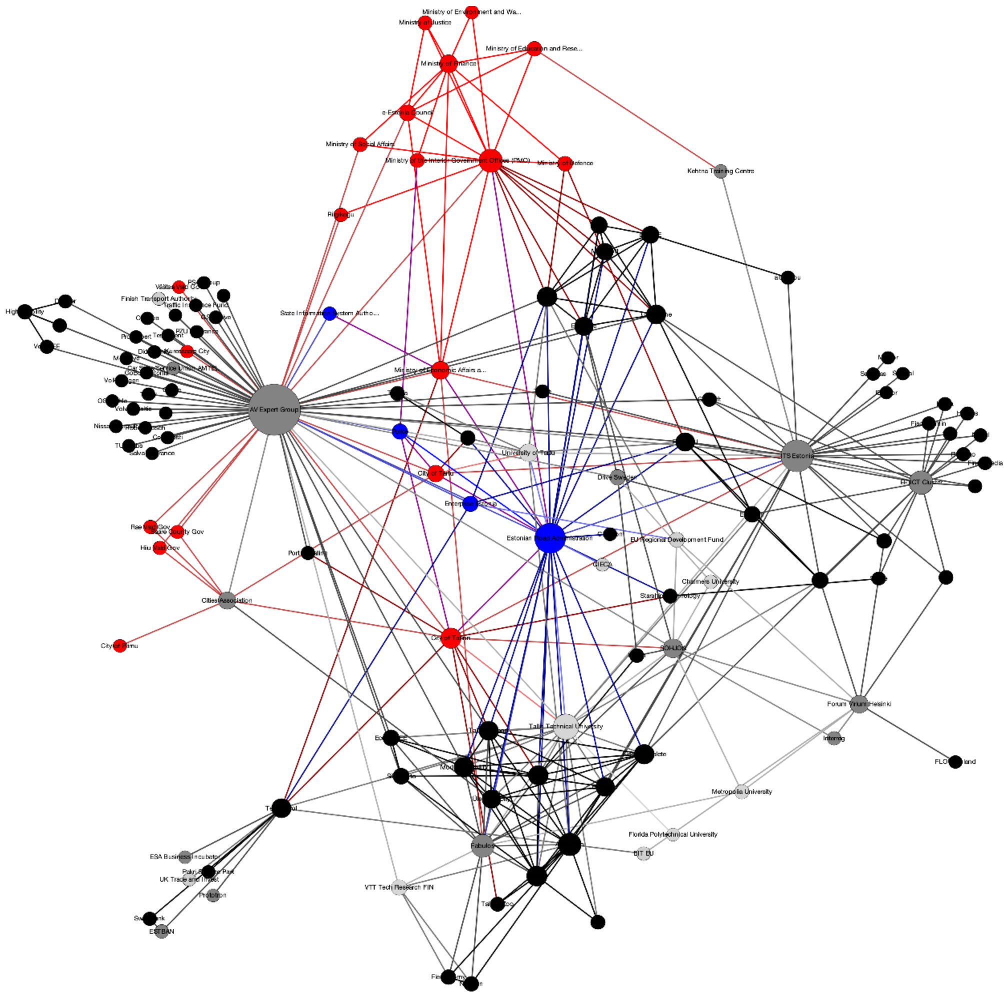

Figure 5.1: Estonian AV innovation network visualisation[90]

The network analysis confirms the centrality of the AV Expert Group (and to some extent also ITS Estonia) – a central forum and also a coordinator for autonomous systems[91]. Not only is the AV Expert Group the most connected actor, but it is also the most central one regarding the measured network centralities (see Table 5.1). This means it is the actor that has (theoretically) most

[90] A larger node implies a higher degree; red: government, blue: government agencies, black: private sector firms, dark grey: intermediaries, light grey: others.
[91] The AV Expert Group will be discussed in detail below.

influence over other actors (eigen centrality) and builds the most efficient link between actors (betweenness and closeness centralities). The clusters forming for AV trials feature the companies involved, the respective municipality, and, as mentioned above, the Road Administration as an executive agency, also responsible for AV regulation. The Road Administration also emerges as a central actor in the network analysis (see Table 5.1). Tallinn University of Technology (Tal Tech) is directly involved in AV trials, emerging as a relatively central node.

Metric	**Highest**	**2nd Highest**	**3rd Highest**
Degree	64 (AV Expert Group)	32 (ITS Estonia)	29 (Road Administration)
Eigenvector centrality	1.000 (AV Expert Group)	0.952 (Road Administration)	0.761 (Tal Tech)
Betweenness centrality	0.580 (AV Expert Group)	0.233 (ITS Estonia)	0.105 (Technopol)
Closeness centrality	0.641 (AV Expert Group)	0.534 (Road Administration)	0.531 (ITS Estonia)
Hubs	0.345 (AV Expert Group)	0.334 (Road Administration)	0.269 (Tal Tech)

Table 5.1: network metrics for Estonia's AV innovation network

The network analysis shows that government organisations, intermediaries, and academic institutions are the network's most central nodes. At the same time, however, most actors in the network are less central private firms. The interaction between them occurs either directly or through an intermediary. This suggests a structure where public agencies are central stakeholders in the innovation system yet not directly involved in (technical) innovation activities. This finding re-iterates the core of this study's research question: What role do government organisations play, given they are central to the network yet do not perform technical innovation task?

5.2.2 Estonia's Politico-Administrative Coordination: the Market-Based Mode

Estonia's approach to coordinating innovation policy is mainly based on what Bouckaert, Peters, and Verhoest (2010) refer to as the 'market-based mode' (see Figure 5.2) (although some network-oriented characteristics are discernible as well (cf. Uudelepp, Randma-Liiv, and Sarapuu 2014)). Accordingly, the interaction between politico-administrative actors is predominantly guided by exchange and competition or emerges spontaneously after negotiation or consultation between two (or more) actors, for instance, ministries or agencies (Bouckaert, Peters, and Verhoest 2010). In this model, the government can create markets through the procurement of goods or services from private firms. In case a market for a particular good/service already exists, the government, according to the theory, can protect and guide this market through policies (cf. Bouckaert, Peters, and Verhoest 2010). Therefore, as we would traditionally expect, supply and demand dynamics structure the interaction between actors, including government ministries or agencies. The model is based on public-choice theory (W. A. Niskanen 1971) and classic neo-institutional thought (DiMaggio and Powell 1983; Goldmann 2005; J. W. Meyer and Rowan 1977). It prescribes power to actors that hold more or better information and, thus, can bargain higher (Bouckaert, Peters, and Verhoest 2010) when exchanging information, goods, or other forms of value or service. Estonia's post-Soviet economic context (in parts) conditions this approach and mirrors the common world view among intellectual and administrative elites in Estonia (Drechsler 2004).

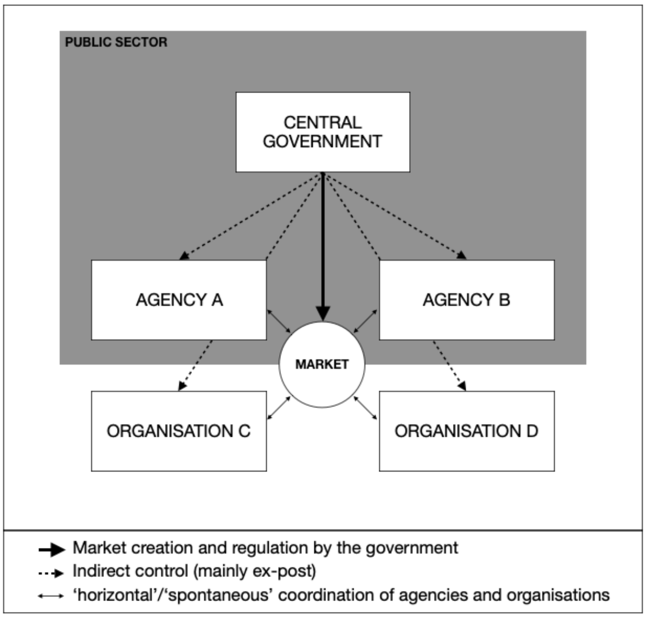

Figure 5.2: market-based coordination model[92]

[92] adapted from Bouckaert, Peters, and Verhoest (2010, 44)

In market-based frameworks, the central government's key role is to create and regulate the development of the market yet to refrain from being a central or leading actor. Instead, other market actors, such as private firms, take on a central role. The government's regulatory responsibility includes, but is not limited to, entry and exit barriers, prices, standards, goods/service quality, and safety for both users and producers (Bouckaert, Peters, and Verhoest 2010; van den Hurk et al. 2016). The principal state intervention tools are regulations or subsidies (Karo and Kattel 2014). Although there is an increasing trend towards tackling policy or societal problems through larger initiatives, regulation remains a main tool and commonly used tactic for Estonia's government to coordinate innovation (EE02). As a result, 'regulatory experimentation' is not uncommon.

Furthermore, the market-based coordination mode suggests that government actors operate largely independently, driven by the interests they represent, e.g. to pursue a particular policy implementation strategy and cooperate with partners – public and private. Where government organisations do not have the capacity to perform a specific task, they outsource this task to other actors, including private firms. Estonia is still in the process to transform some of its governance processes from the performance-based and indicator/measurement prone NPM style (which emerged in the country post-independence following international trends) to a more service-oriented, 'New Public Service' style system (EE02; cf. M. Robinson 2015). As progress varies, this process affects ministries and agencies differently (EE02). This transformation requires government organisations to acquire the relevant comprehensive skills and knowledge. Novel multi-technology innovations, such as AVs, may create a challenge in this regard (EE02). The small size of Estonia's government apparatus, including ministries, the fact that people from different government organisations often know each other, and the resulting short communication pathways between organisations contribute to the capacity of the public administration, as information can quickly be sourced and arduous bureaucratic processes can often be avoided (EE02).

According to the market-based model, in theory, policy implementation and policy design efforts should be aligned. However, the Estonian case shows that, at times, this is not the case, for instance, when ministries or agencies pursue their agendas without corresponding with others beforehand (EE02, EE07). The relatively small government ministries responsible for policy design often refrain from engaging in implementing particular policies, instead passing on these responsibilities to associated government agencies (Lember and Kalvet 2014; Sarapuu 2011). Although this increases the independence of government agencies, it may at times also cause tension and reveal the lack of (horizontal) government coordination. On the one hand, this means that responsibilities are clearly separated and agencies can accumulate expertise within a single organisation, expedite processes, and save resources (Sarapuu 2011). On the other hand, the "weak coordination capacity is especially apparent with relation to science, technology, and innovation policy [… as] no central unit is responsible for coordinating the crucial domains of economic development, and different policy domains have all developed distinct intervention logics and policy cultures" (Lember and Kalvet 2014, 132). This renders a relatively decentralised and segmented administrative system with weak horizontal coordination, where specialisation prevails over efforts that would promote better coordination across government entities (Sarapuu 2011; Uudelepp, Randma-Liiv, and Sarapuu 2014). The only exception is the Ministry of Finance, which controls the budget process and maintains a relatively strong coordinating role across ministries (Lember and Kalvet 2014).

The market-based model indicates that overarching goals emerge spontaneously if actors can create them Pareto-efficiently. Generally, Estonian government ministries tend to focus on macro goals (EE02, EE08), such as growth and effectiveness, but also innovativeness and a corresponding international reputation. In some cases, however, more specific goals emerge. Across the Ministry of Economic Affairs and Communication, the Road Administration, and several municipalities, for example, improved transportation efficiency, enhanced mobility offers, a more sustainable transport sector, and the desire to be at the forefront of mobility innovation conjoins many aspects that define the directionality of the AV innovation system (EE01, EE10).

5.2.3 Innovation and Innovation Policy in Estonia

In Estonia, traditionally, 'innovation policy' as such has neither been perceived nor organised as a specific and defined policy field (EE08). Instead, multiple ministries and public agencies devised innovation-related policies within their policy domain, such as education and research, transport, or environment. Instead, the government focused on enabling an environment or ecosystem conducive to innovation. Since the 2000s, however, Estonia has pursued a more elaborate and attentive approach to innovation policy (Karo and Kattel 2010a) which has become more strongly oriented towards resolving societal challenges since the 2010s (Karo and Lember 2016). Today, market dynamics and pressures still shape Estonia's innovation policy (Karo and Lember 2016), as evidence from the healthcare sector suggests (cf. Lember and Sarapuu 2014; Sarapuu and Lember 2015). Typical for such market-based approaches, the state has a limited yet discernible role in the innovation system (Karo and Lember 2016).

In practice, the Estonian government funds various initiatives that appear promising to yield innovative outcomes, either in the form of technologies or services. In 2002, the Ministry of Economic Affairs and Communication and the Ministry of Education and Research founded the 'Knowledge-based Estonia' framework to structure these initiatives (Ministry of Education and Research Estonia 2014). 'Enterprise Estonia' (Estonia's economic development and innovation agency) administers this programme by providing grants or subsidies to promising enterprises or start-ups and liaising with universities or other research outlets (Enterprise Estonia 2019). Furthermore, the Estonian Research Council and KredEx (the Estonian Finance Agency) provide funds for similar purposes, e.g. to universities. Combined, these government-affiliated organisations offer a substantial amount of funding to incentivise innovative projects across a broad range of programmes aligned with mainly generic goals. Yet, innovators and entrepreneurs are left to cover large funding shares through their resources, market-based collaborations, or private investments (EE06). Besides, the Ministry of Education and Research also funds R&D management staff in other ministries, paid for from its core budget (which, in turn, is granted by the Ministry of Finance). This effort aims to improve cross-ministerial coordination of science and technology initiatives (Karo, Lember, and Kattel

2015). The Ministry also finances R&D programmes with other ministries based on a 50/50 principle (Karo and Lember 2016). However, in market-based frameworks, such government initiatives are persistently scrutinised (*ibid.*).

The Estonian government began to support demand-side policies[93] in the mid-2000s, among others, by inducing economic development and innovation through public procurement and by aligning programmes to a more challenge-oriented narrative (Karo and Lember 2016). This has been effective in some areas, e.g. concerning ICT and e-government innovation, where several “enthusiastic and visionary civil servants have been behind the development of information systems in the public sector” (Lember and Kalvet 2014, 139). However, other national science and technology initiatives, such as ‘Estonia 2020’, have thus far merely been guided by “generic goals of increasing competitiveness, productivity, and employment” (Karo and Lember 2016, 13). Only one-third of companies who received publicly procured contracts confirmed that their engagement had ‘some influence’ on innovation (Lember and Kalvet 2014). Hence, the success of these ‘public procurement for innovation’ initiatives has been limited and, in fact, “remains a missing element in the overall innovation-policy mix in Estonia” (Lember and Kalvet 2014, 141). Hence, while the focus of innovation policy shifted from a linear approach to supply-side measures and then increasingly also to demand-side policies, this combination remains difficult to implement given Estonia's decentralised and segmented structure in the public-administrative apparatus (cf. Lember and Kalvet 2014).

For transport and information technologies, particularly concerning autonomous systems, Intelligent Transport Systems Estonia (ITS Estonia) emerged as a central intermediary organisation. ITS Estonia is a non-governmental organisation that combines over 100 Estonian companies and also includes some government organisations and agencies, such as the Ministry of Economic Affairs and Communication, the Road Administration, as well as several municipal governments. By focusing on mobility services, logistics, and smart infrastructure, intending to increase transport safety, sustainability, and

[93] For a more detailed account on the type of demand-side policies with regard to innovation, see Edler (2013). For an analysis of Estonia’s use of demand-side policies for innovation, see Lember, Cepilovs, and Kattel (2013).

efficiency, ITS Estonia generated "enthusiastic involvement by everyone" (EE07). The roundtables serve as a meeting place to discuss common ideas and coordinate joint efforts (also in terms of funding) (ITS Estonia 2020). "It is a key player here in Estonia", a Ministry official explains (EE06). Appendix 1 summarises the key actors in Estonia's AV innovation system.

Across various innovation-related indices, Estonia ranks near the top. The country's politico-economic legacy, in conjunction with its accession to the EU and the associated integration into the European market, its R&D funding programmes, and technology/skills transfer initiatives, among others, explain this circumstance (Kattel and Stamenov 2017).

Table 5.2 provides an overview of seven innovation-related indices:

Index	**Index Scope**	**2017**	**2018**	**2019**	**2020**
Global Innovation Index[94]	global	25	24	24	25
Bloomberg Innovation Index[95]	global	33	36	36	36
European Innovation Scoreboard[96]	Europe	15	17	12	16
Global Competitiveness Index[97]	global	29	32	31	-
Economic Complexity Index[98]	global	27	28	-	-
R&D Investment Index[99]	OECD	27	25	-	-
AV Readiness Index[100]	selected countries	-	-	-	-

Table 5.2: Estonia's rankings in innovation-related indices 2017-2020

Overall, Estonia today is one of the more innovative countries in the world. The Estonian government does not play a central role but often acts as a market

[94] The 'Global Innovation Index' by Cornell University, INSEAD, and the World Intellectual Property Organisation measures overall innovation-related parameters (Dutta, Lanvin, and Wunsch-Vincent 2017, 2018, 2019, 2020).
[95] The 'Bloomberg Innovation Index' gathers general innovation-related metrics (Bloomberg 2017, 2018, 2019, 2020).
[96] The 'European Innovation Scoreboard' compares innovation eco-systems across European countries (European Commission 2017, 2018, 2019, 2020b).
[97] The 'Global Competitiveness Index' by the World Economic Forum annually measures the competitiveness of global economies, which can be considered a proxy for innovation (Schwab 2017, 2018, 2019).
[98] The 'Economic Complexity Index' emerged from the 'Atlas of Economic Complexity' and measures the sophistication of economic activities across countries based on the knowledge intensity of products and services as well as the relatedness of such products and services(Harvard University Growth Lab 2020a) .
[99] The 'R&D Investment Index' measures the share of GDP invested into R&D activities (OECD 2020).
[100] The 'AV Readiness Index' by KPMG assesses the physical, knowledge, political, and economic infrastructures across countries with regard to AVs (KPMG 2017, 2018, 2019, 2020). Estonia does not feature in this ranking (as opposed to the other case studies in this thesis).

creator or supporter, focusing on Estonia's branding as an innovation hub and nurturing the underlying private networks in which innovation systems can unfold. This becomes evident concerning the implementation of innovation policy: In addition to knowledge creators, such as universities, it is primarily private enterprises that contribute to innovation efforts. At the same time, (government-established) intermediary organisations facilitate the interaction between the public and private sectors. The PMO and the Ministry of Economic Affairs and Communication form part of the innovation system and, thus, of the market-based structure, either directly through procurement or indirectly through regulation. Hence, Estonia’s innovation policy mainly follows the market-based structure for policy coordination. What does this mean for the AV innovation system? The following section explores the AV TIS in detail.

5.3 Technological innovation system analysis for AVs in Estonia

The TIS analysis shows that Estonia features an early stage yet largely established AV innovation system. It reveals that market dynamics are critical to the system’s foundation and growth but also indicates that several network-oriented coordination practices are key to resolving the blocking mechanisms that emerged in the early phase of the TIS. The government and public agencies are the primary enablers for the cooperative features of this hybrid approach.

5.3.1 Function 1: Knowledge Development and Diffusion

Initially, the ‘knowledge development and diffusion’ for AVs (F1) in Estonia occurred primarily in universities. First and foremost, these were the Tallinn University of Technology (Tal Tech) and the University of Tartu, both featuring excellent facilities for experts and students to invent and innovate around the AV technology (EE01). The former even made the development of autonomous systems one of its key initiatives (EE01). A research group at Tal Tech successfully designed, engineered, and built a fixed-route autonomous minibus for Estonia’s 100th birthday in 2018, generating an immense amount of technical expertise. This project was firmly pushed by individuals from Tal Tech, who invested substantial amounts of time and resources into the project. Their initial enthusiasm spread to colleagues from within and beyond the university. Several interviewees confirmed that Tal Tech's input was a crucial factor in the success story of the AV technology in Estonia (EE01, EE03, EE06, EE09). Due to the small size of the country and the few technical research organisations with the capabilities and capacity to research such complex technologies, only a small number of AV projects were conducted in Estonia. They could nonetheless generate attention (EE10). The start-ups that emerged now collaborate in various trials (see below) with larger (international) firms to source further knowledge and expertise. Partners include, for example, the Danish firm Holo, which operates AVs across the world, or the French manufacturer Navya, who is one of two larger AV manufactures. These international collaborations also ensure the transfer of technical knowledge and experience into Estonia (EE01).

The knowledge required for regulatory purposes had to be newly acquired by the Estonian public administration, including the executive and regulatory agency: The Road Administration had little to no previous knowledge about AVs, yet had to assess and approve the vehicles before pilots on public roads could commence. The agency acquired the necessary technical expertise through collaboration with domestic and international manufacturers. The applying operating companies had to submit detailed technical documents (EE05)[101]. This cooperation continues today and results in knowledge to build up within the agency – as opposed to the ministry, which according to the Road Administration, is less concerned with the technical details (EE07).

A significant multiplicator for AV knowledge in Estonia was the 'AV Expert Group', headed by Mr Pirko Konsa, "a key individual in the field" (EE01; also mentioned by EE03 and EE07). The group included stakeholders from industry, research organisations, government, intermediaries, and society, including members from abroad. It not only generated a significant push for the technology but also allowed for the exchange of knowledge and ideas. The group was

[101] More details on the regulatory process for AVs can be found in section 5.4.3.

structured along the 'triple helix' approach[102] (EE10). Although the expert group is no longer operating, the individual connections it fostered persist and until today serve as a pool for knowledge exchange and diffusion across the Estonian AV innovation system (EE01, EE07, EE10). The group's final report consolidates key technical, regulatory, economic, and social aspects of AVs and, thus, serves as a foundational pillar for further interaction in the AV innovation system (Riigikantselei 2018b). Today, ITS Estonia organises regular roundtables concerning autonomous transportation systems, taking over the intermediary and facilitator roles for AV-related stakeholders (EE07). Representatives from the Road Administration and the Ministry of Economic Affairs and Communication, although not central actors in these meetings, continue to participate, advise, and inform others about their intentions and governance priorities regarding AVs (EE05, EE07). Hence, public representatives continue to be part of the knowledge diffusion mechanisms rather than abstaining from them. As such, stimuli for 'knowledge development', but especially opportunities for 'knowledge diffusion' follow a collaborative approach rather than a purely market-based approach, with the government as an initial enabler.

Overall, although at first universities led the efforts for AV innovation in Estonia, this role has now shifted towards the private sector. The start-ups that emerged as spin-offs from universities (see below) and large AV companies that operate globally now spearhead the innovation of the technology in Estonia. The government continues to contribute to knowledge diffusion by participating in specifically designed knowledge exchange fora.

5.3.2 Function 2: Entrepreneurial Activity

The 'entrepreneurial activity and experimentation' regarding AVs in Estonia increased significantly since the first pilot project in 2017. However, in absolute terms, business activity remains at tractable levels. The first entrepreneurial

[102] The triple helix includes government, industry, and academia (Etzkowitz and Leydesdorff 2000). It builds on the idea that problems are best solved if organisations and individuals across these three groups collaborate. In some instances, the start-up sector is singled out and specified as a fourth group of actors, rendering a 'quadruple helix'. However, throughout this thesis, start-ups are included in the triple helix.

push emanated from the Government Offices and the Road Administration in collaboration with a group of companies (Milrem, EasyMile, DSV, and Tallink) during the Estonian EU Council presidency and led to the first pilot in the country (Ainsalu et al. 2018). Shortly after that, the research team mentioned above at Tal Tech, led by Professor Raivo Sell, began to construct their own AV 'Iseauto' (Rassõlkin, Sell, and Leier 2018; Sell et al. 2019), which still operates on Tal Tech's campus (EE01). Upon noticing the potential of the technology (Sell et al. 2019) and realising that they are operating in a field of few competitors at the time, the research group founded a university spin-off, AuveTech (Research in Estonia 2020). The start-up AuveTech took over the manufacturing of Iseauto, developed initially at Tal Tech and subsequently attracted significant funding from angel investors (EE01, EE09). AuveTech, together with the University of Tartu, is now developing a hydrogen-fuelled AV (Tähepõld 2020).

Such start-ups play an essential role in the AV innovation system, in particular, and the Estonian economy, in general. "The larger [car] manufacturers are afraid, they are laggards, or at least appear as such", a senior official from the Ministry of Economic Affairs and Communication admits and adds that "this is an opportunity for start-ups and smaller firms here in Estonia" (EE06). Start-ups are generally considered positive for the 'branding' of Estonia, as the experience with the ICT and e-government sectors proved (EE08). The AV advances through start-ups had a catalytic effect: more start-ups formed after the first AV pilots were completed. The impact of government agencies on this development is small, as "agencies are rather reactive" (EE08), "instead of regulating something that isn't even there yet" (EE03). Therefore, start-ups can, at least initially, experiment and "follow a little bit of a trial-and-error strategy" (EE01).

One of the first start-ups to develop AVs that emerged in Estonia was Starship Technologies, a firm of Skype co-founder Ahti Heinla. With his venture capital, the firm developed small delivery robots that today roam the streets of Tallinn (as well as London, San Francisco, and beyond) (EE01). Milrem, a military contractor who initially began to service autonomous vehicles by other manufactures, recognised its capacity and began its own construction efforts. These are primarily military vehicles but can also be used for cargo transport or emergency evacuation. Cleveron, who develops intelligent package storage machines, is another start-up researching the potential use of AVs for logistical purposes and cargo delivery. The market for Starship's, Milrem's, and Cleveron's vehicles is dedicatedly different, though, from all other manufactures included in this study. However, they did contribute to 'knowledge development' and generated interest and investment in autonomous technologies. Bolt, an Estonian ride-hailing provider and the biggest competitor of Uber in the Baltics, also began to invest in AVs to "replace the most expensive part of their business model: the driver" (EE10). Numerous other firms emerged in the vicinity of the AV technology: They provide parts for the vehicles (e.g. Silberauto), code software packages and develop demand responsive transport solutions (e.g. Modern Mobility), provide geolocation and mapping data (e.g. Reach-U), or design business models with which AVs can operate profitably (e.g. Holo) (SE09, EE10).

Similarly, international firms initiated 'entrepreneurial activities' in Estonia. This includes ABB, which supplies vehicle parts to AuveTech and joined the Iseauto pilot at Tal Tech. Another example is the aforementioned operator Holo (formerly Autonomous Mobility), who runs one of Estonia's most prominent AV pilots. Holo already positions itself for future market entry, builds connections with local firms and government agencies, sources employees, and begins to display its name to the public (SE09). Numerous companies specialise in AV-relevant intelligent infrastructure, like smart bus stops or charging points for electric AVs (EE07). This includes the Swedish telecommunications giant Ericsson or the Finish fleet management start-up Fleetonomy. They complement the 'entrepreneurial activity' of firms that focus on AVs themselves. ITS Estonia emerged as an umbrella organisation for both national and international firms, building connections between firms and promoting start-ups to ensure that they are incorporated into the value chain rather than operating in silos (EE07). "All important private sector players are there", states a start-up CEO, adding that the "cooperation between academia and government with the private sector is working well" (EE10). This "deep collaboration" leads to increased efficiency, agility, and expedited time frames in which "we can do things quickly" (EE07).

By allowing AV testing to begin under an exemption model without strictly enforcing existing or creating new regulation, the Road Administration, as well as its parent ministry, actively enabled AV pilots. In the case of Starship's delivery robots, for instance, the mini-robots are considered as 'bicycles' from a regulatory view point (and therefore do not need extra permits) (EE04, EE05). This flexibility by the Road Administration is a response to the activity of the many small and large firms (EE05). Although "regulatory changes are the responsibility of the state", as a representative from the Ministry of Economic Affairs and Communication explains, he also states that "sometimes regulation comes too early and becomes restrictive or framing, and we don't want that" (EE06). "There is a lot of openness towards start-ups, in general, in Estonia", adds an innovation policy and public administration expert who also worked on regulation in Estonia (EE08). And "the start-ups themselves, or rather their founders, are aware of this circumstance, which is one of the reasons why they decided to pursue their business idea in Estonia" (EE07). "It is easy here", confirms AuveTech's CEO (EE09). Yet, "without regulation, AVs will not be surviving […] as this cannot be done by the private sector alone", an AV entrepreneur explains and adds (EE10):

> "In Estonia, we have regulated the service level of Bolt or Uber well so that they are better than regular taxis now and cheaper. Now, there is also the need to regulate the sharing economy in a similar way so that it can be better than the ownership model. […] This is an opportunity for the government and can speed up the process. […] We need the room for things to evolve, flexibility, but then we need to regulate it."

Altogether, AV-related entrepreneurial activity increased strongly in Estonia. The state enabled testing to occur by providing exemptions for AVs but stepped back otherwise after its initial push during Estonia's EU presidency. However, particularly the Road Administration and the Ministry of Economic Affairs and Communication continue to participate in expert groups and roundtables organised by intermediaries, such as ITS Estonia. This continued collaboration, paired with the regulator's enabling initiative – generally rather network-oriented administrative practices – reduces uncertainties and, thus, further incentivises 'entrepreneurial activity'. This induces the growth of the AV innovation system. 'Entrepreneurial activity' resulted in the following AV trials, as Table 5.3 outlines:

Year	Location	Operator	Vehicle	Status
2017	Kultuurikatel - Mere	Riigikantselei / Road Administration / Milrem / DSV / Tallink	EasyMile 'EZ10'	complete
2018	Tal Tech Campus	Tal Tech / Taxify / High Mobility / Tesla Rent / Riigikantselei / Ministry of Econmic Affairs and Communication[103]	Iseauto	complete
2018	Tallinn	Starship Technologies	Starship delivery robot	ongoing
2018	various	Milrem	Milrem autonomous cargo/military vehicle	ongoing
2018	Port of Tallinn	Tallinn Port Authority / Tula Labs / Tallinn Public Transport / Ministry of Economic Affairs and Communication [104]	EasyMile 'EZ10'	complete
2018	Tal Tech Campus	Iseauto / AuveTech / ABB	Iseauto	ongoing
2019	Tallinn	SOHJOA Consortium	Navya ARMA	complete
2020	Tallinn Zoo	Iseauto / AuveTech / ABB	Iseauto	complete
2020	Tallinn Airport	Iseauto / AuveTech / ABB / FABULOS Consortium	Iseauto	complete

Table 5.3: AV pilots completed, ongoing, or planned in Estonia

5.3.3 Function 3: Guidance of the Search

The 'guidance of the search' (F3) for innovation in the AV innovation system, i.e. the advocacy for a particular directionality of AV innovation, first emerged from researchers, then from the government, and later – by large – from the private sector. The first push for the technology, i.e. the first drive to developing AVs, was motivated by academic aspirations and the basic and applied research of the technical components used in AVs, undertaken at Tal Tech and the University of Tartu (EE01). With the (international) AV hype surging in the 2010s (cf. Stilgoe 2020) and the Estonian EU Council presidency on the horizon, the Estonian government began to push a first AV trial, aiming at portraying Estonia and its technophile business environment as a poster child for innovation (EE02, EE06). The initial push, hereby, emanated primarily from individuals in several government organisations. Today, a few years after the inception of the first AVs in Estonia, it is predominantly the private sector pushing for AV advancement.

[103] According to the project description, the Ministry of Economic Affairs and Communication provides "advice, competence, [and] bringing the parties together" (Riigikantselei 2018b, 31).
[104] ditto

The role and efforts of individual should not be underestimated in this context. The advocacy of the Prime Minister's office was primarily a result of its 'Strategy Unit' and the individual responsible for the smart mobility strategy, Mr Marten Kaevats. His personal conviction and enthusiasm led to the Prime Minister endorsing AVs at a time when no full-scale pilots had yet occurred (EE01, EE07). He also motivated universities and convinced private firms to launch a pilot during Estonia's EU Council presidency. Nearly every Estonian interview participant cited his influence (EE01, EE03, EE05, EE06, EE07, EE08, EE09, EE10). Subsequently, Mr Kaevats became a key member and initiator of the 'AV Expert Group', which his office set up and oversaw administratively during its existence, paid for by the 'Operational Programme for Cohesion Policy' funds (Riigikantselei 2018a). He continues to participate in the roundtables by ITS Estonia today. Furthermore, as mentioned above, the 'AV Expert Group' was led by Mr Pirko Konsa, another key individual. It emerged as the principal forum for AV innovation in Estonia. The group is no longer operational today. Mr Kaevats and Mr Konsa continue to be well connected and respected figures concerning AV innovation, however (EE01, EE07). Estonia's small size and the resulting 'short distances' between government offices, research organisations, and private companies – both literally and figuratively – elevate the role and influence of such central personalities even more, as they can individually affect the direction of innovation. One interviewee (EE01) stated about Mr Kaevats:

> "Estonia is a small country with few vectors, and people behind the scenes know each other often times very well. Marten [Keavats] is an innovator with a strong initiative, coordinative skills, aligning the civil community, the industry, and the government. […] This wasn't even a planned government project, it just happened but was welcomed by the Prime Minister. [Marten] helped to remove barriers, so the government could be an enabler of some sorts. He continues to advise the Prime Minister on this topic and, among others, managed the Prime Minister's outreach campaign to international carmakers, advertising Estonia as the ideal testing ground for autonomous mobility solutions. He is still there today!"

AVs have not been part of any politicised discussions previously – and still are not. Elected officials remained largely neutral in this process (EE10). The individuals working for politicians or in organisations such as the Prime

Minister's Office are, therefore, the more important, as "there is often no political mandate to pursue or not pursue a particular trajectory; instead, it is about the people who are in the same network, who know each other, and who can connect the dots" (EE08). Regardless, the AV technology does offer a broad set of benefits that elected officials can exploit politically. Consequently, and after the expert group had published its final report, the political narrative supported the technology on the grounds of improved safety and security of transportation, increased sustainability of future shared mobility solutions, better efficiency, less congestion, and generally, Estonian innovativeness. Estonians like to associate themselves with this characteristic, in general (EE03). Moreover, the technology was incorporated into the Estonian 'Transport Master Plan', emphasising that "the Ministry [of Economic Affairs and Communication] wants to see autonomous vehicles on the roads" (EE04). The municipality of Tallinn, likewise, is planning with AVs in the future (Ainsalu 2018). To this end, senior politicians have reached out to the global AV community, inviting firms to test and develop their vehicles in Estonia (Riigikogu 2017a). In short, political support was easy to generate, as "politicians could ride the wave" but did not have to get directly involved, while "the industry needs to innovate" (EE09).

The principal intermediary organisation, the 'AV Expert Group', influenced the 'guidance of the search' by igniting the communication and interaction between stakeholders as it "connected all relevant partners" (EE05). This led to kick-starting further private sector engagement, a broader interest throughout the Estonian economy, and the increased attention of foreign partners (EE06). The responsible government agencies, particularly the Road Administration, through their participation in the expert group roundtables, recognised that there is a need for more clearly defining the regulatory context in which AVs can and must operate, primarily the Traffic Act §76 (Riigikogu 2017b; see also Soe, Ainsalu, and Tammiksaar 2018). The expert group's deliberation and its final report led to the exemption model employed by the Road Administration: Instead of amending vehicle regulations through new legislation, AVs tested on public roads are for a limited time exempt from some of the usual regulatory restrictions (EE04, EE07). This initiative gave the innovation in the sector a renewed push (EE07, EE10) –

"it was done at the right time in the right place" (EE10; see also Soe, Ainsalu, and Tammiksaar 2018; SOHJOA Baltic 2020c).

In summary, the 'guidance of the search' for AV innovation was initially directly coordinated and pushed by individuals in the Prime Minister's Office, rather than by political organisations or purely by market forces. This resulted in the expert group bringing all relevant industry, policy, and research organisations to the table. Today, the 'guidance of the search' is primarily the result of private sector activity (e.g. through ITS Estonia), including start-ups and larger (international) enterprises. "The first push came from the government, and only the second push came from the companies" (EE03). In turn, continued advances of the technology force the government and especially the responsible government agency to learn about AVs and to pursue a flexible approach to regulation – a situation of mutual co-optation. Collaborations emanate primarily directly through market forces or through ITS Estonia, which replaced the 'AV Expert Group' as the central forum for negotiations regarding AVs, and which also hosts representatives from the government. This form of cooperation and mutual co-optation are features of network-oriented policy coordination.

5.3.4 Function 4: Market Formation

Due to the early stage of the innovation system and the currently scarce deployment of AVs, 'market formation' (F4) in Estonia remains limited. Several start-ups are preparing projects and building up capacity for the future, however. In terms of AV manufacturing, there are few foundations to rely on in Estonia due to the general lack of vehicle manufacturing. Nevertheless, the start-up AuveTech fully launched its own AV production, despite the strong global competition of Navya and EasyMile. AuveTech, a Tal Tech spin-off, plans to produce a lighter and more versatile vehicle at a cheaper cost and, therefore, aims at a more competitive global market position (EE09). "The price and the comfort for the end-user is the overarching goal", the AuveTech CEO explains (EE09). The continued cooperation with Tal Tech (and others) and the beneficial regulatory environment in Estonia allows AuveTech to continue testing their vehicle at a lower cost, which yields more tests in a shorter period (EE09). This means that improvements can be incorporated faster. At the same time, AuveTech offers a complete package for their customers, including software and a teleoperating system to satisfy the 'driver' criteria[105]. The company's business plan builds on this complete package (EE09).

Additionally, various start-ups provide (novel) AV-based business models. This includes MaaS, where AVs provide first- and last-mile transportation to and from public transport hubs (EE07, EE09, EE10) and ride-hailing apps for conventional taxi services – although without a driver. AuveTech, in cooperation with partners and the start-ups Modern Mobility and Holo, is attempting to incorporate this into their business plan. Other firms focus on freight transport, including the above-mentioned delivery robot start-up 'Starship Technologies' (EE10). Estonia's growing technical capabilities also attracted numerous supplier start-ups for both hardware and software, as the 'entrepreneurial activity' section pointed out, slowly forming a value chain around AVs.

Overall, several firms emerged in a growing AV sector, mainly concerning AV production and development. Several business models are being tested. The Estonian state, both in the form of the government and executive agencies, does not directly participate in this market. Other than the AV pilots that have received public funds in some cases (mainly through the EU or through municipalities), no publicly procured AV projects exist. Thus, the AV market remains a 'future market' for which firms begin to position themselves, relying on the continued openness and indirect support of the Estonian government, e.g. in terms of regulatory agility and easiness of opening a business.

5.3.5 Function 5: Resource Mobilisation

Financial resources (F5) for the AV technology mainly emerged from the private sector (EE01). The majority of AV pilots received funding from private investment, including individuals, firms, and private consortia. The Estonian Ministry of Economic Affairs and Communication held an open market

[105] According to regulations, a safety driver must be on board the AV to control the vehicle in case of emergency. AuveTech aims to satisfy this criterion with a teleoperator, who is not physically on board but who can take control of the vehicle in case of unforeseen problems (EE09).

consultation as no government funds were initially allocated to the AV technology (EE06). The result made firms aware that they are expected to fund R&D projects from their budgets or source sub-technologies through private procurement (EE07). 'Starship Technologies', for instance, was one of the first start-ups to use venture capital from one of the Skype co-founders. Milrem, the military contractor, Cleveron, and Bolt all rely on their assets to fund AV research. Cleveron, for example, invests 7% of its annual profits into R&D (EE07).

At the same time, some AV projects did receive public funds. The SOHJOA project (Soe 2020), a cooperation between various Estonian and other European firms, raised financial support from the EU 'Interreg Baltic Sea Region' budget budget and collected a small share from the municipality of Tallinn to run an AV trial in central Tallinn, among others (EE08). Likewise, the still ongoing FABULOS project series, a consortium of Finish and Estonian firms, received GBP 7 million in EU funds for their AV pilots. Besides, several projects emerged and received funding from the collaboration of university research groups and start-ups. University spin-offs, such as AuveTech, who develop the technology further and/or manufacture the AV, initially benefited from (public or third-party) funds granted to the university (EE01, EE09). Today, AuveTech relies on an angel investor who actively pushes the technology forward (EE01, EE09).

Overall, the funding arrangements for AV innovation are mixed, whereas the majority results from private sector contributions, but a not-insignificant amount also emerged from the government and the EU. However, future funding arrangements might look different: As senior officials from both the Ministry of Economic Affairs and Communication as well as from Tallinn Municipality have confirmed, future investment is expected to emanate from private funds alone, generated through domestic and/or international markets (EE03, EE06). Raising resources through market dynamics should, at least in theory, be easier as the technology has developed significantly. Past and ongoing AV pilots (especially SOHJOA and FABULOS) as well as the efforts of the intermediaries in this space (especially the AV Expert Group and ITS Estonia) help to create a network of interested firms, investors, and potential customers (EE10).

5.3.6 Function 6: Legitimacy Creation

The ongoing, non-politicised interest of (senior) politicians, but also senior officials in government agencies, as well as the general attitude and openness of the Estonian public towards innovation and emerging technologies, catalysed each other to create legitimacy (F6) for the AV technology.

The PMO from the start advocated for the AV technology through positive and open rhetoric – particularly during the run-up of the first Estonian EU Council presidency (EE06, EE10). References made about AVs during political deliberations and public speeches, as well as stressing the advantages associated with AVs, shifted the spotlight onto AVs, also across the Estonian public (EE03, EE10). Within the PMO, the Strategy Unit' digital strategy advisor persistently raised the possibility of AV as a potential solution to some of the country's urban transport challenges (EE01, EE07). This includes improving transport links, reducing pollution and congestion, and enhancing the sustainability record. He also highlighted the opportunity to make Estonia a 'testing ground' for smart mobility solutions for international (and national) firms (EE01). This aspect links to the 'innovation nation' narrative often associated with Estonia (EE02, EE03) and adds to Estonia's positive reputation in the tech scene. The general attitude in the PMO at the time was that "autonomous vehicles are coming, yes or yes, so we want to be prepared" (EE03). Through this rhetoric – portrayed inside and outside the government apparatus – the PMO promoted "ideational factors around innovation and innovativeness that play a huge role when it comes to accepting new technologies" (EE02) (see below).

Government agencies also contribute(d) to this 'creation of legitimacy'. The Road Administration, for example, is involved in an EU-wide programme to coordinate the regulation of AVs through CIECA, the International Commission for Driver Testing (EE04). This, in turn, signals to AV manufacturers and operators that the regulatory and executive agency is interested in creating an unequivocal legal situation, which reduces the risks associated with additional funding and further RD&D. The Road Administration also states that AVs can increase traffic safety (EE05; also cf. Vellinga 2017). After test driving a Navya bus used in a pilot in Tallinn, the examiner of the Road Administration stated that "these vehicles definitely are not more dangerous than human drivers [as] human drivers often cannot cope as well with obstacles on the road, as they don't react as quickly" (EE04). With such statements, the Road Administration contributes to the erosion of remaining concerns about AVs and leads to the creation of additional legitimacy of the technology.

Novel, emerging technologies generally tend to be embraced rather than resisted in Estonia. This is due to the generic openness to new technology and the public's drive for innovativeness (EE07) – especially concerning products made in Estonia by Estonians (EE09). In Estonia, "we want to be innovative; we want to do innovative things around here", says a Tal Tech researcher (EE02). In the first pilot project in Tallinn, nearly 4000 individuals used the opportunity to ride an AV (SOHJOA Baltic 2020a). The feedback was overwhelmingly positive, and users showed great interest in the shuttle buses (SOHJOA Baltic 2020d). Even school classes requested to undertake field trips to the test site in Tallinn's city centre (EE03). ITS Estonia adds to the understanding of the public by producing media campaigns that explain smart mobility technologies and invite the public to learn about AVs (EE07). Irrespective the small number of pilots, public acceptance for AVs is, therefore, high.

Overall, the government in the form of the PMO, but also government agencies and the public itself contribute to the 'creation of legitimacy' for AVs. Continuing to actively participate in the innovation system, e.g. through ITS Estonia's roundtables, but also through assessing AVs, the government facilitates the acceptance of the technology in society. This fuels Estonia's general openness towards innovation. Companies benefit from this circumstance and further push the technology, e.g. through ITS Estonia and additional pilot projects, allowing users to experience AVs first-hand. When the Tallinn pilot was put on hold due to weather conditions in winter 2019/2020, the vehicle was put on display in a highly frequented shopping mall to increase its visibility further. The work towards a common goal following a joint vision resembles a feature of network-oriented approaches to coordinate activities in the innovation system.

5.3.7 Function 7: Positive Externalities

As AVs are still in a maturing phase, 'positive externalities' (F7) are limited. Although some positive effects emerged concerning technical spill-overs and business models, other externalities remain predicted at this point.

From a technological viewpoint, the advancement of the AV technology feeds into the RD&D of AI, data storage and analysis, as well as privacy and cybersecurity (EE07). Often, firms either work on these aspects themselves or closely collaborate with other companies or experts. ITS Estonia, above all, includes such topics in its roundtable discussions, aiming to be a catalyst for Estonian firms and "bringing added value to the sector along the entire value chain" (EE07). Milrem, a military technology provider, for example, benefited from enhanced AV knowledge and developed autonomous robots for military and civil use. Cleveron and Starship Technology work on logistics and improved parcel delivery. All of these technologies affect people's lives, improving their handling of everyday situations even if not directly linked to AVs.

In addition, experts project various positive knock-on effects of AVs, which form part of the motivation of firms and politicians to promote the technology. These include increased safety for all traffic participants and a higher efficiency of the use of urban infrastructures, such as road space and parking lots (EE07). Experts also highlight the improvements for vulnerable groups, such as children, seniors, or disabled citizens, as transport solutions can be customised without relying on a privately-owned car (EE01). Furthermore, companies stress the enhanced environmental record of shared AVs (EE09, EE10). In short, AVs can provide "a more human-centric approach to mobility" (EE10).

As mentioned, several new AV business models already launched. Cleveron's autonomously designed parcel pick up stations, Starship's autonomous delivery robots, Milrem's autonomous rescue and military vehicles, or CityBee's car rental service that rely on the sharing principle complementing autonomous cars are good examples (EE10). Further business ideas are "already in the pipeline and will explode in the coming years [and] will disrupt retail business, too", the former head of Estonia's AV Expert Group explains (EE10). The current push in this "hot topic" (EE03) and one of the globally most hyped technologies (Stilgoe

2019) can add to Estonia's image as a technology and innovation hub, which may help to attract further funding and business activity in other sectors.

'Positive externalities' might also affect the country's public administration: The novelty of AVs prompted the responsible agency and its line ministry to expand their technical knowledge to ensure they can fulfil their regulatory tasks. "The government had to learn to be an enabler" in this space (EE07). The unproblematic and agile approach to accommodating the needs of firms and researchers, the availability of testing grounds, and the fast approval of business and testing licenses all paint a positive image of Estonia as an "ideal breeding ground" (EE06) for novel and complex technologies.

Overall, despite the early stage of the technology, several 'positive externalities' have emerged, whereas others remain predicted. The entrepreneurial and economic impact, as well as the positive image regarding innovation, catalyse additional activity within and beyond the sector. Simultaneously, the government and the Road Administration added to their experience and technical knowledge portfolios and proved agility and flexibility concerning regulation – attributes associated with network-oriented policy coordination.

5.3.8 Functional Analysis Conclusion

In conclusion, the AV TIS in Estonia reveals significant sophistication across most of the seven system functions, despite the early stage of the technology. 'Knowledge development' (F1) began at two of Estonia's leading universities before it moved towards the private sector as a result of university spin-offs, the interest of existing Estonian firms, and the international influx of AV-related companies and consortia. The 'AV Expert Group', set up by the PMO, kick-started 'entrepreneurial activities' (F2) by providing a forum for such enterprises, as well as for government representatives. The small size of the country, the enthusiastic efforts by some individuals, and the participation of government organisations generated significant momentum and led to a fast expansion of the group's membership across both private and public sectors. The group quintessentially shaped the 'guidance of the search' (F3) for AVs. The continued growth of AV activities, such as pilots, forced the executive and regulatory agency (the Road Administration) to clarify the regulatory framework in which AV operate in Estonia. Operators have to apply for temporary registration and vehicle inspection. A licensed driver (inside or outside the car) must always be on stand-by. Following these rules, operators can test AVs in the public domain and have the option to provide passenger transport without further permits and no additional requirements or standards for AVs (SOHJOA Baltic 2020c). The 'market' for AVs (F4) remains small due to the technology's early stage. Firms 'mobilised financial and human resources' from angel investors, private enterprises, (international) consortia, but also the government and the EU (F5). The initial political support for AVs has neither faded nor intensified but contributes to the 'creation of legitimacy' of the technology, just as the pilots do as well (F6). The long-term economic benefits due to increased activity in associated sectors and the influx of (foreign) capital, but also the impact on traffic safety, accessibility, and environmental sustainability, are potential 'positive externalities' (F7) that yet have to materialise large-scale. Overall, the AV TIS is on track to grow further in Estonia, as all system functions are established and of mostly high quality, such that they can catalyse each other.

The market-based orientation is strongly discernible in this innovation system. Whereas the government initiated some processes across system functions (e.g. the foundation of the Expert Group or indirect sponsoring of AV trials), underlying market dynamics provided a strong stimulus for firms to advance the technology across all functions. This includes creating university spin-offs, angel investments, consortia formation, business model development, the founding of start-ups along the AV value chain, and more. At the same time, the government and its executive and regulatory agencies remained a participant in this market, yet not through demand and supply creating policies, but rather through incentivisation, advice, and flexible governance approaches – following a vision of Estonia as innovative, inclusive, and sustainable economy.

This approach hints towards network-oriented policy coordination features that focus on cooperation and information sharing rather than the 'invisible hand'. This especially concerns the TIS functions where market mechanisms alone have blocked rather than induced innovation. For example, instead of over-regulating the technology before its take-off, the Road Administration approved trials based on regulatory exemptions. This renders the approval process comparatively fast and straightforward (e.g. compared to other European countries) (SE09). The government's agility ensured mutual trust, which in turn ascertained investment, and induced further collaboration, also with government organisations. In other words, the government became a market enabler – and even a catalyst, withstands the usual market dynamics but maintains a position in the network that allows for intervention if challenges emerge that can be solved through cooperation. The network is governed mainly by the network participants themselves (cf. Provan and Kenis 2008).

Hence, the functional analysis suggests that market and network-oriented administrative mechanisms shape the Estonian AV TIS. What is the role of public sector organisations in this dynamic, and how do they shape the innovation system in such a scenario? The following section will discover this in detail.

5.4 Coordinating AV Innovation: the Market-Network Hybrid Mode

The innovation system for AVs in Estonia principally reflects a market-based approach but also features network-oriented coordination characteristics – rendering a hybrid model. There is no central, coordinating actor in the innovation system, companies and research organisations mostly interact with each other, and public sector organisations cooperate with actors in innovation processes yet do not control any stakeholder directly. This section analyses how policy coordination practices in Estonia contributed to this outcome by discussing the impact of each politico-administrative element (E1-4) on the TIS functions (F1-7) in turn.

5.4.1 Element 1: Centrality and Leadership

The 'centrality and leadership' (E1) of public sector organisations is crucial regarding the system function of 'entrepreneurial activity and experimentation' (F2). The government's influence catalysed the emergence and growth of businesses in the AV sector in Estonia – not as a consumer or producer itself, but as an enabler of markets. On the one hand, individuals from the Government Offices established the 'AV Expert Group', bringing all relevant stakeholders from across the industry, academia, and government around a table. This was neither a politically mandated nor an institutionalised effort (EE06). Instead, the smart mobility advisor of the Prime Minister's Strategy Unit, Marten Kaevats, personally promoted this group and installed Pirko Konsa, a widely respected AV expert, as its chair. He was able to lobby and coordinate industry stakeholders and also liaised across government agencies and ministries, "removing any potential barriers" (EE01). "In a small country like Estonia, such individual efforts can go a long way" (EE02). The group emerged as the focal point for AVs and birthed several collaborative projects and business connections. On the other hand, the government acted as a market enabler by removing regulatory barriers that had hindered companies, especially small start-ups, to enter into the AVs testing phase. The demonstrated flexibility and agility regarding regulation signalled to firms that the government stands behind the technology and is willing to accommodate the companies' needs. This signal reduced uncertainty because firms no longer had to fear that the technology would be 'over-regulated' (EE05). Particularly the Road Administration as executive government agency (who is also responsible for regulating AVs) embodied this aspect (also see section 5.4.3 below).

The 'centrality and leadership' of state actors has since declined, and 'entrepreneurial activity' today mainly results from the estimated potential of the AV sector and the growing (international) interest in the technology, paired with Estonia being an "ideal breeding ground" (EE06) for emerging technologies[106]. Hence, the central government organisations, above all the PMO, the Ministry of Economic Affairs and Communication, and the Road Administration pushed the technology initially through cooperative approaches – a form of network-oriented governance. Today, the market-based dynamics mostly define the interaction of (government) actors.

[106] (In)formal networks of stakeholders regarding a specific societal challenge are forming around other topics as well, particularly involving stakeholders from the public sector, but also experts from research organisations or industry (EE02), e.g. a working group on MaaS (EE07).

For the three TIS functions 'knowledge development and diffusion' (F1), 'guidance of the search' (F3), and 'legitimacy creation' (F6), the government's initially central role had medium influence. As the generation of knowledge occurred at first in universities and subsequently in private firms, the government's impact on this aspect was not significant. However, concerning knowledge diffusion, the government's effort to establish a continued knowledge exchange across the entire triple helix (e.g. in the 'AV Expert Group') contributed to the acceleration of the system formation, especially during its early stages. The knowledge diffusion includes the spread of technical knowledge to Estonia's public administration (EE05, EE10) and shaped the 'guidance of the search' function. Although the AV topic had never been politicised, the additional information available on the technology led to elected officials symbolically approving the emerging innovation efforts as they saw a trajectory in which AVs can contribute to the goals prescribed by the country's transport master plan (cf. Republic of Estonia Ministry of Economic Affairs and Communication 2020): making the Estonian transport sector "people-centred, smarter, [and] greener" (Wright 2020). The positive (political) support by state officials, both elected and administrative, also added to the technology's legitimacy.

The system functions of 'market formation' (F4), 'resource mobilisation' (F5), and 'positive externalities' (F7) have hardly been shaped by the government's 'centrality and leadership' on the topic. Although (parts of) the government initiated some AV-related dynamics, the early-stage market formed primarily was a result of firm activity and the creation of start-ups, who then also raised funds through angel investors and EU grants, the formation of (international) consortia, or by investing their profits. To meaningfully analyse the 'positive externalities' that were created, it is yet too early.

In sum, the centrality and, in parts, also the leadership of government organisations led to the formation of the main platform to exchange knowledge and form cooperation in the AV sector, which accelerated the growth of the AV innovation system in Estonia. (Note, however, that the group itself was not government-led, it was only its set-up that resulted from government activity, or rather, from individuals in the PMO.) The government representatives who participated in the expert group could gather information and expertise about

AVs and, on this basis, subsequently, contributed to both designing and implementing policies relevant to AV innovation. In other words, the government initiated a forum that led to the formation of a potential market for the technology and continued to incentivise cooperation – also among public sector organisations. These aspects represent features of both a market-based and network-oriented policy coordination approach.

5.4.2 Element 2: Capacity and Independence

The 'capacity and independence' of government organisations (E2), i.e. the extent to which they can decide independently and have the capacity to govern a particular subject, overall was less significant in shaping AV innovation. In general, ministries enjoy relatively high independence from the PMO in Estonia (EE02), whereas agencies, in turn, enjoy less autonomy from line ministries (EE08). This is not to say that public agencies are not independent or do not have the relevant capacity. Rather, those public organisations that do, influence the innovation system relatively less.

'Capacity and independence' are comparatively most relevant to the second system function, 'entrepreneurial activity' (F2). The Road Administration, for example, participated in the 'AV Expert Group' independently from its line ministry (the Ministry of Economic Affairs and Communication) – and did so noticeably as an independent actor (EE10). At times, the representatives from the Road Administration revealed distinct opinions as opposed to the ministry, at times even contradicting (EE10). This was possible as the Expert Group discussions focused on a specialist and technical level rather than on a political level (EE07). Since the same individuals from the Road Administration usually attended the meetings, they built a network with others in the group, which increased mutual trust. Learning directly from the manufacturers and developers, this practice also allowed them to accumulate the technical knowledge necessary to regulate the new AV technology, about which not much previous knowledge existed in the agency. They fed this newly acquired knowledge back into the government agency, which accelerated the permit process and improved the interaction between the agency and the applicants

(EE01, EE10). At the same time, industry representatives could learn about the legal framework and associated regulatory processes first-hand from the Road Administration (EE05), which fostered knowledge diffusion (F1).

Shaping the ‘guidance of the search’ (F3), the efforts mentioned above from individuals in the Prime Minister’s Strategy Unit would likely not have been possible if it was not for the unit's relative independence within the central Government Offices (EE01, EE03). The same independence explains the Road Administration's continued participation in the Expert Group and today in ITS Estonia. It signals that the agency itself continues to be interested in AVs, as they also have to examine the vehicles before granting trial permissions. “The fact that the agency participates in these sessions is super important”, explains the former head of the Expert Group (EE10), which the director of ITS Estonia reiterates (EE07). Hence, ‘capacity and independence’ are closely tied together, as increased independence allows for the targeted and specific increase in required capacity, as the example of the Road Administration shows. Improved capacity, in turn, leads to the ability to shape the future direction of AVs, e.g. by continuing to participate in ITS Estonia and informing manufacturers and researchers about what is possible from a legal, regulatory, and possibly even political perspective – and what is not.

‘Capacity and independence’ only marginally impact the remaining TIS functions ‘market formation’ (F4), ‘resource mobilisation’ (F5), ‘legitimacy creation’ (F6), and ‘positive externalities’ (F7). These functions are primarily fostered by the activity of Estonian and international AV firms rather than government (agencies). Exceptions exist, however, as one of the first pilots in Tallinn reveals, where the City of Tallinn in parts financed the project. The municipal Transport Department also contributed with its expertise and advice, shaping the development and advancement of the pilot project directly (EE03). Although municipalities are involved in most pilot projects (at least for granting permission to use the public roads, for liaising with the local police, etc.), their capacity and their independence are not of key relevance. Thus, the second politico-administrative element was not of defining character for any of these remaining functions.

In sum, 'capacity and independence' define primarily the system functions of 'entrepreneurial activity', 'guidance of the search', and 'knowledge diffusion', whereas the impact on the remaining system functions is lower. This shows especially regarding the Road Administration's capacity (and capability) to understand technical aspects of AVs when testing them and to pass the permit exemptions. Intra-organisational learning – across stakeholders, in general, and among government organisations, in particular (e.g. through exchange with its line ministry, the Ministry of Economic Affairs and Communication) – enabled this capacity growth and allowed for AV testing to begin which in turn stimulated 'entrepreneurial activities'. This collaboration among government organisations and industry stakeholders in a specifically designed forum is a feature common to network-oriented policy coordination.

5.4.3 Element 3: Creative Regulatory Experimentation

'Regulatory experimentation' and flexibility (E3) emerged as a key accelerator for developing the AV TIS in Estonia. The uncertainty resulting from (unclear) regulations formed a blocking mechanism, slowing the innovation system's growth, particularly restricting 'entrepreneurial experimentation', overshadowing the 'guidance of the search' and hindering 'legitimacy creation'.

'Regulatory experimentation' directly influenced 'entrepreneurial activity' (F2) regarding AVs, as it enabled the testing of vehicles on public roads. AV pilots are a crucial step in the RD&D processes of AV manufacturers and operators. Initially, the Estonian vehicle regulation framework followed the Vienna Convention on Road Transport – the international cornerstone of vehicle regulation (United Nations 1968), which does not account for autonomous, driverless vehicles, however (cf. Soe, Ainsalu, and Tammiksaar 2018; SOHJOA Baltic 2020c). The regulatory misalignment caused uncertainty for manufacturers and operators, on the one hand, and regulators, on the other (EE05). Initially, the Ministry of Economic Affairs and Communication contemplated to amend the existing legislation to accommodate AVs (EE06). Instead, the Road Administration as executive agency who is also responsible for the regulation of AVs designed an exemption model, where AV manufactures and operators applying to test their vehicles can be granted a temporary permit much more quickly[107]. Beforehand, the vehicles are thoroughly inspected both on paper and in practice, including a test drive in the public domain with an official examiner on board (EE04). The fact that there was no longer a need for new (or amended) legislation significantly shorted the period between the first applications for pilot projects and their implementation (EE10). Manufacturers, such as Iseauto, and operators, such as Holo, praise the speed of the Estonian agencies in this regard, e.g. compared to Denmark or Sweden (SE09, EE09)[108].

In this arrangement, the Road Administration handles all AV-related matters and coordinates the pilot projects' regulatory aspects. In turn, operators have to engage with only one administrative organisation instead of making applications to several state authorities. The concept of a 'one-stop shop' is not uncommon in Estonia as it is also applied to various other areas of public-authority interaction (EE07). The Road Administration's agility and flexibility regarding AV regulation led to the recognition of the Baltic state as an ideal testing ground of the technology and "as a frontrunner for AVs" (EE07) which explains why several firms chose Estonia to test their vehicles (EE06, EE10).

The Road Administration's approach also shaped the 'guidance of the search' (F3) in the Estonian AV innovation system. By showing a positive attitude towards AVs and enabling its testing, the agency sent a positive signal to innovators and entrepreneurs, in line with the general motto in many Estonian minds: Estonia is an innovative country. The agency did not intend to regulate a technology that "is not yet there" (EE10) and, therefore, allowed firms the space to explore, rather than providing a mandated, uniform trajectory along which the technology ought to develop. This approach increases the space for creativity and innovativeness within firms (EE09, EE10). Similarly, the PMO and the Ministry of

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[107] This process began when Starship Technologies applied to license delivery robots to operate in the public domain. The robots proceed with a maximum speed of 6 km/h and mostly drive on sidewalks. The Road Administration and the Ministry of Economic Affairs and Communication simply consider them as 'bicycles' instead of AVs, rendering the need for adjusted regulations obsolete. The mini robots could instantly be tested and are now in use for parcel delivery (EE01).

[108] Holo (formerly Autonomous Mobility) operates AVs among others in Sweden, Denmark, Norway, Finland, and Estonia. According to Holo's CEO, obtaining a Danish AV license took 670 days, calculated from first submission to the day of award (SE09). The same process took approximately 200 days in Sweden and 35 days in Estonia (*ibid.*). The CEO of Estonia's AuveTech confirms that this process is "significantly easier in Estonia than in Denmark" (EE09).

Economic Affairs and Communication publicly endorsed the technology, emphasising that “we want to see autonomous vehicles on Estonian roads” (EE04). They refrained, however, from devising a strategy how this can be implemented or achieved. Nonetheless, such strong advocacy also shapes the Road Administration's behaviour, e.g. regarding the interpretation of regulations or their strategies to accommodate the needs of private firms.

Furthermore, the government's rhetoric and unequivocal intentions (and also by government agencies) support the ‘creation of legitimacy’ (F6) within society. As the primary goal of the regulatory process is to maintain a safe and secure road environment for all traffic participants (EE04), the fact that the authorities approved AVs made it clear to every traffic participant (including pedestrians) that “the technology must be safe” (EE05). As a consequence (and also due to the general interest of many Estonians in new technologies (EE02)), society generally approved of AVs and tried them during one of the pilot projects. The Estonian government also introduced the ‘E-Estonia Council’, which discussed the legal framework for AVs within the broader scope of regulating AI (Republic of Estonia Government 2019), further promoting AV legitimacy.

The influence of ‘creative regulation’ on the remaining TIS functions is comparatively more limited. ‘Knowledge development’ (F1) occurred before the technology had to be regulated for testing. Thus, the Road Administration’s conduct in this regard only had an effect insofar as firms (and universities) could continue their RD&D efforts without concerns about whether or not they would be able to test their products later on. The same applies for both ‘market formation’ (F4) and ‘resource mobilisation’ (F5): Innovators, investors, and entrepreneurs can rely on being able to launch AV pilots under the existing exemption model, as long as their vehicles do not deviate substantially from previously approved safety and security standards. The impact of regulatory agility on ‘positive externalities’ (F7) remains challenging to assess due to the small scale of AV projects (thus far). From an administrative perspective, the approach to AV regulation has added to the Road Administration’s (and the responsible ministry’s) expertise in handling multi-technology innovations – this might be beneficial regarding future multi-technology innovations.

In sum, 'creative regulation', i.e. the experimentation, flexibility, and agility regarding existing regulations, contributed to advancing the AV innovation system. Due to the exemption model, firms could innovate, invest, and build business models around AVs, which pushed the technology forward. Particularly the Road Administration demonstrated the willingness to support the innovation of AVs (EE07, EE10), maintaining a relatively independent role in the innovation system. This approach, the participation in AV fora, the collaboration with industry players, and the openness to learning contributed to the formation of a market along the AV value chain – in which the government itself was not taking part. In short, the regulator enabled the growth of AV-related markets. The cooperation between public and private entities and among public sector organisations led to the emergence of reciprocity and trust – features pertaining to the network-oriented policy coordination mode.

5.4.4 Element 4: Common Goal-Orientation

Common goals (E4) among system actors and throughout the innovation system are, overall, less influential across the seven TIS functions. The creation and diffusion of knowledge (F1) is motivated by different goals across system stakeholders. Tal Tech, for example, that began researching and constructing AVs in Estonia, worked on the technology from an applied, academic perspective, aiming to push the scientific frontier in their discipline and advance technical knowledge (EE01). AV companies are profit-driven (although most are not yet profitable) and intend to contribute towards their respective niche in a globally growing AV market. Thus, sharing information – a competitive advantage – is limited. Simultaneously, the 'AV Expert Group' induced collaboration, sharing of expertise, and the diffusion of knowledge following an open innovation logic (including government actors), accelerating the innovation system's expansion. The common goal to establish Estonia as an innovation hotspot at the forefront of the AV technology unites government actors, researchers, and many private firms – and thus induces 'entrepreneurial activity' (F2) for AVs (EE07).

The ability of AVs to serve societal needs follows the 'common goal-orientation' as outlined above and shapes the narratives that inform the 'guidance of the search' (F3) and the 'creation of legitimacy' (F6). Promoting efficiency, safety, sustainability, and innovativeness is catchy, intuitive, and difficult to argue against (EE07). Specifically, this goal can materialise in increased road safety through automated traffic systems for all traffic participants, lower pollution and environmental impact, particularly in urban areas, enhanced accessibility for vulnerable groups such as older or disabled citizens, and the introduction of shared vehicles to reduce traffic congestion and increase mobility-related efficiency (EE05, EE06, EE07, EE09, EE10). In general, "the biggest [reason] we all want this to happen is the future potential for public transport, especially regarding last-mile transportation", a senior advisor in the Ministry of Economic Affairs and Cooperation confirms (EE06). The economic benefits that may result from increased automation of road transport, thriving businesses, and knock-on effects in other sectors add to this positive narrative, despite the relatively long time horizon until these 'positive externalities' (F7) can materialise and the doubtlessly existing risks associated with AVs.

A common goal among actors influenced 'market formation' (F4) and 'resource mobilisation' (F5) within the innovation system relatively little. The founding of start-ups and the investments by international businesses and consortia were primarily motivated by the opportunity underlying the AV technology (EE09, EE10). Strategies for business models or investments tend to depend less on society's altruistic improvements and more on a direct potential for a firm or venture. In the future, the overarching impacts underlying these endeavours may also provide a positive economic impact. Such an 'economic mission' and the aspiration to develop Estonia further into a competitive economy and innovation hub also influenced the decisions by both policy designers and implementers, distinctly complementing the missions around resolving transport-related challenges (EE08)[109].

In sum, the orientation towards a common goal unites actors across the triple helix in general terms. Partially, these goals are promoted by government organisations and individual politicians. However, differentiating goals,

[109] This aspect prompts questions about the competition, alignment, and complementarity – and therefore the coordination – of different 'missions', which goes beyond the scope of this thesis, but which might be a fruitful and important future research trajectory (see section 7.6).

particularly related to the business objectives of private firms, persist. This is not unexpected. The common goals shape primarily the legitimisation and reasons for advocating for the technology and send a signal to entrepreneurs and researchers, smoothing the way for the innovation system's growth. Forming common goals or purposes to tackle a jointly recognised problem within society based on shared values is a characteristic common in network-oriented policy coordination modes.

5.4.5 Public-Administrative Influence: Synthesis

The market-based model represents the dominant policy coordination approach in Estonia. In the context of AV governance, a prime example of multi-technology innovation, the Estonian government and its agencies rely largely on such market-based approaches. This means that, in general, the government's influence on innovation processes and practices, as observed in the AV innovation system, is comparatively low. However, government influence remains significant in a very specific way: Government organisations and their representatives initialised and catalysed fora for information exchange and (market-based) network formation, which incentivised 'entrepreneurial activity'. In addition, the state's involvement in such fora, particularly the government agency responsible for regulating AVs, signals to entrepreneurs, investors, and society the indirect approval of the technology. The public administration also significantly influences the AV innovation system through its approach to regulation. The open and flexible approach allowed firms to test their vehicles and attracted continued investment. The Road Administration also strengthened the legitimacy of AVs by declaring them safe for traffic use.

As Table 5.4 outlines, public sector organisations in Estonia strongly influence the innovation system in only a few system functions and through selected means. These influences, however, are highly impactful as they target key elements of the innovation system and roadblocks that needed to be resolved for the innovation system to advance further.

Impact of PA elements ... / ... on the TIS functions	E1: centrality / leadership	E2: capacity / independ.	E3: creative regulatory experiment.	E4: common goal-orientation
F1: knowledge development/diffusion	medium	medium	low	medium
F2: entrepreneurial activity/experimentation	high	medium	high	medium
F3: guidance of the search	medium	medium	medium	medium
F4: market formation	low	low	low	low
F5: resource mobilisation	low	low	low	low
F6: legitimacy creation	medium	low	medium	medium
F7: positive externalities	low	low	low	medium

Table 5.4: analysis of politico-administrative elements in Estonia's AV TIS

However, the conduct and intervention patterns of the Estonian public administration on the AV system functions deviate from the classic market-based mode. Most features that led to the Road Administration's influence are based on cooperation, shared values, mutual co-optation, increased trust, and inter-organisational learning. These are characteristics of network-oriented policy coordination. This type of public influence resolved the emanating stumbling blocks, such as those regarding regulation. It induced the further advancement of the innovation system by catalysing, for instance, 'entrepreneurial activity' or 'legitimacy creation'. The cooperative and networked approach structures, to a large extent, the interaction within the innovation system – between the government, its agencies, and the academic and private sector stakeholders.

Hence, in the Estonian context of AV governance, the dynamics inherent to a dominantly market-based policy coordination system were paired with features from network-oriented models. Accordingly, Estonia employs a hybrid market-network coordination model to govern AVs (Figure 5.3). The central government creates a network, which industry stakeholders then lead, and in which public sector organisations participate. Public agencies are part of key fora and emphasise 'regulatory experimentation', enable a market to emerge, advance, and grow, and thus, push the advancement of the multi-technology innovation system of AVs. Innovative activity occurs primarily within firms, who interact through a market and shape, push, and advance the innovation system according to their own goals and requirements. All network participants cooperate to advance and develop the mostly private-led network further. This leads to an overall sophistication of the innovation system.

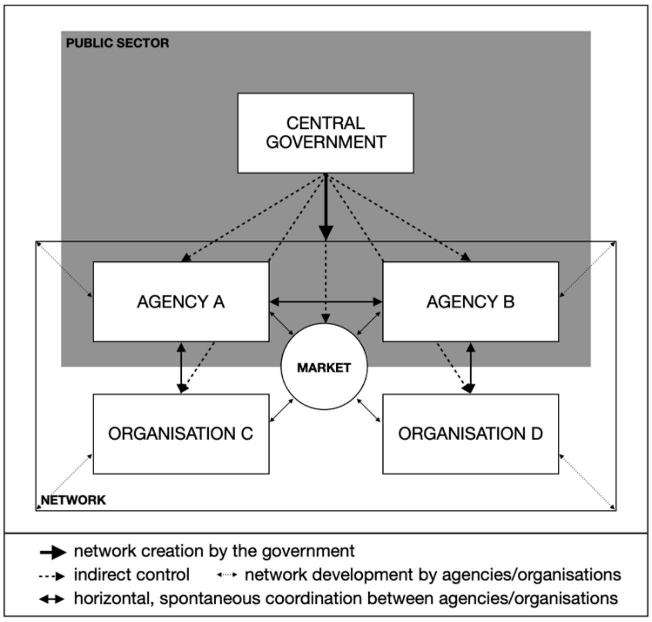

Figure 5.3: hybrid market-network coordination mode[110]

5.5 Case Conclusion

This case study investigated the governance arrangements for the AV innovation system in Estonia. It showed that the system is already established and advancing rapidly across most functions, especially through the ongoing and completed pilot projects. The innovation system is based mainly on market dynamics, as is the country's politico-administrative approach to policy coordination.

In the form of individuals from the PMO, the government contributed significantly to establishing the innovation system by setting up the AV Expert Group as a forum for information exchange and networking. As the innovation system grew, the government increasingly surrendered this initiating role yet continues to participate in subsequent fora, like ITS Estonia, led by private firms. The cooperative approach between public and private sectors and especially

[110] adapted from Bouckaert, Peters, and Verhoest (2010)

across government organisations led to an increase of trust, inter-organisational learning, cooperation in pilot projects, and, in parts, mutual co-optation. This means that government organisations and companies triggered each other to act and contribute to mutually beneficial outcomes. This allowed public sector organisations to remove blocking mechanisms in the innovation system. For example, the agility and 'regulatory experimentation' with exemption models by the Road Administration enabled 'entrepreneurial activity' and 'created legitimacy' for the technology. Hence, the public administration enabled the innovation system to develop and a market to form through its collaborative participation. These characteristics common in network-oriented coordination modes fused with the observed market approach into a hybrid model.

Furthermore, the case study confirms that the market-based approach to innovation and policy coordination can be fruitful but that socio-technical multi-technology innovation, due to its complexity and its regulatory challenges, benefits from network-oriented elements. Estonia managed to establish a hybrid model, where the main burden of innovation and advancement rests on the shoulders of the private sector, but where public sector organisations contribute and enable innovation through cooperation and flexibility. This hybrid model renders Estonia a successful innovator in the AV sector and confirms its international reputation as an innovative economy (EE09).

The hierarchical approach to policy coordination in Singapore in the previous chapter and Estonia's market-based approach in this chapter revealed the importance of network-oriented features to policy coordination in the context of multi-technology innovation. The next chapter discusses this network-oriented mode in the context of AV innovation in Sweden.

6 Autonomous Vehicles in Sweden: Network-Oriented Coordination

6.1 Case Introduction

This chapter analyses the governance arrangements for the AV TIS in Sweden until 2020. The AV innovation system developed under a strong network-oriented policy coordination approach which intensified as the system grew. This intensification is due to the challenges that emanated from governing multi-technology innovations, such as AVs: a large variety of stakeholders involved, systemic interactions and interdependencies, and various forms of uncertainty, particularly regarding regulation. Network-oriented coordination fosters inter-organisational learning, flexibility and adaptability concerning the regulatory framework, and close collaboration among public and private stakeholders. A critical factor that enables this cooperation across stakeholders is the mission-oriented embedding of the entire innovation system: to increase the sustainability and reliability of Sweden's public transport network. Sweden's public sector organisations emerge as network participants and enablers and focus on consensus decision-making and mission-oriented innovation – processes that may consume additional time but lead to striking results.

Sweden's dominantly network-oriented policy coordination mode is a result of its politico-economic context (Section 6.2). The political and administrative cultures in Sweden have a history of collaborative and consensus-seeking practice (SE01). This includes the administration's dualistic structure, i.e. the strict separation between policy design on the ministerial level and the implementation in government agencies. This separation provides agencies with the freedom to interpret policies and to autonomously exercise discretion. The budget allocation process that provides mandates to public organisations manifests this practice. Throughout the innovation system, stakeholders emphasise the triple helix notion, which conjoins interests and processes across government, industry, and research organisations. The resulting interwoven network of stakeholders strongly shaped the AV TIS, led to its rapid expansion, and accelerated the technology's innovation (Section 6.3).

According to public administration theory, network-oriented policy coordination implies that decisions tend to be taken consensually based on shared values and trust. The approach builds on network theory and coordinates through cooperation and solidarity across stakeholders. This does not render the government or its associated organisations obsolete, as it is the (central) government that initially builds and nurtures the network. Network-oriented coordination also includes research organisations and the private sector. The approach may also lead to purpose-built organisations or intermediaries representing specific goals or missions funded or arranged by the government. In the Swedish case, the active role of the public administration in the AV innovation system shows that only a tightly knit collaboration yields innovative results and progress on the way to achieve the pre-defined mission of greener public transport.

Hence, this case study reveals that the network-oriented approach to policy coordination is useful to govern complex multi-technology innovations, such as AVs. The approach is best apt to accommodate the uncertainties and complexities that emerge within the innovation system, such as the multitude of stakeholders. It can prevent or resolve blocking mechanisms in the system, such as lacking capacity or regulatory uncertainty. Sweden's AV innovation system emerges as a case of intensified network-oriented policy coordination to govern the transition towards sustainable and automated transport solutions.

6.2 Context and Background of AV Innovation in Sweden

6.2.1 Structure, Actors, Interaction: Politico-Economic Overview

The politico-economic structure and the role and interaction of the different stakeholders in Sweden's innovation eco-system define to a large extent the development of the AV innovation system. Sweden is constitutionally structured[111] as a unicameral parliamentary democracy and organised as a decentralised unitary state (Petersson 2016; Regeringskansliet 2015). The responsibilities to govern are, therefore, divided across national and local levels (Regeringskansliet 2004): The central government maintains control of core regulations and the distribution of national funds (P. Hall 2016), as well as through national laws passed by the central legislative body, the '*Riksdag'* (Maycraft Kall 2010; Regeringskansliet 2015). The Prime Minister's Office (PMO), the ministries, and the Office for Administrative Affairs make up the 'Government Offices' (*Regeringskansliet*). The central executive is supported by local self-government, spread across two levels: 21 directly elected regional councils and regional administrations, as well as 290 municipal assemblies and executives. Local self-government (Regeringsformen 1974 Ch. 1, Art. 1) remains responsible, among others, for spatial planning and environmental protection, and to some extent also for energy, essential services, industry support, and public transportation (Ahlbäck-Öberg and Wockelberg 2016). In other words, several policy domains relevant to AVs reach across these levels of government.

Sweden's public administration features approximately 400 semi-autonomous government agencies (Statskontoret 2010), fulfilling tasks which in many other countries are completed by government ministries (P. Hall 2016). Since 1975, the "lion's part of the central state administration is […] situated outside the Government Office, in central government agencies" and "outside the ministries", creating an "organisational divide between the government ministries and government agencies (Ahlbäck-Öberg and Wockelberg 2016, 131–32). The Government Offices only employ approximately 1% of Swedish public employees (P. Hall 2016, 300). As a consequence, ministries and ministers do not have direct control of state agencies (Regeringsformen 1974, Ch. 7, Art. 3) as agencies remain largely independent and autonomous, preventing the misuse of power that government officials hold by virtue of their office (Ahlbäck-Öberg and Wockelberg 2016). The 'Instrument of Government' defines this relationship – also known as 'dualism' – as follows (Regeringsformen 1974, Ch. 12, Art. 2):

[111] Refer to Petersson (2016) for details regarding the four fundamental elements of Sweden's constitution (Instrument of Government, Act of Succession, Freedom of Press Act, Fundamental Law on Freedom of Expression).

Independence of administration
"Art. 2: No public authority, including the *Riksdag*, or decision-making body of any local authority, may determine how an administrative authority shall decide in a particular case relating to the exercise of public authority vis-à-vis an individual or a local authority, or relating to the application of law."

The divide of responsibilities between policy design and implementation is not a result of NPM, however, as 'agencification' has historically been a feature of the Swedish governance apparatus (P. Hall 2016; Sundström 2016; Verschuere 2009)[112]. The impact of similarly output-oriented and 'modern' performance philosophies[113] are nonetheless discernible in Sweden (P. Hall 2016), which transformed agencies "into normal organisations with their own goals, recruitment policies, logos, homepages, etc." (Sundström 2016, 327).

Sweden boasts one of the strongest European economies (European Commission 2020b; OECD 2013). As a member of the European Union, as a stable welfare state, and as a country with sound macroeconomic policies (cf. Fiscal Policy Council Sweden 2019; Schwab 2019), the Swedish economy is open and prone to innovation, investments leading to innovation, and challenge-oriented RD&D (OECD 2013). The automotive industry has a considerable tradition in Sweden, with the multi-national companies Volvo and Scania featuring two global leaders in their respective industries, in addition to numerous suppliers (*ibid.*). Although not as strong as in neighbouring Norway, the electric vehicle sector grew starkly over the last decade. In terms of telecommunications technology, Ericsson is a prominent global player. This means that parts of the relevant value chains for AVs already exist, ranging from components, to software packages, and maintenance infrastructure.

[112] Features of NPM have been part of the Swedish public administration before the term was coined. Its immediate impact was therefore felt less. This 'layering' of approaches increases the complexity the Swedish government and its agencies face (as argued by Sundström 2016). This chapter does not discuss the specific extent to which NPM has affected the Swedish public sector. For a more detailed account see Sundström (2016).

[113] These include 'lean thinking' and 'total quality management'. The former relates to goods production but has also been applied to services and government organisations ('lean government'). It intends to optimise production (or a service delivery) whilst minimising waste or inefficiencies in terms of cost, time, employment capacity, value, etc. (Womack and Jones 1996). The latter implies the constant, all-encompassing, organisation-wide performance and quality control, aiming at systematically achieving a quality guarantee (Kamiske 2000).

In terms of infrastructure, the Swedish road network provides excellent grounds to operate AVs (cf. KPMG 2020). Adapting public roads to the AV technology and the associated infrastructure elements requires an approval process as it needs to consider the safety and security of other (non-autonomous) traffic participants, including pedestrians. Necessary infrastructure amendments include connectivity installations allowing vehicle-to-vehicle and vehicle-to-infrastructure communication, space for charging and (un)loading, signage and road markings, as well as safety-related alternations. For testing purposes, facilities on private grounds exist in Sandhult/Borås, operated by AstaZero and jointly run with AV operators and Swedish research organisations, among others the Research Institutes of Sweden (RISE). The test site is open to companies involved in the construction and development of AVs. The annual 'Autonomous Vehicles Readiness Index' (AVRI) concludes that Sweden ranges among the countries most ready to embrace AVs (KPMG 2017, 2018, 2019, 2020).

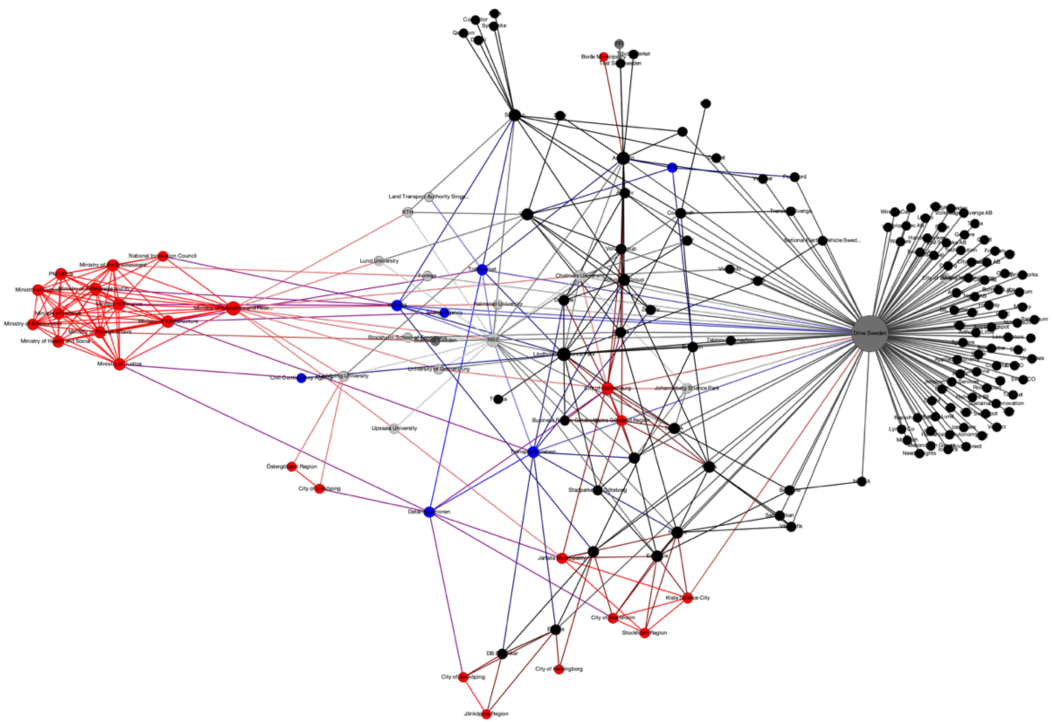

Figure 6.1: Swedish AV innovation network visualisation[114]

[114] A larger node implies a higher degree; red: government, blue: government agencies, black: private sector firms, dark grey: intermediaries, light grey: others.

Metric	Highest	2nd Highest	3rd Highest
Degree	122 (Drive Sweden)	21 (Ministry of Research)	21 (RISE)
Eigenvector centrality	1.000 (Drive Sweden)	0.3199 (RISE)	0.2855 (Lindholmen)
Betweenness centrality	0.8194 (Drive Sweden)	0.0861 (RISE)	0.0642 (Asta Zero)
Closeness centrality	0.7319 (Drive Sweden)	0.5276 (RISE)	0.5000 (Transport Admin.)
Hubs	0.5881 (Drive Sweden)	0.1853 (RISE)	0.1673 (Lindholmen)

Table 6.1: network metrics for Sweden's AV innovation network

Turning to the specific actors within the AV innovation system shows that AV innovation is a prime example of the Swedish triple helix approach (SE08): the joint involvement of academia, industry, and government for the purpose of innovating a particular product. As shown in Figure 6.1, the AV actor-network in Sweden is diverse, including stakeholders from across that triple helix. The Government Offices and the ministries (red) do not form a central part of the AV innovation network. Although they are highly connected among themselves, they cluster to the far left of the network visualisation. Instead, the most central node (by a margin) is Drive Sweden (DS), the purpose-built intermediary funded by *Vinnova* (i.e. the government). It is the most connected and most central node by all centrality metrics and is also the most influential node (by eigenvector centrality) (see Table 6.1). DS connects mostly companies, domestic and international, who work on or with AVs in Sweden. These are often not connected with each other. However, a significant group is linked to other network stakeholders, forming the central part of the network visualisation. Among these are, for instance, AstaZero, which operates the testing grounds, or Lindholmen Science Park, which hosts a multitude of companies working on AVs. Other government organisations, such as the innovation agency *Vinnova*, are not central to the network either, although it is connected to the most influential nodes in the network, primarily DS and the Ministry of Education and Research. *Transportstyrelsen* (the Transport Agency) and *Trafikverket* (the Transport Administration), the two transport-relevant executive agencies, form connections with a small selection of firms and other government organisations but are also not central to the network. The network visualisation also highlights the importance of the different research organisations involved in AV research, such as Chalmers University of Gothenburg or RISE (light grey). In terms of network metrics, for most metrics, RISE is the second most central organisation. However, the numerical margins between RISE and DS, as depicted in Table 6.1, indicates that DS is the significantly more central node.

The network distribution that both the network visualisation and the calculated network metrics indicate reveals two insightful findings. First, the AV innovation system forms a relatively flat network. Except for DS, on the one hand, and the government cluster, on the other, the network is relatively evenly connected and distributed, with no other nodes standing out in terms of degree or centrality. Second, the government forms no central part in any cluster other than among itself. Although some government organisations are involved in AV projects, fund AV research or tests, or regulate the use of AV (*Transportstyrelsen*), the central government itself remains a distant participant rather than the controller of the network. In sum, this suggests that Sweden implements a network-oriented policy coordination mode based on cooperation when governing multi-technology innovations, such as AVs, where the central government, through its innovation agency, sets up a network, which then develops based on the input and effort of network participants. These insights re-iterate the principal research question of this thesis: What role do government organisations play in complex innovation systems – especially in a case like Sweden, where they are not central to the innovation network?

6.2.2 Sweden's Politico-Administrative Coordination: the Network-Oriented Mode

Sweden's innovation governance operates based mainly on what Bouckaert, Peters, and Verhoest (2010) refer to as the network-oriented mode (see Figure 6.2). Accordingly, the interaction and coordination of politico-administrative actors depend mainly on voluntary cooperation and mutual solidarity (Börzel 1998; Kooiman 1993; Powell 1991). Networks are "(more or less) stable patterns of cooperative interaction between mutually dependent actors around specific issues of policy (or management)" (Bouckaert, Peters, and Verhoest 2010, 44). Therefore, coordination is not enforced through power but emerges as a result of the legitimacy of stakeholders, negotiation and bargaining, and possibly mutual co-optation creating interdependencies (*ibid*.). Consequently, coordination occurs through a network of actors, managed and controlled informally by government actors, whereas agencies and other organisations coordinate horizontally and spontaneously, or informally, with each other (Peters 1998b). Coordination, therefore, relies on a common understanding of the context and the issue(s) at stake as well as shared values for possible solutions (Kickert, Klijn, and Koppenjan 1997; Mintzberg 1979). Note, coordination can also manifest itself in binding contracts (O. E. Williamson 1985, 1993).

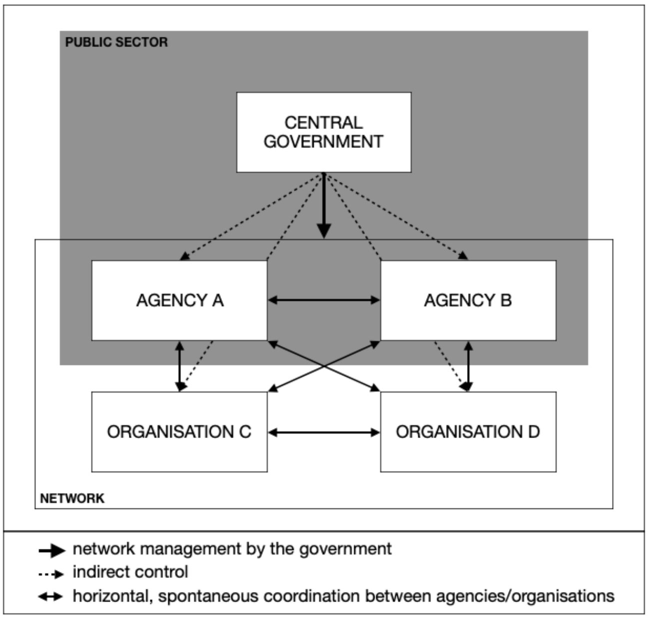

Figure 6.2: network-oriented coordination model[115]

The network-oriented coordination mode emerges from the dualistic structure intrinsic to the Swedish administrative system. Consensus-seeking, pragmatism, and trust, among others, define the relationship among government actors and between the government and the public – quintessential network-oriented characteristics. 'Consensus-seeking' refers mainly to decisions taken in the cabinet, which serve as instructions and mandates for government agencies. These decisions are made collectively upon detailed discussion (Larsson 1995). Dissenting members of the cabinet must declare this on record (Ahlbäck-Öberg

[115] adapted from Bouckaert, Peters, Verhoest (2010, 49)

and Wockelberg 2016). In turn, the cabinet is also collectively accountable for these decisions (Ahlbäck-Öberg and Wockelberg 2016). Moreover, "consensus still serves as the overarching rationale for state-society relations […] as a precondition for stability" (P. Hall 2016, 311). 'Pragmatism' describes the frequently mentioned self-image of Swedes: In line with the consensus-seeking principle (which, as opposed to pragmatism, is to some extent constitutionally defined), the predominant rationale among public administrators is to find solutions that please all (or most) stakeholders. "Often, we won't leave the room until everyone is happy" (SE07), explains a Senior Advisor in the Ministry of Finance, rendering compromises and trade-offs the norm, even if that takes more time – this is the "Swedish way" (SE07, SE15; see also Crouch 2019). 'Trust' defines most personal interactions across the triple helix of government, industry, and academia in Sweden (SE01). The organisations involved are often not very large, the 'distances' between government organisations are short (SE11, SE19), and previous co-workers have formed linkages across organisations (SE03, SE19). "We mostly know each other" (SE03), explains a senior AV researcher at RISE. "You can call anyone any time and ask a question, especially in agencies. They are all calling each other by their first name, Martin, Gustaf, Lasse, and so on, and that is not just a formal arrangement, but a mindset thing. Across agencies as well, the Tax Authority, the Transport Agency, the Transport Administration, and so on" (SE03). Besides, 'openness'[116] and 'public debate'[117] are intrinsic factors defining the work of Sweden's public administration, which have had less influence on the AV innovation system.

In practice, this cooperative and consensus-seeking approach[118] effectively shapes the annual budget allocation process by the Ministry of Finance (Wockelberg 2010). Once a year[119], the central government "places an order with each agency regarding both activities to be carried out (goals) and results to be accomplished (results requirements), as well as information about activities

[116] Swedish government documents are principally open to the public (*Offentlighetsprincipen*) and public servants are free to express their opinion in public (P. Hall 2016).
[117] The principle of 'public debate' invites officials to justify decisions publicly (cf. P. Hall 2016).
[118] See Rothstein (1992) for a detailed account on the emergence of 'Swedish corporatism'.
[119] Mandates may be altered several times a year, depending on context and changes of requirements or funding (SE02).

actually carried out and results accomplished (reporting-back requirements)" (Sundström 2016, 318). Sweden is "to a high degree governed by the budget process, which is very strong; pretty much everything that moves in the Swedish government is connected to that budget process" a Finance Ministry official confirms (SE07). The Ministry of Finance[120] maintains a strong influence on state organisations that depend on its funds. Generally, the government highlights priorities through the budget process (Regeringskansliet 2018a, 2019a). It can emphasise particular aspects, goals, and practices in 'mandate letters' and even allocate additional financial resources, which may purposefully strengthen the cooperative, network-oriented character of governance practices[121]. It follows that the budgeting process coordinates policy goals and administrative practices by strategically allocated funding and by tilting the playing field towards a particular, carefully considered purpose (cf. Mazzucato 2013b, 2016, 2017b).

In the case of AVs, *Transportstyrelsen*, the Swedish Transport Agency, and *Trafikverket*, the Swedish Transport Administration are the responsible executive (and to some extent also regulatory) agencies responsible for traffic and transport – and therefore for AVs. *Transportstyrelsen* is the Swedish government agency responsible for regulating the Swedish transport system and vehicles, including AVs, reporting directly to the Ministry of Infrastructure. Its mission is "to achieve good accessibility, high quality, secure and environmentally aware rail, air, sea and road transport" (Transportstyrelsen 2014). *Trafikverket* maintains roads and is in charge of road construction and infrastructure alternations that might be necessary for AVs.

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[120] This process occurs jointly with *Riksrevisionen* (National Audit Office) and *Statskontoret* (Swedish Agency for Public Management). *Statskontoret* collects data and evidence for the evaluation of policies and "provide[s] the Government and Ministries with relevant, concrete and useful studies in all areas with the aim of making the public sector more efficient" (Statskontoret 2018). This serves as one determinant for future funding allocations and mandates (*ibid.*).

[121] Christensen and Lægreid argue that since the budget has been of high importance for steering the direction of government organisations for a long time, other reforms within the NPM school of thought as well as the 'whole of government' idea have been less impactful in Sweden (2007b).

6.2.3 Innovation and Innovation Policy in Sweden

Sweden's government maintains an active yet no central role within the country's innovation ecosystem, as the AV network analysis above demonstrated. This results from the dualistic and hands-off approach to policy implementation and the imperative of consensual decision-making. In addition to the Government Offices and the relevant ministries, two public organisations are more directly involved in Sweden's innovation policy processes: *Vinnova* (the innovation agency) and the National Innovation Council (NIC)[122].

Vinnova is an autonomous government agency with the goal to "help to build Sweden's innovation capacity, contributing to sustainable growth, [… and] paving the way for innovation that makes a difference" (Vinnova 2020). "*Vinnova's* vision is that Sweden is an innovative force in a sustainable world" (*ibid*.). *Vinnova* is a relatively small agency (approx. 200 employees) and reports directly to the Ministry of Enterprise and Innovation. However, "in a collaborative spirit" (SE02), the agency maintains strong contacts also to the Ministry of Research and Education, as well as to the Finance Ministry and other government ministries, depending on the project (SE02, SE04). *Vinnova* receives its mandate from the government (SE02, SE07). Usually, these 'government assignments' are relatively open, giving *Vinnova* scope for interpretation and, thus, decision-making power. It acts as a mediator between innovators and the government, feeding back insights from practice into the policy cycle by bundling the interests of multiple stakeholders (SE04, SE05, SE06). *Vinnova* invests approx. SEK 3 billion (GBP 245 million) yearly to enable firms and organisations to "experiment and test new ideas before they become profitable" (Vinnova 2020). "Our conviction is that actor-driven agendas in collaboration across the triple helix will drive innovation […] focusing on the wider scope of societal needs", as its director explains (Isaksson 2021). For this purpose, *Vinnova* launched the mission-oriented innovation initiative in 2019 (Vinnova 2019). *Vinnova's* deputy director elaborates (SE02):

[122] See OECD (2013) for an in-depth analysis of Sweden's innovation policy.

> "There is the growth part and the sustainability part. I think it is not just something we say lightly. Sustainable growth is easy to say, but those words are key to the *Vinnova* operations. We cannot do it by burning out the private sector. Collaboration is the key. […] Also, we have always been working with all policy areas […and] have very intense informal contact between *Vinnova* and the government offices […] If we do not do it jointly, we will not be able to move with the speed and couldn't be creating this directionality that is needed. Sweden, since we have a system that is built on these autonomous agencies, we tend to be very good and very efficient in our silos. But if we want to address climate change […], it will not be solved by single agencies reporting to single ministries. […] Therefore, we incentivise collaboration. We incentivise collaboration for sustainable growth. That's basically our mission statement."

In practice, most projects follow a bottom-up approach and are run in partnership with other stakeholders, such as research institutes or private firms. Such projects are based on a 50/50 principle, where *Vinnova* (through public funds) and the partner each provide 50% of the funding. This strategy ensures commitment while at the same time allowing for experimentation – and failure (SE04). In other words, "*Vinnova* provides opportunities" (SE02). Additionally, several projects are run 'top-down' through 'Strategic Innovation Programmes' (SIP) whenever the agency detects the need for a particular innovation or a larger, overarching strand of research (SE04). However, *Vinnova* itself does not have the (technical) capability nor the capacity to innovate specific technologies itself and instead "orchestrates the stakeholders who have that competence" (SE04). Accordingly, the SIPs allow participating institutes and firms to shape the development of the programmes themselves, based on societal needs and their capabilities (Grillitsch et al. 2019), but *Vinnova* remains involved as mediator, advisor, and funder. SIPs promote especially more complex technologies, such as smart mobility or the digital transportation infrastructure (SE03, SE04).

One of *Vinnova's* SIPs is 'Drive Sweden' (DS)[123]. DS is the central intermediary concerning AVs (see Figure 6.1). It provides a forum for domestic and foreign companies, researchers, government actors, and other stakeholders involved in the AV innovation system (SE01, SE03) – in short, it is "the initiative that everybody cooperates around" (SE15). It describes itself as "a cross-functional

[123] DS is funded by *Vinnova*, the Swedish Energy Agency, and *Formas* (the Swedish 'Research Council for Environment, Agricultural Science, and Spatial Planning) (Formas 2020).

collaboration platform that drives the development towards sustainable mobility solutions for people and goods. Together, we develop and demonstrate efficient, connected and automated transport systems that are sustainable, safe and accessible for all" (Drive Sweden 2020b). *Vinnova's* Director states that "DS has been the forerunner in making much-needed system perspectives clear" (Isaksson 2021). It is hosted by Lindholmen Science Park[124] in Gothenburg.

The other directly innovation-related public organisation, the NIC, is a small consultative committee. It comprises the Ministers of Finance, Enterprise and Innovation, Environment and Energy, as well as Education and Research and is chaired by the Prime Minister. It also includes ten external advisors and experts from industry, academia, and unions (Edquist 2019). The NIC convenes three to four times a year for one-day meetings each time (SE07) to informally set Sweden's innovation agenda[125]. The council is neither constitutionally enshrined nor elected, does not draft or pass bills, and decisions are only of advisory character. Due to this 'loose' arrangement, the council's influence on innovation policy is disputed (SE01, SE07), and its impact on the AV innovation system is minimal (SE03). However, the NIC does provide a forum for information exchange, shaping ideas, and aligning policy goals within a holistic approach to innovation policy (cf. Edquist 2019; Schwaag-Serger, Wise, and Arnold 2015).

In addition to the government, innovation in Sweden is shaped by several highly ranked and reputable research organisations, featuring strong research outputs. In terms of universities, these include the Karolinska Institute and Lund University ranking among the 100 best universities globally, the universities of Uppsala, Stockholm, and Gothenburg among the top 200, as well as the Royal Institute of Technology (KTH) and Chalmers University in the top 300 (Times Higher Education 2019). In addition, RISE represents a "strong innovation partner who can provide comprehensive support and a broad range of

[124] Lindholmen Science Park AB, established in 2000 by the City of Gothenburg and Chalmers University, houses over 250 companies, research organisations, and public agencies in the areas of telecommunications, smart mobility, transport systems, and media. This includes Volvo Cars, Ericsson, *Vinnova*, the Vastra Götaland Region, and the Swedish Road Administration (*Trafikverket*). Several Swedish universities cooperate with Lindholmen and have satellite campuses in the vicinity (Lindholmen Science Park 2020).

[125] The NIC temporarily ceased operations in 2018 (SE07) but was re-initiated in October 2019 (Regeringskansliet 2019b).

perspectives […] accommodating a wide range of research areas, testbeds and demonstration facilities as well as 2800 problem solvers" (RISE 2020a). Following the "vision of being a leading international innovation partner" (RISE 2020c), RISE aims to ensure "sustainable growth, by building structures and processes for innovation that make our customers and partners competitive on the international stage" (*ibid.*). The institute features an interdisciplinary group of experts, conducts research independently, collaborates with industry and other research facilities, and consults the government on innovation-related topics. RISE acts as "a catalyst for innovation that, while it may occur without us, becomes more effective through our participation in the process" (RISE 2020c) – it accelerates innovation. RISE is active across 25 cities in Sweden and abroad and focusing on five areas, among others, digital systems, the built environment, as well as safety and transport, which includes projects on AVs (RISE 2020b). Appendix 1 lists the key actors in Sweden's AV innovation eco-system.

Index	**Index Scope**	**2017**	**2018**	**2019**	**2020**
Global Innovation Index[126]	global	2	3	2	2
Bloomberg Innovation Index[127]	global	2	2	7	5
European Innovation Scoreboard[128]	Europe	1	1	1	2
Global Competitiveness Index[129]	global	7	9	8	-
Economic Complexity Index[130]	global	9	8	-	-
R&D Investment Index[131]	OECD	3	4	-	-
AV Readiness Index[132]	selected countries	-	4	5	6

Table 6.2: Sweden's rankings in innovation-related indices 2017-2020

[126] The 'Global Innovation Index' by Cornell University, INSEAD, and the World Intellectual Property Organisation measures overall innovation-related parameters (Dutta, Lanvin, and Wunsch-Vincent 2017, 2018, 2019, 2020).
[127] The 'Bloomberg Innovation Index' gathers general innovation-related metrics (Bloomberg 2017, 2018, 2019, 2020).
[128] The European Innovation Scoreboard compares innovation eco-systems across European countries (European Commission 2017, 2018, 2019, 2020b).
[129] The 'Global Competitiveness Index' by the World Economic Forum annually measures the competitiveness of global economies, which can be considered a proxy for innovation (Schwab 2017, 2018, 2019).
[130] The 'Economic Complexity Index' emerged from the 'Atlas of Economic Complexity' and measures the sophistication of economic activities across countries based on the knowledge intensity of products and services as well as the relatedness of such products and services (Harvard University Growth Lab 2020a).
[131] The 'R&D Investment Index' measures the share of GDP invested into R&D activities (OECD 2020).
[132] The 'AV Readiness Index' by KPMG assesses the physical, knowledge, political, and economic infrastructures across countries with regard to AVs (KPMG 2017, 2018, 2019, 2020).

Sweden ranks highly across the most commonly cited international innovation-related indices and can be considered one of the world's most innovative economies (see Table 6.2). The EU Commission regarded Sweden as the "European Innovation Leader 2019" (European Commission 2019). The Global Innovation Index highlights Sweden's 'business sophistication' (global rank: 1), 'knowledge and technology outputs' (global rank: 2), and 'infrastructure' (global rank: 2) (Dutta, Lanvin, and Wunsch-Vincent 2019) – key parameters also for AV innovation. Sweden's macroeconomic stability is also considered to contribute to the innovative environment (Schwab 2019).

Overall, Sweden today is one of the most innovative economies globally, not just technologically, but particularly concerning governance innovation and services – a trait rooted in the country's politico-administrative culture. The government and government agencies – above all the innovation agency – actively support innovation by participating in the innovation network and setting the direction of innovation through funding and generic support. They can build on a sophisticated industry and market structure while actively funding and promoting innovation – a fruitful, long-term collaboration between public and private stakeholders (cf. Fridlund 2000; Lember, Kattel, and Kalvet 2014). In addition, specific purpose-built organisations, but also universities and the private sector cooperate in joint projects tailored to resolve commonly acknowledged challenges. The Swedish approach to governing innovation policy, hence, represents a typical network-oriented policy coordination mode. What does this mean for multi-technology challenges? The following section explores this question by analysing the AV innovation system in detail.

6.3 Technological Innovation System Analysis for AVs in Sweden

The TIS analysis for AVs shows that Sweden features an early yet already well-established innovation system for AVs. It reveals that network-oriented coordination dynamics dominate the interaction of stakeholders in the system, both within the innovation system as a whole and among government organisations. In fact, an intensification of network features helped to resolve blocking mechanisms that emerged in the early phase of the TIS. The government agencies and their initiatives serve as the primary enabler for the initial collaboration in the system, and thus, for its progress and growth.

6.3.1 Function 1: Knowledge Development and Diffusion

The 'knowledge development and diffusion' of the AV technology in Sweden is strong and continuously expands further (SE03, SE13, SE19) due to the pre-existing vehicle industry, an extensive research infrastructure, and the engagement of various intermediary and government organisations. Industry experts assert that the knowledge for "the technology really is here; it is time to make the change happen" (Kornehed 2020). Now, "there are other pillars that we need to make this technology work" (Alkim 2020).

In terms of 'knowledge development', the leading Swedish vehicle manufacturers contribute to the development of the AV technology. Volvo[133] provides extensive technical expertise concerning base and complementary technologies of vehicles, including supply chains and the subsidiary industry. The firm focuses on individually owned AVs for private use. Together with other firms and academic organisations[134], Volvo Cars founded 'Drive Me' in 2013, a research venture intended to kick-start the development of AVs and test their safety (Volvo Cars 2016). The programme was in parts funded by the SIP for vehicle research and innovation, yet Volvo Cars itself invested approximately SEK 75 million (GBP 6 million) into the project (Rothoff 2019). However, Volvo had to pause parts of the project due to ongoing technical difficulties until 2021 (Hawkins 2017). Scania, one of the leading truck manufacturers in the world, explores options for using automated technologies for freight transport, e.g. truck platooning (SE06, SE18). Although both of these use cases for AVs go beyond the scope of this thesis, the insights and experiences by Volvo and Scania contribute

[133] The ownership of Volvo Cars transferred to the Chinese holding company 'Geely' in 2010 (Crouch 2019). However, Volvo's headquarters and its primary activities remain based in Sweden, including their work on AVs (Volvo Cars 2010).
[134] These are Autoliv, Chalmers University, Lindholmen Science Park, the City of Gothenburg, the Transport Agency, and the Transport Administration (Volvo Cars 2016).

to the AV knowledge in Sweden and expand the knowledge in intermediary organisations in which they participate, such as DS.

The strong technical research at Swedish universities additionally contributes to ‘knowledge development’, as it builds the foundation for innovations in the private sector and offers opportunities for university spin-offs (SE11). The proximity to and interaction with private firms allows universities to provide practice-oriented education/research and enables firms to tap into the knowledge pool built in academia (SE02, SE17). A good example is the campus of Chalmers University, located at Lindholmen Science Park, where manufacturers test AV shuttles, where DS and RISE are based, and where many start-ups begin their AV-related work (SE01). RISE itself is “involved in many projects regarding AV”, as a senior researcher explains, and adds that RISE “got the task within the scope of Drive Sweden to investigate the development of these projects” (SE03). The institute contributes to AV ‘knowledge development and diffusion’ through studies concerning the opportunities and challenges of the use of AVs (Schnurr 2018), through a policy lab on the regulatory dimension of AVs (Burden and Andersson 2019), and through a project focusing on the human dimension and the interaction with automated systems in the urban space (Fors 2019).

In terms of knowledge diffusion, the triple helix approach catalyses interaction and renders knowledge transfer opportunities across the aforementioned actor groups. The number of AV-focused events in Sweden increased substantially over recent years. DS organises most of these events. The biannual ‘Drive Sweden Forum’, for example, offers a marketplace for members across the industry, academia, and government (including members from abroad). Firms present state-of-the-art projects, including newly developed software packages, mapping solutions, connectivity and telecommunication features, or new business models. Simultaneously, research institutes present planning approaches to urban innovation, government agencies introduce regulatory novelties, consultancies reveal new ideas about collaboration, and municipalities announce new projects and service proposals for AVs. The forum, thus, serves as a knowledge multiplier and creates networking opportunities, especially between industry and government actors (SE01). DS also includes international members, enabling knowledge transfer from abroad to enrich the domestic knowledge base for AVs.

The shuttle buses in use at Barkarby and Gothenburg, for example, are provided by the French companies EasyMile and Navya. The Lindholmen shuttle is run by a Danish company (which operates across the Baltic Sea region) (SE09, SE16).

Beyond the technical knowledge, government organisations contribute to the creation and diffusion of legal and regulatory knowledge regarding AVs. Many companies are uncertain about the existing regulations, specific safety standards, and ethical aspects regarding AV – especially smaller firms that do not have legal departments (SE05). Both *Transportstyrelsen* and *Trafikverket*, but also RISE, aim at improving this shortcoming. The Transport Agency, for instance, established information meetings for AV permit applicants, where they are advised about regulatory features they must comply with. In turn, the agency learns about the newest technical developments (SE05, SE06, SE10) (see below).

Overall, AV 'knowledge development and diffusion' benefit from the triple helix approach and "intense collaboration [… and] a joint effort between companies and knowledge-producing institutions" (SE02) as well as the government (SE04). The cooperation between established industry players, renowned research-heavy universities and institutes, and all relevant public sector organisations fertilises the knowledge network. The networked interaction of a vast web of partners through Drive Sweden and via RISE, in turn, provides the grounds for shared problem analyses and solutions based on an overarching vision, akin to the mission statements of *Vinnova*, DS, and RISE. Hence, the knowledge infrastructure fosters the understanding of mutual benefits and collaboration as a fundamental principle to grow the AV innovation system. This is in line with practices already established in Sweden but intensified due to the requirements of the AV technology and the pre-defined goals associated with it: improving the sustainability and efficiency of urban transport. In other words, the network-oriented coordination of policies and stakeholders grew stronger as a result of the early implementation of AVs.

6.3.2 Function 2: Entrepreneurial Activity

The 'entrepreneurial activity and experimentation' regarding AVs in Sweden increased substantially since the first AV test. Activity concentrates in and around DS, which has been growing rapidly since its inception in 2013. Today, DS's total membership counts 152 partners across 16 countries (Drive Sweden 2021b). This includes large incumbent vehicle manufacturers, small start-ups producing hard or software, car sharing providers, transport companies, and telecommunication firms and mail delivery services, research institutes, government agencies, municipalities, and more[135] (*ibid.*). DS offers firms to network, highlights pathways of collaboration, and signals the future direction of innovation in the field of autonomous transportation. As DS also has international members, e.g. from Silicon Valley in the US, from across Europe, and from East Asia (SE01), membership is invaluable for Swedish entrepreneurs and larger firms alike if they operate within the AV innovation system (SE09).

The Swedish Transport Agency (*Transportstyrelsen*) reports a total of six approved applications for AV trials on public roads (trials on private grounds do not need official approval) (SE05). Several reasons led to this comparatively low number of applications. First, the regulatory framework by which AV manufacturers and operators have to abide was unclear. AVs, in principle, fall under the 1968 Convention on Road Traffic regulations, colloquially known as the 'Vienna Convention on Road Traffic' (United Nations 1968). Accordingly, they must follow the prescribed safety and security standards (as discussed above). Second, the regulatory approval process for AVs that firms have to pass before starting their pilot project is lengthy and complicated (SE08, SE09).

Both of these issues have been rectified by close collaboration and 'creative regulatory experimentation' by Swedish public agencies in close collaboration with firms and research institutes – across the triple helix (see section 6.4.3 for details about this approach). Their engaged and pro-active strategy based on reciprocity and solidarity among public sector organisations, reduced uncertainty, and made the application process significantly shorter and more "customer-friendly" (SE05). The process increased 'entrepreneurial activity' and AV pilots. Applications have increased since, and at the time of writing, five (or six, if counting the Kista and Barkarby trials separately) AV pilots have been granted permits (see Table 6.3).

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[135] A full list of members is available on the DS website (Drive Sweden 2021b).

Year	Location	Operator	Vehicle	Status
2017	Johanneberg Campus, then Lindholmen Science Park (Gothenburg)	Holo	Navya 'Arma'	ongoing
2018	Kista Science City, then moved to Barkabystaden (outside Stockholm)	Nobina	EasyMile 'EZ10'	ongoing
2019	Gothenburg	Drive Me	Volvo XC90	tested, but postponed
2019	Jönköping	Einride / DB Schenker	Einride T-Pod (cargo)	ongoing
2019	Highways between Stockholm, Malmö, Gothenburg, and Jönköping	Zenuity	Volvo XC90	ongoing
2021	Barkabystaden	Nobina / Scania	Scania Citywide LF (80 passengers)	planned

Table 6.3: AV pilots completed, ongoing, or planned in Sweden

At all test locations, AVs operate in the public space: as a minibus service in mixed traffic yet on a fixed route (in Gothenburg and Kista/Barkabystaden), on roads/highways in mixed traffic but individual cars or trucks (in Gothenburg, Jönköping, and across the country), or in a larger autonomous bus on a fixed route (in Barkarby). The pilot at Kista Science City, also known as Stockholm's Silicon Valley, was the first AV pilot by Nobina, Sweden's most prominent public transport provider. In October 2018, Nobina moved its pilot to neighbouring Barkarby(staden), where the same shuttle bus was incorporated into the public transport network as line 594. Nobina and Scania plan to expand the Barkarby trial, using a full-length, Scania-manufactured bus for up to 80 passengers connecting Barkarby's centre with a metro station of the Stockholm transit system (Drive Sweden 2019b).

In sum, 'entrepreneurial activity' for AV increased significantly throughout recent years as the number of firms who joined DS and the number of AV pilots increased. Uncertainties pertaining to the regulatory framework and the technology's complexity initially slowed the pilot permit process, forming a stumbling block. The active role of the Transport Agency, DS, RISE, and other government organisations and their joint initiatives with industry partners resulted in the exemption model used today that enables 'entrepreneurial activity' (see below). The underlying pragmatism and consensus-seeking culture within and among stakeholders catalysed this process because it allowed for mutual trust, informal encounters, and inter-organisational learning. Although pre-existing in Sweden, these network-oriented features intensified due to the nature and complexity of the initial blocking mechanisms. Combined, the intensification of the network-oriented coordination mode directly enabled the growth of the system and increased 'entrepreneurial activity'.

6.3.3 Function 3: Guidance of the Search

AV innovation in Sweden is distinctly guided by the government, its adopted policies, its missions, and the rhetoric of officials. Yet, "AVs are not centrally governed" (SE03). The government orients itself, among others, towards the mission of a fossil-free Sweden by 2045 (Crouch 2019; Mazzucato 2021; Regeringskansliet 2018a). *Vinnova's* SIPs represent the most prominent and direct approach to 'guiding the search' for innovations. Among others, this resulted in the creation of DS, now the central hub of AV-related activities in the country, and an excellent example of *Vinnova's* (and the government's) narrative of challenge-oriented policies (SE07) and mission-oriented innovation (Vinnova 2017, 2019). It fosters a systemic orientation towards innovation, not just looking at particular technologies, but taking into account the entire system in which a given technology operates and how it can address a larger, overarching challenge (the mission). At DS, therefore, the focus is not only on the technical development but also on business models, public engagement, society planning, digital infrastructure, and policy development (Drive Sweden 2020c). The mandate of *Vinnova* reflects this approach as well (SE02).

The rhetoric and symbolic acts of senior officials, such as cabinet ministers, contribute to guiding the direction of innovation for AVs. For example, the prime minister, Stefan Löfven, attended the initial launch of Volvo's first AV in China in 2015 (Volvo Cars 2015). Moreover, he ostentatiously signed a cooperation agreement concerning innovation and 'green solutions' with the French President in 2017 (Regeringskansliet 2017a). Shortly after that, the Minister of Infrastructure, Thomas Eneroth, in response to this agreement, joined his French counterpart to open an exhibition on transport solutions in Lyon and took part at a roundtable focusing on autonomous mobility (*ibid*.). This resulted in an open call by *Vinnova* for French-Swedish projects regarding innovative solutions of smart mobility (Drive Sweden 2019a). Similarly, the previous Minister for Infrastructure, Anna Johansson, in 2016 delivered a speech regarding AVs and visited the Kista pilot (Drive Sweden 2016).

Similar observations can be made regarding public agencies. The Transport Administration regularly addresses the infrastructure adjustments needed for AVs, also highlighting its benefits for the mission of achieving a sustainable, efficient, and accessible transport system (Trafikverket 2017b, 2017a, 2018). In addition, *Vinnova* discusses AVs as a continuation of the development and implementation of AI-based solutions (Vinnova 2018). On the local level, municipalities and regional transport offices refer to AVs in their future mobility strategies (cf. Hellberg et al. 2014). All of these activities combined signal the openness and willingness of the Swedish government, across levels and organisations, to push the AV technology forward and highlight the importance of AVs from the state's point of view.

By adopting the 'Ordinance on Trials for Self-Driving Cars' in May 2017 (Regeringskansliet 2017b), the Swedish government solidified its manifest interest in the AV technology. The ordinance defines the general guidelines for obtaining a testing permit, complements the exemption model, and "create[s] better conditions for trials of self-driving vehicles" (*ibid*.). This government guideline arrived comparatively early in Sweden, revealing that the government does not intend to block testing of new smart mobility technologies (SE04). In conjunction with *Vinnova* and other partners, RISE launched the policy lab, which resulted in the current permit process (SE03, SE10).

Additionally, the NIC, although not directly involved in any AV efforts, promotes and enables the search for sustainable mobility and also announced its support for AVs (SE07). Yet, since the NIC does not have policymaking powers and cannot propose bills, its influence remains merely symbolic. However, it can still affect the 'guidance of the search', as the informal discussions between senior elected officials (including the Prime Minister) and experts from industry and academia contribute to elevating AVs onto the radar of ministries and agencies.

In addition to official and formal influences on the 'guidance of the search', many of the values inherent to the missions presented by government organisations are rooted in the Swedish self-perception and identity (SE02).

Hence, policies that direct innovation into a greener, more efficient, and smarter direction receive a positive reaction from society (SE02, SE21). As such, the new mission-oriented approach by *Vinnova* (as well as the former, challenge-driven approach) serve as a legitimacy creator (see below). This development has been catalysed by the 'Fridays for Future' movement starting in 2019 and its omnipresent (media) engagements, focusing on issues such as climate change, sustainable living, and the future of urban planning (SE02, SE06). Thus, the societal awareness of environmental sustainability and the trend towards sustainable mobility contributes to the 'guidance of the search' from a social angle (SE04). In this light, and as a continuation of these sentiments, the government stipulates that "Sweden should be a permanent world exhibition for the implementation of new, environmentally friendly, and smart technologies, not at last when it comes to transportation" (Cederfeldt-Östberg 2021).

To summarize, the 'guidance of the search' for AV innovation in Sweden emanates primarily from the government and its funding programmes, run by *Vinnova*, as well as from symbolic acts and rhetoric by senior officials. The desire to maintain a reputation as an innovative country, paired with the technological capabilities of research centres and the industry, as well as the deeply-rooted affinity to environmental sustainability, intensify this dynamic. Thus, the goal-oriented collaboration for AV across the triple helix is based on consciously designed purposes emanating from shared values and a consensus about the future of the country's mobility system (cf. SE08, SE10, SE17, SE18, SE20, SE22). This approach clearly reflects the network-oriented mode for policy coordination, both in the public sector itself and in the wider innovation system.

6.3.4 Function 4: Market Formation

The AV innovation system in Sweden is still in an early stage, so there is not yet a significant market forming for AVs. The installed capacity of AVs in Sweden is very low as only in one case – in Barkarby – they form part of the public transport system (SE08). However, at the same time, several activities by industry players deserve attention concerning (future) 'market formation'.

First, the existing tests suggest that companies prepare for a larger installation of AVs in Sweden. The pilots at Lindholmen Science Park (Holo), in Barkarby and Kista (Nobina), in Gothenburg (Volvo), in Jönköping (Einride), and Stockholm/Gothenburg/Malmö (Zenuity) are all run by private firms who either already established a business model for AVs (e.g. Holo, Nobina) or who cooperate closely with firms that have such a business model established (e.g. Volvo). The ongoing interest of large public transportation providers, such as Nobina, indicates that their business model promises a feasible business case in future scenarios (SE08). Holo's expansion of trials in other countries (e.g. Denmark, Estonia, Norway) suggests a similar trajectory (SE09).

Second, there is a market forming around the AV value chain, rather than for AVs themselves. This refers to companies who produce components, such as sensors or cameras, but especially to firms supplying software solutions for AVs. The membership list of DS, for example, reveals a variety of firms that exist either because they cater for the growing AV market as tier 1 and tier 2 suppliers or because they built a business model relying on AVs. 'HERE Technologies', for instance, develops live mapping solutions for AV systems. 'Kyyti' provides MaaS solutions based on AVs. Numerous start-ups formed similarly.

Third, the Swedish government, as well as regional and municipal governments, are interested in AVs for public transport purposes. Officials at the Municipality of Gothenburg and the *Västra Götaland* region[136], as well as at the City of Stockholm, indicated their intention to pursue strategies where AVs form a part of the transport system. This includes first/last-mile connectivity and AV-use in urban centres, for park and ride offers, or areas with a high pedestrian density, where classic mobility solutions are not feasible (SE12, SE14, SE20, SE21, SE22). Municipalities consider AVs as "a reason to re-design our cities for the better" (SE15) and "as an opportunity for urban development" (SE14).

Combined, the market for AVs remains small. Nonetheless, the formation of a supplier market around the AV technology is growing rapidly. The future trajectory of the AV market is promising based on the intentions of private and public stakeholders. Especially public transport is a policy domain where local,

[136] Mostly, public transport is a regional matter in Sweden.

regional, and national policymakers and implementers interact closely. The joint planning and consensus about overarching goals in this direction indicate a network-oriented coordination model. Simultaneously, due to the nature of the innovation system and its early stage, market-based features are also present in the system, where the government remains a distant actor.

6.3.5 Function 5: Resource Mobilisation

The ‘mobilisation of resources’ for AVs in Sweden occurs financially mainly through the private sector and the government-funded SIP, and in terms of skills and workforce primarily through the industry and universities.

The government funding via *Vinnova’s* SIPs, as mentioned above, follows the 50/50 principle: The project costs are shared in equal parts between *Vinnova* and the project partners, which equals a government subsidy of 50% (SE04). Given the structure of the Swedish national budget process (see section 6.2.2), *Vinnova* also has the legal and political freedom to allocate funds independently based on its mandate to support specific projects, e.g. AVs (SE02, SE04). The SIP ‘Drive Sweden’ obtained guaranteed government funding via *Vinnova* until (at least) 2027 (Drive Sweden 2020b). In other words, the funding structure of *Vinnova* promotes collaboration across the economy. Its Deputy Director (SE02) states:

> “Innovation is driven by firms, it’s almost an ideological conviction that innovation investments in R&D are key in order to sustain growth both from a private sector point of view but also from a union point of view and a public policy point of view. […] More than 85% of our budget is allocated to projects where you have more than one participant. So, it’s basically consortia that we are funding.”

Additional funds indirectly related to AVs emerge from research organisations like RISE, which is also funded by the government (SE03).

The financial contributions that emanate from the private sector can only be estimated. The investment data by firms such as Volvo or Scania, in terms of manufacturers, or Nobina and Holo, in terms of operators, are not all public. Volvo, for example, invested SEK 75 million (GBP 6 million) into the Drive Me project (Rothoff 2019) and additional funds into a project on AVs in Singapore

(Nanyang Technological University Singapore 2019). Its additional investments into technology RD&D are unclear, however. Concerning smaller firms, the expanding member list of DS promises continued private investment in AVs.

The mobilisation of knowledge resources occurs mainly through DS and RISE (SE01). As mentioned above, both organisations, particularly DS, provide an extensive network of stakeholders boasting a vast array of expertise (Drive Sweden 2021b). Individuals' skills are mainly sourced from universities, as the technical training, e.g. in engineering, follows a high standard in Sweden (SE18).

In sum, resources are mobilised through two channels: Private firms invest into their own RD&D programmes and the government funds projects through *Vinnova*, RISE, and DS. Personnel and skills are mobilised through universities, research institutes, and the broader network that DS provides. These funding arrangements stimulate collaboration between stakeholders, including public agencies. The success of the resulting project is contingent upon the extent and willingness to which stakeholders actually cooperate, which results in a state of mutual co-optation. Hence, the *Vinnova*-induced funding structure reveals a starkly network-oriented approach to 'resource mobilisation', which in turn results in successfully expanding the AV innovation system.

6.3.6 Function 6: Creation of Legitimacy

AVs already have a substantial amount of legitimacy across society. Several measures by the media, government, research organisations, and industry actors contributed to the acceptance of AVs. First, the availability of AV pilots allowed Swedes to experience the technology first-hand, especially the autonomous minibuses in Gothenburg and Kista/Barkarby. The pilots – and AVs in general – were extensively covered by Swedish media outlets, further increasing their visibility and legitimacy (cf. Dagens Nyheter 2017, 2018b, 2018a, 2020; Göteborgs-Posten 2019a, 2019b, 2020b, 2020a). The Holo-operated shuttle at Lindholmen Science Park, for example, which I could try myself, carries approximately 100 passengers every day (Drive Sweden 2018). Data raised in the Gothenburg pilot suggests that 90% of passengers had a positive experience riding the shuttle bus, 92% state that they find the service useful, 96% feel safe or fairly safe while on the bus (Drive Sweden 2018).

Second, the political support from the government, the NIC, public transport agencies (e.g. *Transportstyrelsen*, *Trafikverket*), the innovation agency (*Vinnova*), and beyond emphasises the role AVs can play to resolve some of the traffic-related challenges in Swedish cities (cf. Regeringskansliet 2018c). As discussed above, the rhetoric concerning AVs and the actual policy measures undertaken, e.g. to accommodate AVs in the regulatory framework through an exemption model, demonstrate to citizens that the government deems the technology safe and legitimate. Municipal organisations echo this rationale: The Transport Authority of Gothenburg (*Trafikkontoret Göteborgs Stad*), Gothenburg's Parking Administration (*Stads Parkering AB*), as well as the City of Stockholm Transport Office (*Trafikkontoret Stockholms Stad*) confirmed that they are anticipating AVs to be part of future solutions for traffic, mobility, and environmental issues in their respective cities (SE12, SE14, SE15, SE20, SE22), even though "there is still a long road to go [and] still many challenges need to be overcome" (SE14).

Third, research undertaken by RISE and several universities introduce AVs as a viable solution to future mobility concepts. The policy lab approach by RISE, for instance, signalled that AVs can be incorporated into the regulatory framework and can, thus, follow existing safety and security standards – a key determinant when attempting to gain legitimacy for a novel technology. Research at the Stockholm School of Economics shows the potential of AVs as a feasible and cost-effective means of transport when incorporated into public transport networks and hints towards lucrative business models for private as well as public operators (SE11). Besides, *Formas*, the Swedish Research Council, provides a positive review of the efforts by DS (Modig, Palmberg, and Schofield 2018), further adding to the legitimacy of DS and the AV technology.

Fourth, researchers of Halmstad University[137] focused on "a human approach to designing future smart mobility services" – the 'A Human Approach' project. Employing design anthropology, they provided "new human-centred methods

[137] In partnership with Monash University (Australia), and Aarhus University (Denmark), Volvo Cars, and the municipalities of Gothenburg and Helsingborg.

for and modes of visioning future intelligent mobility systems (Fors 2019, 2). The team concentrated on the real necessities, anxieties, and expectations of people regarding future smart cities, including preferences regarding transport-related sustainability. The project revealed a "shared agenda for future smart city developments with connected and automated vehicles and mobility services" (Fors 2019, 5). The human-centred approach and the direct involvement of citizens in the project, paired with the media attention on these factors, helped to legitimise AV (and related services, such as MaaS) as a viable mobility solution.

Fifth, the Swedish government undertook a public consultation regarding AVs. The respective online portal states (translation from Swedish):

> "The transport sector is becoming increasingly connected, digitized and automated. The technical development of vehicles with automatic driving systems that take over an increasing part of the driver's tasks is in rapid progress, as is the development of business models and services where automated vehicles are included. Both the Swedish and the international regulations in the field of transport have mainly been added during a time when all driving of vehicles took place manually. They are therefore not intended for or adapted to high or fully automated driving. […] Sweden should, as far as possible, affirm a rapid introduction of vehicles with automated functions, as part of a larger context where the entire transport sector is facing major changes." (Regeringskansliet 2018d). "Before the government takes a position on a proposal, it is sent for consultation to the relevant authorities, organisations, municipalities and other stakeholders. The government wants to know what those affected think and what support the proposal has. The public also has the right to comment" (Regeringskansliet 2018b).

Over 100 submissions have been recorded, across the triple helix, among others from *Vinnova*, DS, RISE, *Transportstyrelsen*, *Trafikverket*, Volvo, Scania, Starship, numerous municipal and regional governments, as well as societal interest groups and individuals (*ibid*.). The process spurred legitimacy among stakeholders across society and the innovation system, including the public, and in addition contributed to inform government organisations about the needs, visions, and evaluations of existing AV activities.

Overall, various stakeholders and dynamics create legitimacy for AVs. The policy, research, and early 'entrepreneurial activities' introduce AVs as a possible means of transport of the future. The current AV trials and prototype projects, combined with the consensus around the AV technology as a solution to a common problem, have built the foundation for legitimacy. The joint effort to promote this technology across government organisations reveals a cooperative approach that relies on a common understanding of current issues and future trajectories, despite diverging interests of (some) stakeholders. This demonstrates features of network-oriented policy coordination among government actors, specifically, and the innovation system as a whole, generally.

6.3.7 Function 7: Positive Externalities

In general, AVs continue to be in a maturing phase. 'Positive externalities' are, therefore, only recognisable to a limited extent. Some positive effects emerged concerning technical spill-overs and novel business models; other externalities merely remain predicted at this point. First, the AV trials demonstrated that the technology principally works and that it can contribute to sustainable and smart mobility solutions. The technology can also be used and implemented in other areas, such as in cargo transport, on private grounds such as factories, or in other means of transportation. Researchers and companies, such as Scania, are working on solutions in these areas.

Second, the AV trials proved that shared minibuses can, at least in part, resolve the first-/last-mile problem, as shown in Kista and Barkaby. Moreover, they can contribute to an overall reduction in traffic volume due to a lower number of privately-owned vehicles, a more reliable public transportation network, better access to transportation for a wider group of people, a decrease of pollution/emissions, and therefore a positive environmental benefit. According to DS, these impacts may ultimately yield a change of urban design and architecture since space previously occupied by road and parking infrastructure will become available (Drive Sweden 2020b).

Third, the increased cooperation of DS with foreign members renders fruitful cooperation beyond the AV technology, e.g. business relation to foreign partners, export potential, or sources for technology and knowledge transfer. Exemplary for this positive externality is the DS hub in Silicon Valley in California, based at the Nordic Innovation House in Palo Alto (SE01). The initiative, also supported by *Vinnova*, expands the Swedish AV network into the US, fostering partnerships that might go beyond AVs in the future (SE01, SE02).

Fourth, new business models emerged from the potentially widespread availability of AVs. Several companies, such as Kyyti or Springworks, recently joined DS and plan to offer new forms of ride-hailing and MaaS services based on AVs (P. Niskanen 2019). MaaS services expand the variety of available transport modes and make the transportation system more inclusive, e.g. for people with disabilities or the elderly. Successful services using conventional vehicles are already in operation, e.g. in Finland, Gothenburg, and Stockholm (Drive Sweden 2020a), and could be complemented and streamlined by using AVs (SE22).

Altogether, although 'positive externalities' remain limited and indicative at this point, several potential trajectories could contribute to the overarching missions set by *Vinnova*, RISE, and DS. Incorporating AVs into public transport networks requires the collaboration of public authorities. Grounding these collaborations on potentially positive future externalities and the common goals by *Vinnova* and DS strengthens the innovation system. In this arrangement, hence, government organisations operate as network enablers and catalysts.

6.3.8 Functional Analysis Conclusion

In conclusion, the AV TIS in Sweden, although at an early stage, reveals significant sophistication across most system functions. As is typical for emerging systems, some of the latter functions, e.g. 'market formation' and 'positive externalities' are less developed.

'Knowledge development' (F1) is strong, primarily in private firms, such as Volvo and Scania, but also in research organisations and universities. This applies not just to technical aspects but to legal, ethical, and policy issues, as projects by RISE demonstrate. They contribute to the general understanding of the socio-technical impact of AVs. RISE and DS serve as knowledge diffusion hubs, boast domestic and international membership, and function as a marketplace for technology transfer. As a result, 'entrepreneurial activity' (F2) increased in Sweden. Particularly the production, programming, and development of parts and software solutions surged over recent years, such as for mapping, imaging, sensor technologies, or business models. *Vinnova* supports this development through its partial funding offers. As such, *Vinnova*, in particular, and the government, in general, 'guide the search' (F3) of AV innovation towards an environmentally sustainable, cost-efficient, and human-centred direction. The government and leading politicians, e.g. within the NIC, formed a narrative fostering AVs as a possible future solution to urban mobility. Due to the early stage of the innovation system, there is no large-scale 'market formation' (F4) at this point. Only in Barkarby are AVs included in the regular transport network on a single bus line. However, the market along the value chain for AVs is increasingly competitive. This value chain also attracts private investments, even though large parts of financial resources are mobilised (F5) through the government, especially via the SIP of *Vinnova*. The engineering and technical training programmes at Swedish universities shape the skills pool for human resources in the AV innovation system. The political support, the existing AV pilots, and the resulting media attention fuel legitimacy (F6) for AVs. Combined, the AV technology provides a potential for 'positive externalities' (F7), including novel businesses, improved accessibility, and environmental sustainability.

The AV TIS, hence, demonstrates a significant sophistication. Particularly the first functions are well developed and benefit from support across government, industry, and academia – the often-cited triple helix. The innovation system's development follows the mission-oriented approach to resolving grand challenges regarding sustainable transport and urban innovation. This fits nicely into the national narrative that considers Sweden an innovation nation and a country connected to nature and the environment (SE02). The dominant policy coordination mode within this mission, generally, and for the AV innovation system, particularly, is network-oriented. In this case, DS functions as a network administrative organisation or broker (cf. Provan and Kenis 2008). Although the network mode is not new to Swedish government organisations, the challenges emanating from the complexities inherent to the AV technology caused an intensification of network-oriented policy coordination.

The intensified network-orientation shows across the innovation system. To reduce the uncertainties related to the regulatory framework in which AVs are embedded, the Transport Agency introduced a novel collaborative advisory process, on the one hand, and an 'Agency Arena', on the other. Both initiatives sparked inter-organisational learning, stipulated mutual trust, and created a common understanding of challenges. The purpose-built intermediary DS, funded by the government, emerged as the focal point for learning, knowledge exchange, networking, and signalling. The participating organisations united behind a common goal that extended the economic interests of industry players and responded to the commonly defined challenge: sustainable, smart, and efficient urban mobility (this does not mean that they forfeited their economic interests). The continued cooperation across the triple helix paired with the general inclination towards pragmatism and consensus-seeking in Swedish government organisations led to the willingness to innovate, e.g. through a policy lab, resulting in a regulatory exemption model. Hence, the common problem analyses and solutions based on shared values shaped the innovation system of AVs, similar to many other innovation systems that developed in Sweden under the aegis of *Vinnova* and through the funding of the Swedish government.

Hence, the analysis suggests that the intensified network-oriented approach with public agencies as initial enablers and later as participants catalysed this development by removing stumbling blocks and instead creating inducing mechanisms: funding, networks, cooperation, and beyond. How do agencies like *Vinnova* implement the network-oriented approach, and how do their actions result in its intensification? The following section discovers this in detail.

6.4 Coordinating AV Innovation: the Intensified Network-Oriented Mode

The innovation system of AVs in Sweden reflects an intensified network-oriented mode, deepening the network-oriented structures that have already existed in Sweden for a considerable time. The national government is not central to the innovation system, even though it has a noticeable influence through funding arrangements and collaboration. Instead, the most central actor is a government-funded programme, DS, that incorporates participants from academia, industry, and government into a growing, purpose-oriented network. Continuous cooperation across this network enables the exchange of ideas, the formation of partnerships, persistent learning, the building of mutual trust, the analysis of common problems, and the decision-making based on a consensus about commonly beneficial solutions. This becomes particularly helpful regarding the initial blocking mechanisms: regulatory uncertainty, lack of inter-organisational learning, and the lack of capacity in (some) public agencies. The following sections analyse how the coordination of the public administration in Sweden has contributed to this outcome by discussing the impact of each politico-administrative element (E1-4) on the TIS functions (F1-7) in turn.

6.4.1 Element 1: Centrality and Leadership

The ‘centrality and leadership’ of public sector organisations substantially impacts ‘knowledge development and diffusion’ (F1). Although ‘knowledge development’ occurs mainly in private firms and universities (technologically) and public research organisations (conceptionally, ethically, and legally), the diffusion of knowledge occurs mainly through DS. It enables interaction and networking between stakeholders, from which further knowledge-generating activities can emerge. DS is a new and purpose-built organisation, serving as the central focal point in the AV innovation network. Various government organisations, among others *Trafikverket* and *Transportstyrelsen*, but also municipal transport departments, come together under the umbrella of DS to exchange ideas and experiences regarding AVs. DS was – unusually – designed in a top-down manner by *Vinnova* (SE04) as a SIP to trigger challenge-driven innovation for smart and sustainable mobility solutions. *Vinnova’s* leadership and the centrality of DS combined, thus, catalysed ‘knowledge development and diffusion’ for AVs, complementing the work of larger private enterprises (who also actively participate in DS).

For most system functions, the ‘centrality and leadership’ of government organisations is of medium influence, as government organisations do not drive the respective functions but are still necessary for their development. ‘Entrepreneurial activity’ (F2) increased due to the slowly growing innovation system as a whole, although heavily catalysed through the network that emerged through DS. Many smaller firms and start-ups provide their own ideas and initiatives but benefit from the financial resources mobilised (F5) through *Vinnova*, the central marketplace at DS, and the human resources trained by Swedish universities. Public organisations, thus, do not lead but instead enable the mechanisms for entrepreneurs to build on – hence the medium influence.

The political leadership on the overarching mission for sustainable, efficient, and smart mobility paired with the societal quest for sustainable urban living contributed to 'creating legitimacy' (F6) and to 'guiding the search' (F3) for AVs – as one possible future solution among several. Legitimacy is created by approving messages from the NIC and leading individual politicians, such as the Prime Minister, but also through signalling by *Vinnova*, when creating the funding call and the SIP, of which DS was a result. Other government agencies also put efforts into the technology, such as the Transport Agency and the Road Administration. Their approval highlights the technology's safety and security, which are crucial for citizens to accept the new technologies as an alternative to conventional means of transport. The 'legitimation' of AVs relies on the interaction between government organisations and the mutually designed common goal – typical network-oriented characteristics. The approach is successful not at last because Swedish public agencies principally enjoy a fairly high amount of legitimacy, trust, and credibility among the populous (SE11).

The functions of 'market formation' (F4) and 'positive externalities' (F7) are only marginally established and only minorly influenced by the 'centrality and leadership' of public organisations. Although DS is likely to form the central meeting place for future market operators (it already forms a hub for 'entrepreneurial activity'), this market has not yet materialised. 'Positive externalities', such as international business ties, reduction of urban pollution, or improved access to mobility solutions, may emerge. These aspects are too early to be evaluated against the central impact of any public agency, however.

In sum, the 'centrality and leadership' of *Vinnova*, but especially DS, significantly contributed to the growth of the AV innovation system in Sweden. Its most decisive impact is discernible in terms of 'knowledge development/diffusion', but other functions also benefit from DS's central position. Although DS cannot be classified as a classic public agency (it is rather an intermediary), it has been founded by *Vinnova* and relies on (financial) government support. DS was installed through a SIP because *Vinnova* recognised that AVs – and similar multi-technology innovations – can only develop if policy domains and regulatory frameworks are bridged. This is why government organisations continue to be part of DS (e.g. *Transportstyrelsen*, *Trafikverket*, municipalities). Ultimately, DS created a forum of which being a member is invaluable for AV firms and public organisations alike (SE01, SE03, SE04, SE19). In terms of removing stumbling blocks associated with the regulatory framework, the Transport Agency, together with RISE, demonstrated leadership in initiating roundtables and an 'Agency Arena' in addition to the forum established by DS. This allowed government agencies to exchange ideas, jointly analyse challenges related to AVs, and find common solutions based on the prevailing principles of pragmatism and trust. This intensified network-oriented coordination mode and the leadership of several agencies concerning critical junctures in the innovation system enabled the removal of stumbling blocks and, in turn, the rapid development of AVs.

6.4.2 Element 2: Capacity and Independence

'Capacity and independence' of government organisations in the Swedish AV TIS affected the system's development strongly, overall. This became most evident regarding 'entrepreneurial activity' (F2), 'guidance of the search' (F3), 'resource mobilisation' (F5), and 'legitimation' (F6). This public-administrative element in the Swedish case is also affected by the individuals working in and for the government. Swedish public administrators are trained to be reflexive and innovative, enabling them to make decisions and evaluate situations independently (Mellbourn 1986). Accordingly, decisions are made based on the evidence of individual cases rather than political contingencies (SE07), meaning that administrators have discretion. The 'dualism' approach (Pierre 2001), as introduced above, grants governance agencies this discretion, as the central government cannot interfere directly in decisions regarding individuals or specific cases. This 'Swedish model of administration' implies "both the duality of the Swedish executive and the idea that central and local government authorities enjoy a constitutionally protected independence of administration in their application of law in individual cases" (Ahlbäck-Öberg and Wockelberg 2016, 133)[138]. Combined, this approach also demarcates policy design and policy implementation (cf. Page 2012). Elected officials ought to focus on setting overarching goals, passing bills into law, and defining objectives, instead of interfering with administrative business. Agencies, in turn, pick the means necessary to achieve these goals independently (Sundström 2016).

'Capacity and independence' influences 'entrepreneurial activities' (F2) because *Vinnova* has a relatively free mandate only guided by the Ministry of Finance's budget allocation letter and the innovation agency's mission statement, both of which are fairly open. "Formally we are an autonomous agency", explains *Vinnova's* Deputy Director, emphasising that "the Swedish governance system by design is pretty hands-off" (SE02). Due to the dualistic governance arrangement, the innovation agency can independently decide how to operate and how to best support sustainable and smart transport solutions. The SIP, such as DS, embody this approach. Although not an agency itself, DS provides space for public organisations to expand their capacity by exchanging knowledge and learning from manufacturers about the intricacies of AVs (SE06).

Vinnova's mandate, its self-perception as an innovation catalyst, and its capacity as a well-established and connected expert agency, therefore, also strongly defines the 'guidance of the search' (F3) for AVs – more so than any other ministry or government organisation which are rooted in their individual policy domains. In addition, the innovation system also benefits from the 'capacity and independence' of *Vinnova* as a funder, mobilising financial resources (F5). As a large proportion emanates from *Vinnova's* budget (in many cases, up to half of the project funds), this support is invaluable to businesses, especially smaller firms. *Vinnova's* funding calls and framing of SIPs signals to companies and researchers into which direction the innovation agency (and the government) intends to push any particular technology. Due to its relative independence from the central government, *Vinnova* also acts as a mediator between firms within the AV innovation system and among government organisations (SE04).

[138] Sweden's constitution only defines 'administrative autonomy' negatively, i.e. prohibiting government representatives to interfere with agencies' case work. This leaves scope for interpretation, however (Molander, Nilsson, and Schick 2002).

Vinnova signals to stakeholders and the Swedish public alike that AVs can be a fruitful addition to the Swedish urban transport systems and that the technology can contribute to a broader, overarching mission. This creates legitimacy (F6). Although Swedish politicians also support the technology (see above), agencies are trusted more, and their independent assessment and support carry a different and more trustworthy weight (SE03).

The influence of 'independence and capacity' on 'knowledge development and diffusion' (F1) is moderate. 'Knowledge development/diffusion' benefits from independent universities, *Vinnova*, and RISE. It means that research projects at universities can independently target topics of interest and need, including technical aspects of AVs, whereas the innovation agency can independently decide how funding and support arrangements are allocated. RISE (and in parts also *Vinnova*) investigates the social and legal dimensions of AVs, contributes to the design of the regulatory framework, and conducted a policy lab. As such, RISE contributes to the general knowledge stock regarding AVs, e.g. through futures and foresight activities such as scenario planning, but not to its technical aspects.

The influence of government actors' 'independence and capacity' on 'market formation' (F4) and 'positive externalities' (F7) is limited. A market for AVs does not yet exist, and private firms dominate the market of components and software. However, the interest of municipal and regional administrations in the AV technology (cf. SE14, SE22) contributes to forming a potential future market. Future scenarios for urban transport solutions, including AVs, already exist in Gothenburg and Stockholm (SE14, SE15, SE20, SE22). Similarly, public transport providers, such as Nobina, intend to cater for this change, which opens up business opportunities and a market for AVs (SE08, SE09). Public organisations, thus, stimulate private markets through scenario planning and the proclamation of future strategies that include AVs (SE04). The influence of 'independence and capacity' on 'positive externalities' cannot (yet) be determined at this point.

In sum, the 'capacity and independence' of public agencies significantly shape the AV innovation system. Noting the early stage of the TIS, the strength of functions F2, F3, F5, and F6, where the impact of 'independence and capacity' is significant, specifically supports the innovation system's growth. The general 'dualistic' structure in Sweden's public administration (see section 6.2.1) makes this possible. The dualistic governance arrangement indicates that the core functioning of the administration is based on network-oriented principles. However, the introduction of multi-technology solutions, such as AVs, induced several additional (coordination) challenges. To resolve tension and maintain a high quality of governance, *Vinnova* independently decided to form an additional forum for information exchange and learning. *Transportstyrelsen* and *Trafikverket* decided independently to participate in DS. Knowledge exchange, inter-organisational learning, mutual trust, and the shared interpretation of problems and solutions based on consensus ultimately enabled agencies to enact and interpret policies such that they benefit the development of AVs. Besides, the financial support, also independently allocated, e.g. to DS (a SIP), boosted AVs. Hence, the network-oriented approach intensified to remove some of the regulation- and information-related blocking mechanisms. In this way, the independent actions of agencies paired with the AV innovation system's complexity led to a stronger turn towards network-oriented policy coordination.

6.4.3 Element 3: Creative Regulatory Experimentation

‘Creative regulatory experimentation’ is a defining element that shaped the AV innovation system in Sweden substantially. Initially, regulatory uncertainty and a lengthy application process emerged as the key blocking mechanisms in the TIS, which got resolved through cooperation and ‘regulatory experimentation’. The CEO of an operator, when referring to the regulator, stated that “they had no clue” about the technology and “were not ready to assess the safety and security of the vehicles, mainly because this was new to the regulator as well” (SE09). In turn, the Department Manager at the Transport Agency responsible for regulating AVs (SE05) expressed his frustration with the applying companies stating that

> “they didn’t understand the regulations, […] they thought it is so easy for us and we will just approve anything. […] Everyone was new to this, we as an agency as well as the companies who applied […] and we wanted to see so much more than what they provided us with initially on that form. […] Our main focus is safety and security, and they have to understand that.”

The required documents included comprehensive risk assessment, the vehicle's complete technical documentation, contingency planning for vehicle failures or accidents, and safety-related documentation (SE05). Car manufacturers, however, desired to be more secretive about their technologies, fearing a loss of competitive advantages if they disclosed sensitive details. In short, “there were resources and capacities lacking on both sides” (SE03).

The combination of both factors emerged as a key stumbling block for AV development (SE05, SE09, SE18) and required reconciliation from manufactures and regulators (or other agencies) as a pre-condition for further ‘entrepreneurial activity’. To better understand the regulatory challenges and test new approaches, the Transport Agency, jointly with DS and several of its member organisations, guided by RISE, established a ‘policy lab’ (discussed below). To facilitate the process, the Swedish government adopted the ‘Ordinance on Trials for Self-Driving Cars’ in May 2017 (Ministry of Enterprise and Innovation Sweden 2017; Regeringskansliet 2017b): “The ordinance introduces the requirement of a permit to conduct trials of self-driving vehicles. The Swedish Transport Agency will examine matters concerning permits and will have a mandate to grant a permit with conditions“ (*ibid*.).

Today, both challenges have been remedied by the Transport Agency and its collaborative approach, jointly with the Transport Administration, DS, RISE, and the applying AV companies (cf. Transportstyrelsen 2019). The process works as follows: Before applying for a testing permit, companies must submit a ‘letter of intent’. The Transport Agency then organises a confidential ‘start-up meeting’ where participants can “talk more freely and get on the same level” (SE05), ask initial questions, and set mutual expectations. This is followed by the formal evaluation of the application, factory and site assessments, and, if passed, a temporary permit (Transportstyrelsen 2019). Although *Transportstyrelsen* initially guides applicants through the application process, the Department Manager points out that the agency serves merely as an advisor. “We should always be careful because we are the ones issuing these permits, so we should not be directly involved in those projects [and act] instead more like a reference group” (SE05). The application's assessment is a different process without the interference of the applying company (SE05). In other words, the Transport

Agency takes part in the pre-development of the application for a trial project but then leaves the project before the manufacturer submits the application (SE04). Companies and the Transport Agency have expressed their appreciation for this process, as it decreases lengthy correspondence to correct mistakes or to explain misperceptions (SE05, SE08, SE09).

In addition to cooperating with the AV manufacturers and operators, the government agency and regulator *Transportstyrelsen* continuously exchanges experience with other government agencies. The Head of Department responsible for AV permits at *Transportstyrelsen* (SE05) explains:

> "We actually started something called the Agency Arena for different Swedish agencies in order to collaborate on autonomous vehicles. For at least two years now we had quite regular meetings with the police, firefighters, Trafikverket [the Road Administration], but also Datainspektionen [the Swedish Data Agency], different municipalities, and the ones in charge of city planning, and, generally, quite a broad spectrum of different interest groups that we have been talking to regarding this. Not just concerning the trial activities but also in further perspective with coming regulations regarding self-driving vehicles."

"It is important to create understanding" across agencies, explains the Director General of *Trafikverket* (Erixon 2020). This approach, notably, also contributed to the 'legitimation' of AVs, both across government organisations and among the public (see Function 6).

As a result of this consultative process, the initial permit application document developed into a more sophisticated application package, including more details and more comprehensive indications about expectations and minimum requirements. Additional applications also meant improved understanding on behalf of the caseworkers in the Transport Agency to assess the application. Similarly, firms are increasingly aware of the information necessary to please the Agency. The actual testing permit is based on an exemption model. For a limited period, operators are exempt from Vienna Convention (and associated) regulations. Additionally, to guarantee safe and secure operations, vehicle operators must follow pre-defined rules and need to report back to the regulator any activity that for any given reason causes the trial to breach those (safety) rules (SE05). Besides, the Transport Agency can impose further restrictions on any AV trial, depending on the location or the general testing conditions.

Hence, 'creative regulation' emerged primarily as an enabler of 'entrepreneurial activity' (F2). AV manufacturers and developers depend on testing their prototype vehicles on public roads in real-life situations. This was only possible once *Transportstyrelsen*, as a transport regulator, established the appropriate regulatory framework, resolving all outstanding uncertainties. The AV pilots stimulated 'entrepreneurial activity', as "without the trials, the development of AV would have come to a halt" (SE09). The Transport Agency stroke a balance between collecting all necessary information to assess the pilot project and allowing manufacturers space and freedom to conduct tests based on their needs and interests (SE05, SE06, SE08, SE09). This included preparatory meetings with firms but also with fellow agencies, such as the Transport Administration and municipal/regional governments. These agencies also continued to participate in DS. Hence, the flexible approach of *Transportstyrelsen* regarding regulation emerged as a key enabler of 'entrepreneurial activities', even though this is not the agency's primary task.

Similarly, the flexibility and adaptability concerning regulation contributed moderately to 'knowledge development and diffusion' (F1), particularly concerning legal and regulatory knowledge. As a manager at *Transportstyrelsen* confirmed, "everyone was new to this [… and], we were learning on the job" (SE05). The 'Agency Arena' significantly contributed to knowledge diffusion on the government side as it fed back experience from previous applications to other government organisations. It also served as a sense-checking forum for agency representatives (SE05, SE06). Likewise, DS and the policy lab by RISE channelled legal knowledge into the industry. Hence, the learning experience was bidirectional and inter-organisational.

In a moderate way, 'creative regulation' also shaped the 'guidance of the search' (F3). By interpreting regulations in certain ways and by allowing exemptions, the Transport Agency could nudge the forthcoming development of AVs into the desired direction, for example, concerning expected safety standards. In other words, the Transport Agency could clearly outline its expectations. An expert from Scania describes the discussions with the agency as "tenacious" (SE18). However, the Transport Agency considers them fruitful, as "in the end, the chats with companies really contributed to the completeness and quality of permit applications" (SE05). Moreover, regarding the 'Agency Arena', the exchange between the executive and regulatory government agencies responsible for different policy domains could be a blueprint for similar technologies in the future (SE03). Paired with the practice that one agency remains in charge of the ultimate approval process, it enhances clarity and simplicity for applicants. These mechanisms prove the strongly network-oriented approach to policy coordination. The sophistication of this process, combined with the respect towards public agencies, also signals to the population that AVs can be considered safe – adding to the technology's 'legitimacy' (F6).

To a lesser extent, 'regulatory experimentation' shaped 'market formation' (F4), 'resource mobilisation' (F5), and 'positive externalities' (F7). Although no explicit markets for AVs exist (yet), the regulatory framework indicates the parameters in which the technology can evolve in the future to suppliers and developers. Continued testing and openness by the government invite investment for AVs. 'Positive externalities', as mentioned above, are still difficult to assess. However, the regulatory exemption model does build the basis for the aforementioned 'positive externalities' to manifest themselves.

In sum, 'creative regulatory experimentation' and flexibility is a crucial enabler for advancing the Swedish AV TIS – the system would not have developed without 'creative regulation' (SE04)[139]. "What really makes Sweden unique is a huge acceptance and willingness to change and alter readily set processes. […] This mindset makes processes easier" (SE03). This mindset, the learning-by-doing mentality, and the close collaboration across the triple helix manifested in the 'Agency Arena' as well as in the roundtables between the Transport Agency and manufacturers. These efforts increased mutual trust, allowed for the informal evaluation of ideas, and enabled feedback from policy implementers to designers. Both official and unofficial channels allowed for the continuous exchange of ideas between network participants, extending beyond DS. Hence,

[139] AVs might still have developed, as testing could have taken place abroad. However, tests in real-life settings and mixed traffic are inalienable before incorporating AVs into public transport systems. Without regulatory adaptations this would have been unlikely (SE04, SE05).

'creative regulation' represents an intensified version of the consensus-seeking and pragmatic approaches that Sweden's public administration usually employs. In other words, the stakeholders involved in regulating AVs relied on an even stronger form of network-oriented policy coordination than previously.

6.4.4 Element 4: Common Goal-Orientation

The orientation towards 'common goals' shaped the development of the TIS functions strongly overall, especially concerning functions F3, F5, and F6. The predominant goals focused on the sustainable development of smart, safe, and efficient mobility solutions for Swedish cities, adding to a high living standard and being universally accessible (SE02, SE14, Vennersten 2021). The foundation for this goal is the intention to reduce transport emissions by 70% by 2030 and reach nationwide net neutrality by 2045 (Cederfeldt-Östberg 2021). Note that as such, this goal does not select a particular technology but instead remains open and merely mission-oriented. Any single technology is likely to form only a part of achieving the goal as a whole. This assertion turns this goal into the 'mission' of the innovation system. More specifically, DS developed an 'Outlook 2030', which outlines the details of this mission in the context of AVs, which consequently serves as a guidance for AV system actors (Drive Sweden 2021a).

Most prominently, this mission shapes the 'guidance of the search' (F3) function in the Swedish AV TIS. The mission guides and motivates stakeholders both technologically and politically towards achieving this smart and sustainable leap in mobility provision (SE01). The 'common goal-orientation' akin to the whole-of-government idea (Christensen and Lægreid 2007a) and the joined-up government approach (Pollitt 2003) fosters the alignment of government actions based on a particular purpose. Across actors in the innovation system, this goal reverberates in the philosophies of companies and vision statements of public organisations, such as at *Vinnova*, DS, and RISE (Drive Sweden 2020a, 2020b; RISE 2020c; Vinnova 2020). It advises actors to decide how and where to invest (SE02), which partners to rely on (SE01), and which projects to pursue (SE04).

As a result, the 'common goal-orientation' also shapes the 'mobilisation of resources' (F5), at least concerning public finds. *Vinnova's* SIPs, for example, form the basis for many AV activities through DS, which emerged based on *Vinnova's* mission statement. Although not preoccupied with entirely congruent objectives, the national government organisations and municipal and regional governments share the sustainability- and efficiency-related aspects of the mission, which help to mobilise non-financial resources such as expertise. Furthermore, the annual mandate letter from the Ministry of Finance reminds agencies of their obligation towards overarching missions.

Furthermore, framing a technology as part of a solution to a societal challenge helps to legitimise (F6) the technology. Government agencies across policy domains support the technology through their missions and actions. In short, the lack of contradiction across public organisations and individual politicians leads to an increase in legitimacy for the AV technology. This, in turn, catalyses the positive development of other system functions (cf. Hekkert et al. 2007).

The remaining functions are shaped moderately by the common goals that dominate the AV narrative. In terms of 'knowledge development and diffusion' (F1), the overarching mission provides a cornerstone around which organisations like RISE and several universities structure their research (SE02, SE11). In the private sector, where more technical research is undertaken, these common gaols are less dominant yet still guide the direction of innovation (SE18), as the notions of 'connectedness to nature' and 'innovativeness' are also present among industry stakeholders (cf. SE06, SE08). It also shows in start-ups specialising in 'smart' or 'green' aspects of autonomous mobility (SE04). Common goals, hence, to some extent also shape 'entrepreneurial activities' (F2). Since no established market exists (F4), a sound analysis of mission-influence is not feasible. However, the framing used by public organisations indicates that common goals will also be catered to in later stages of AV development. The potential 'positive externalities' (F7) align with the overarching goals of the innovation system, yet it is too soon to evaluate them. However, if they materialise based on the mission, they will indeed benefit society as a whole.

In sum, the common goal-orientation significantly shapes the practices of most stakeholders in the innovation system, including the private sector (although to a more limited extent and, mostly, for different reasons). However, the public sector organisations are conjoined through the overarching idea of a sustainable, smart, safe, and efficient transport solution for Swedish cities. The joint efforts to resolve regulatory uncertainties, to arrange funding, to create fora for information exchange and learning, and, in general, to purposefully design policies and collaborative practices re-emphasises this common mission. These practices rest on solidarity, commonly defined values, joint analyses of problems and solutions, and loyalty – aspects that commonly defined goals and missions embody. They are also characteristics of strongly network-oriented policy coordination approaches. These factors enable the close cooperation of government organisations, as the Swedish governance arrangement for AVs shows. Hence, governing multi-technology innovation, such as AVs meant to contribute to an overarching mission, works well through a network-oriented approach to policy coordination.

6.4.5 Public-Administrative Influence: Synthesis

To govern AVs, Sweden's public administration continues to pursue the network-oriented approach to policy coordination – although in an intensified manner. Some network features, like purposefully created fora for information exchange, joint decision-making based on consensus, trust between government organisations, and mutual co-optation, become particularly strong. The complexity of the technology provokes this intensification: AVs cut across policy domains, they initially caused regulatory uncertainty, the innovation system includes a large variety of actors, and their impact on society can be immense. These features of AVs created blocking mechanisms that could only be overcome through an intensified version of network-oriented policy coordination. Public agencies, and in parts also private actors, conjoin around the mission to establish smart, efficient, safe, and sustainable transport solutions. This framing accelerates the intensification of the network mode as it facilitates decision-making and nudges behaviour in the desired direction. Hence, the public administration, although not a central actor in the innovation network per se, strongly influences the AV TIS. Table 6.4 summarises these findings.

Impact of PA elements ... / **... on the TIS functions**	E1: centrality / leadership	E2: capacity / independ.	E3: creative regulatory experiment.	E4: common goal-orientation
F1: knowledge development/diffusion	high	medium	medium	medium
F2: entrepreneurial activity/experimentation	medium	high	high	medium
F3: guidance of the search	medium	high	medium	high
F4: market formation	low	low	low	medium
F5: resource mobilisation	medium	high	low	high
F6: legitimacy creation	medium	high	medium	high
F7: positive externalities	low	low	low	medium

Table 6.4: analysis of politico-administrative elements in Sweden's AV TIS

Not all public-administrative elements contributed equally to this intensification, however. Although *Vinnova* founded and funded DS and although *Transportstyrelsen* and *Trafikverket* took over key roles during the AV testing permit process, they are not leaders in the innovation network. 'Entrepreneurial activity' (F2), 'guidance of the search' (F3), and 'legitimacy creation' (F6) are the three most significantly influenced system functions by the public administration. They were primarily shaped by the independence and capacity of agencies, as public organisations could pragmatically accommodate the needs of individual firms through discretion and the flexible interpretation of regulations. Therefore, they not only removed the blocking mechanisms pertaining to regulatory uncertainty but also created inducing mechanisms (e.g. further AV pilots) that boosted 'entrepreneurial activities' and 'legitimation'. The Transport Agency created the 'Agency Arena' because of a lack of knowledge and collaboration between government organisations. This promoted inter-organisational learning and fast-tracked the AV permit process. *Vinnova's* formation of DS, in turn, created a marketplace, which stimulated entrepreneurship, but also lifted AVs onto the agenda of elected politicians and the media, portraying the technology as a viable solution to the jointly designed mission.

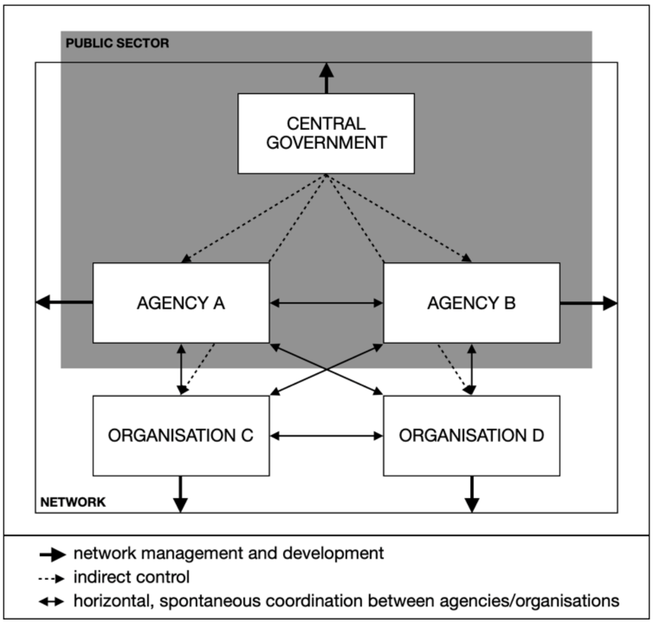

Figure 6.3: intensified network-oriented coordination mode[140]

In the intensified network-oriented coordination mode, as Figure 6.3 shows, the central government jointly with public sector organisations, in this case, *Vinnova*, initially creates the network. After that, the central government takes part in this network as enabler and participant, not through command-and-control measures. Other organisations in the network, both public and private, strengthen the network through their actions, joint efforts to promote the mission, and interactions based on trust and consensus. The central government has only limited direct control over other organisations, and even other state agencies have a significant degree of independence. Organisations across sectors coordinate horizontally and spontaneously, depending on projects and priorities. This may include forming a purpose-built intermediary, such as DS, the network's central actor. Cooperation is based on reciprocity, mutual co-optation, shared values, and consensus. As the Head of Digitalisation at *Trafikverket* states: "Collaboration with the public sector is needed – authorities, cities, regions, etc. – […] and we need input from the industry to know where we are going" (Johansson 2020). Its Director General adds: "This development is only possible if public and private actors are well-coordinated and work together, […] just what DS is doing" (Erixon 2020).

[140] adapted from Bouckaert, Peters, and Verhoest (2010)

Hence, multi-technology challenges that are intended to contribute to the fulfilment of a particular mission benefit from a strongly network-oriented approach. Although this approach is common in Sweden, the complex nature of AVs intensified the existing arrangements. These provide for coordination instruments that are mainly inducive to the individual functions of the innovation system, which allow its rapid development. Private and public actors lead and participate in this network, responsible for distinct tasks and parts of innovation system advancement.

6.5 Case Conclusion

This case study explored the governance arrangements for the AV innovation system in Sweden. The chapter showed that Sweden features a sophisticated innovation system for AVs that is growing rapidly. The innovation system is governed through an intensified version of the network-oriented policy coordination mode – an approach that is well-established in Sweden.

The case study confirms that the network-oriented approach to policy coordination is well-suited to accommodate the complexities inherent to multi-technology innovation, such as emanating coordination issues due to regulatory uncertainty and the vast number of stakeholders within the innovation system. From an initially relatively weakly coordinated actor-network among government organisations (Hellsmark et al. 2016), Sweden established an intensified version of the network-oriented mode, which might slow some processes due to the additional time needed for meetings, learning processes, trust-building, and consensus formation. Yet, the result is inclusive, incorporates the interests of most actors, and builds on solidarity and trust. Feedback loops can easily form in this environment which bridge the gap between policy implementation and policy design and ascertain that the experience gained is used for future policy decisions. The approach is, therefore, fruitful to govern multi-technology innovation and socio-technical systems. In short: “Cooperation is the key to success. This is an eco-system, so of course we are all interdependent” (Ivari et al. 2021). Sweden’s successful approach to governing

AVs is considered to be a result of this collaborative process: “Nobody, no authority itself can do it. All of this is connected to each other” (SE06).

The hierarchical approach to policy coordination in Singapore and the market-based mode in Estonia in the previous two chapters, as well as the Swedish case in this chapter, all revealed the importance of network-oriented features to policy coordination when governing multi-technology solutions and socio-technical innovation systems in the context of mission-orientation. What else do these cases have in common, and what can policy implementers learn from them concerning the coordination of innovation (policy)? The final chapter compares and contrasts the case studies, places them in perspective to the theoretical and scholarly contexts, draws final conclusions, and delivers a selection of recommendations.

7 Comparative Analysis and Conclusion

7.1 Introduction

AVs now roam the streets of Singapore, Tallinn, Gothenburg, and Stockholm – just to name a few urban areas where AVs provide an addition to local mobility. Around the world, in many other countries, AVs are tested and are on the brink of large-scale deployment. Therefore, governments around the world will face the challenges – and will have to answer the questions – that the governments of Singapore, Estonia, and Sweden have already answered: How can such complex technologies, like AVs, be governed?

The empirical chapters of this thesis investigated the development of the AV innovation systems across three countries: Singapore, Estonia, and Sweden. They began with different industrial pre-conditions, are embedded in diverse political and economic contexts, and feature various goals regarding AV deployment. All three countries emerged at the global forefront of AV innovation. Yet, they employed different strategies to achieve this, particularly regarding the implementation of AV-related policies.

AVs represent a prime example of a multi-technology solution that forms a socio-technical innovation system in the context of mission-oriented policies. In this case, the objective is to establish a safe, clean, smart, and efficient addition to the transport systems that allows for access to mobility for the entire spectrum of the population, especially in urban centres. As such, AVs, similar to other complex, socio-technical innovations, trigger coordination challenges for policymakers and policy implementers, as the technologies cater multiple purposes and cut across policy jurisdictions, domains, and organisations. Although many studies investigate coordination and others explore the intricacies of innovation systems, few have thus far examined the role of coordination practices of public sector organisations within innovation systems – the gap this thesis aimed to fill. This thesis asked the following research sub-questions and, consequently, the overarching, principal research question:

(1) How and to what extent do public sector organisations influence socio-technical innovation systems?
(2) How and to what extent do socio-technical innovation systems influence public sector organisations?
(3) How can the relationship between public sector organisations and socio-technical innovation systems be conceptualised and analysed?

How do public sector organisations and socio-technical innovation systems mutually shape each other, particularly in the context of mission-oriented policies?

This chapter concludes this thesis. First, it summarises the key findings of each case study. Second, the chapter contrasts and compares the reciprocal influence of public sector organisations and the AV innovation system across the three countries – answering research questions 1 and 2 in the results section. Third, the chapter consolidates these results into implications and derives (policy) recommendations for policy design and implementation. Fourth, it highlights the role of the analytic framework employed, emphasising its usefulness for future studies and pointing towards possible research trajectories – answering research question 3. Finally, the fifth section answers the overarching research question and concludes this thesis.

7.2 Summary of Case Studies

7.2.1 Singapore

The case study in Singapore revealed a fairly sophisticated AV innovation system, especially given the light industrial preconditions concerning vehicle manufacturing. Nine AV trials have been conducted or are in progress, and others are planned. AVs are mainly used as mini shuttles, accommodating up to ten passengers (including the safety driver), intended for first- and last-mile connectivity in the island's transport network. Thus far, they have only been used in testing sites, mainly in the vicinity of Singapore's most prominent universities and in the tech hotspot area One-North. AVs are also developed for freight transport, such as in the harbour area or for truck platooning on highways. However, autonomous freight transport remains in the planning stage. The innovation network in Singapore is the smallest of all three case studies. The government, particularly the transport agency LTA, features as the central actor in the network. Other government agencies are also directly involved but are less central to the network. Singapore's AV network expands internationally as well, as several multi-national corporations and research organisations are involved.

The principal challenges in Singapore's AV innovation system were uncertainties pertaining to regulation, the lack of inter-organisational linkages, as well as the lack of expertise, both from a technical and legal point of view. First, in terms of regulation, AVs fell in between existing regulatory frameworks for road vehicles, which complicated testing. By passing a technical reference specifying standards and procedures for AVs, the government accommodated the technology in the regulatory framework and defined how AVs can be used in the public domain. Second, linkages between organisations were not deeply rooted, as the policy spectrum remained relatively siloed initially. However, the introduction of AVs and the corresponding need to coalesce policies from different policy domains forced public agencies to collaborate. The LTA, as executive transport agency and transport regulator, took a leading role. It became responsible for the coordination of policies regarding AVs, for the necessary infrastructure, for safety and security, as well as for the communication about the technology on the government's behalf. Third, as new linkages also formed between public agencies and the research domain, between academia and the private sector, as well as between industry and the public sector, AV knowledge could spread to inform policymakers and implementers. This cooperation manifested itself in the formation of an advisory committee for AVs, comprising experts from industry, government, and academia.

Singapore's public administration was able to have this influence due to collaborative and network-oriented practices. Although the LTA has the most central role in the network and is used to a top-down approach to policy implementation, in this case, it cooperated with most other stakeholders in the system. This allowed the LTA to learn about the technology, respond quickly to industry needs, and, thus, implement policies such that they benefit the development of the AV innovation system. This enabled a more bottom-up model, where companies, universities, and research centres could work on the technical solutions, while the government supported these clusters with appropriate policies, funding, and positive feedback or signalling. Combined, this approach ensured quick responsiveness, permanent financing, legitimacy for the technology, and possibly even a future market. Overall, the Singaporean case shows that the government's leading role in the innovation network can contribute to establishing successful AV pilots that are due to expand across the entire country within the coming years.

7.2.2 Estonia

The Estonian case study revealed a slightly less advanced but still sophisticated AV innovation system. All TIS functions except 'market formation' were at least in parts developed, some very strongly, e.g. 'knowledge development and diffusion'. There have been eleven AV pilots in Estonia, and further tests are planned. The focus in Estonia is on mini shuttle buses on fixed routes. In addition, last-mile cargo delivery robots and autonomous military vehicles are tested and in operation. In general, few government actors are involved in the AV network, the most prominent one being the Road Administration, i.e. the executive agency for transport which is also tasked with regulating AVs. At the core of the innovation network are intermediaries, most importantly the 'AV Expert Group', a purpose-driven unit consisting of over 50 members from across government, industry, and academia. The group's main tasks were information exchange, network building, and problem analyses for arising issues regarding all aspects of the AV technology.

The principal challenges in Estonia's AV innovation system were regulatory uncertainty, the lack of expertise in government organisations about AVs, and the market-driven imperative that has shaped the Estonian economy and its approach to governing since the re-establishment of independence in 1991. First, the regulatory challenge, similar to the Singaporean case, resulted from the pre-existing regulatory framework that did not include AVs and, therefore, required features that are not useful to AVs. Second, the government agency responsible for regulating AV use in the public space, the Road Administration, had only limited knowledge about the technology, yet still had to create a testing regime and implement safety and security standards. Third, the dominant market-based imperative suggesting that government agencies are only meant to interfere little with market dynamics emerged as a further stumbling block.

Estonia resolved these issues through three key measures based on increased cooperation across government organisations but also across the innovation system as a whole. First, the 'AV Expert Group', which emerged due to the effort of several individuals from the PMO, brought together experts from across the industry to share knowledge, trigger joint projects, set the AV agenda, and inform the government about future pathways. The Road Administration and the responsible ministries participated in this initiative. 'ITS Estonia', Estonia's information technology intermediary for transport-related challenges, took over the role as central intermediary and meeting place after the 'AV Expert Group' ceased operations. Second, in terms of regulation, the Road Administration devised a regulatory exemption model that temporarily allows AV pilots under specifically defined circumstances and on pre-defined routes and with previously tested vehicles. Third, this approach meant that the Road Administration only had to intervene minimally, as the traffic, vehicle, and transport regulations did not have to be changed. This also helped to speed up the application process. Overall, the Estonian case shows that private sector and research actors can actively advance the AV innovation system, even without the government's central coordinating role. However, Estonia's public administration contributed significantly to resolve key stumbling blocks and, therefore, to enable AVs.

7.2.3 Sweden

The Swedish case study demonstrates the most sophisticated innovation system for AVs in this comparison. Thus far, only six pilots have been conducted (less compared to Singapore and Estonia), nevertheless, the innovation system as a whole shows strengths in nearly every single function. Although 'market formation' is also the weakest function here, there are striking efforts by local transport providers to form such a market, and in at least one case, AVs have already been integrated into the public transport network. In addition, Sweden shows the strongest value chain formation among the three case studies, especially concerning software and business models. The AV innovation system builds on a significant industrial precondition (e.g. Volvo, Scania) and focuses on nearly all types of autonomous vehicles – mini shuttles, individual cars, trucks, and even larger buses. All of these vehicle types are tested. The government is not a central actor in Sweden's AV innovation system. Nevertheless, multiple public agencies have a substantial impact – not directly in the RD&D process, but as funders, coordinators, and network builders. The most impactful one is Drive Sweden, a strategic innovation programme funded by the country's innovation agency *Vinnova* (who is also collaborating with stakeholders in Singapore and Estonia). DS is the central and leading actor in Sweden's AV network and can be considered a purpose-built intermediary.

The principal challenges that Swedish innovators, entrepreneurs, and government stakeholders faced were regulatory uncertainty as well as the lack of experience and expertise across agencies and firms. First, the existing regulatory framework did not foresee AVs, which initially caused considerable delays regarding testing permits. The Transport Administration (*Trafikverket*) and the Transport Agency (*Transporstyrelsen*), but also the affected municipalities, were forced to delay permits due to lack of clarity and detail from the manufacturers. These, in turn, were uncertain about expectations and requirements on behalf of government organisations. Second, this lack of expertise concerning technical and legal matters on both sides caused misunderstandings about expectations, standards, and the technical process and resulted in time-consuming iterations of application documents. These issues also endured because of the consensus-seeking approach deeply embedded in working and decision-making processes in Sweden's public administration. Combined, the initial permit process was extraordinarily long.

Many of the critical measures that resolved (some of) these challenges are the result of collaborative initiatives launched by DS. On the one hand, these are the immediate benefits from bringing actors within the network together to share their concerns and needs, coordinating projects funded by the innovation agency, and giving smaller AV stakeholders a voice in the quickly expanding network. On the other hand, it also included policy development work and research projects jointly run with Sweden's research institute RISE and universities, among which the policy lab tackling the regulatory framework for AV was the most impactful. The project's result contributed to the formation of the permit model and the re-framing of regulatory practices seen today. Besides, agencies also took the initiative themselves, e.g. the Transport Agency organised an 'Agency Arena', which included the agencies involved in governing AVs, with the goal to exchange knowledge, define basic requirements, and share best practices. Overall, the network that formed around DS, in which government agencies took part, led to a successful formation and expansion of the AV innovation network.

7.3 Comparative Analysis

7.3.1 Regulatory Uncertainty, Flexibility, and Experimentation

The most pressing systemic blocking mechanism for AV innovation across all three case study countries emerged from uncertainties related to the regulatory framework for AVs. Existing regulations, following the Vienna Convention on Road Traffic (United Nations 1968), although not prohibiting AVs per se, prescribed features and traffic behaviour unsuitable or irrelevant for AVs. Examples include, but are not limited to, the permanent presence of a driver, a steering wheel, headlights, and a rear mirror. AVs instead use lidar, cameras, sensors, and other technical components, rendering them – by the standard of the regulation – unsafe for traffic (although experts stipulate these features actually increase traffic safety (SG07, EE04, SE09)). Initially, the lack of regulatory clarity led to delays in test trials across the three countries and caused manufacturers and operators to consider investments into AVs carefully. Changing regulations to accommodate novel, multi-technology challenges would affect various regulatory domains. Regulatory amendments, thus, have to be coordinated across policy fields, which requires a conversation between policymakers, policy implementers, manufacturers, operators, and users, especially about the safety, security, and ethical aspects of autonomous systems.

Although Singapore, Estonia, and Sweden resolved this stumbling block differently, they all showed elements of regulatory flexibility and experimentation. Singapore introduced 'Technical Reference 68' (TR68), a supplement to the existing regulation. TR68 outlines the specificities and standards with which AVs must comply if operators or manufacturers wish to test their vehicles in the public domain. Permits are administered by the LTA, just as other vehicle regulations. TR68 is targeted at AVs and leaves little room for re-interpretation. Estonia operates an exemption model that keeps existing vehicle regulations in place and unaltered but relieves AV operators temporarily from some obligations. Permits are granted after rigorous safety tests. At the same time, operators have to follow restrictions and trial-specific conditions. The process is conducted by the Road Administration that is also responsible for conventional vehicles, working closely with the municipal governments where testing is intended to take place. In Sweden, the Transport Agency jointly with RISE designed a policy lab to analyse various regulatory approaches for AVs (Burden and Andersson 2019) – within the existing vehicle regulation framework. Within the 'lab', the permit process remains dynamic and changes from application to application, based on the feedback from participants, previous experience, the requirements of the vehicle, the safety and security precautions needed, the testing location, the current state of the art of AVs, and the current knowledge of all actors involved (SE05, SE06).

Two striking similarities can be observed across the three cases: First, all three countries created a pathway to accommodate the AV technology into existing regulatory frameworks. AVs must comply with existing regulation but are allowed to deviate from some regulatory features if necessary. It is the process to establish this deviation that differs: a legal amendment (Singapore), an exemption (Estonia), or an individual permit based on collaboration (Sweden). Second, in all three cases, it is a single government organisation – Singapore's LTA, the Estonian Road Administration, and the Swedish Transport Agency – who administer the AV permit process. Singapore's LTA had previously been responsible for such approvals. Estonia's Road Administration found novel ways to cooperate with municipalities and research organisations to build the knowledge capacity necessary to test AVs. Sweden's Transport Agency invited other organisations and municipalities to an 'Agency Arena' revealing a trusted and practical approach to interpreting the existing regulatory framework. This implies, in parts, also a transfer of jurisdictions towards these executive (and also regulatory) agencies. Although public sector cooperation existed before, the AV technology triggered an intensified cooperation to address aspects of AVs.

Hence, the experimentation and flexibility regarding regulation directly influenced the AV innovation systems across the three case studies. Through their initiatives, the public administration primarily affected three system functions: Enabling deviation from regulatory norms signals to developers and innovators alike that the government supports the technology and that AVs are likely to be considered a viable mobility solution. This means 'regulatory experimentation' guides the 'direction of the search', but as a consequence, also incentivises 'entrepreneurial activity'. Furthermore, government approval highlights to society the safety of the technology, which 'creates legitimacy'. This legitimacy is catalysed by the cooperative nature of AV governance across the three countries, including (public) research organisations that enjoy high credibility, trust, and saliency. This shows particularly in Singapore, where the influence of public agencies across these three functions is especially strong (although Sweden and Estonia also reveal a significant public agency influence on these functions). This means that the cooperation across and joint effort of government organisations to enable 'regulatory experimentation' is useful to eradicate uncertainties. Although the specific practices differ across the three case studies, the need for regulatory clarity caused public agencies to abandon their conventional approaches and collaborate with innovators and researchers, resulting in a networked approach to implementing the AV transition.

7.3.2 Expertise, Capacity, and Learning

The second most pressing stumbling block pertains to the knowledge and the capacity to govern novel and complex technologies, such as AVs. Government organisations struggled with the technical details of AVs, even though that is inalienable to governing the technology. "The fact that regulators have to make decisions on a technology they do not fully understand will inevitably cause problems", an AV innovator stated (SE09). Public agencies often "simply did not know what was important in a pilot project" and, thus, what AV innovators intended and needed (EE09). Similarly, however, industry stakeholders struggled with the legal understanding of regulations and administratively institutionalised processes. For example, often, innovators used highly technical language on forms or official documents and refrained from disclosing relevant details in fear of intellectual property theft, leading to misunderstanding at the responsible government agency. Hence, "the frustration emerged on both sides", as a civil servant from the Swedish Transport Agency admitted (SE05). This knowledge gap created misleading expectations, caused additional iterations of application documents, and extended the period between the initial submission of a permit request to final approval (SE09, EE05).

Singapore, Estonia, and Sweden employed different strategies to accommodate this issue. Concentrating all responsibility for AVs in a single statutory board (the LTA), Singapore's government ensured that only one public organisation had to substantiate its knowledge capacity and expertise about AVs. The LTA fostered its knowledge capacity by closely cooperating with research organisations and AV companies, creating testing centres, and inviting foreign experts to serve in its advisory committee (CARTS). In Estonia, regulatory and executive responsibilities also concentrated in a single agency: The Road Administration expanded its knowledge capacity through participation in the purpose-built AV Expert Group (and ITS Estonia). These fora allowed public and private organisations to learn and teach about technical and legal aspects of AVs. Furthermore, the close interaction of public agencies and local governments with AV consortia ensures a continuous exchange of experience. In Sweden, knowledge and information exchange concentrates in the purpose-built intermediary DS. It serves as a forum for industry, but also for government organisations. The thematic areas covered by DS, e.g. policy development, society planning, or digital infrastructure, add further depth to the knowledge pool (cf. Drive Sweden 2020c). The 'Agency Arena' initiated by *Transportstyrelsen* supplements knowledge exchange and learning, particularly for public agencies.

There are two aspects these cases have in common. First, despite the large number of stakeholders involved, all three countries increased the interaction between stakeholders across government, industry, and academia to enhance knowledge diffusion. Government organisations turned from being surveyors, observers, and evaluators to advisors, participants, and even members of AV projects, as the LTA and the Road Administration have shown. This shift increased mutual understanding and learning, facilitating the joint assessment of problems and potential solutions. "When sitting in the same boat, you think twice about what you do", one government agency representative from Sweden stated (SE06). Across all three cases, interviewees highlighted the ease and accessibility of communication channels across government organisations (and beyond) as the main source of knowledge exchange – simply picking up the phone and calling someone familiar at the other agency reduces the effort and facilitates learning immensely (SE04, EE04, SG08). In this light, "hands-on learning by doing is often the best teacher" (SE04). Second, as mentioned above, in all three cases, public agencies have (at least in part) transferred some jurisdiction and responsibility to other government organisations to create a single agency responsible for regulating AV-related matters. This increased efficiency and capacity (as only one agency had to cope with AV regulation), reduced misunderstandings, avoided misalignment, and shortened bureaucratic processes, e.g. as observed regarding the Road Administration, the LTA, and *Transportstyrelsen*.

Hence, the improved knowledge capacity of public agencies and learning through inter-organisational linkages accelerated the expansion of the AV innovation system in all three case studies. The public administration influenced primarily the 'guidance of the search' and the 'entrepreneurial activity' functions, as government organisations who knew more about the technology could implement policies in a more targeted and beneficial manner. In the Swedish case, this knowledge capacity also led to the formation of interest to use AVs as a means of public transportation, which could yield a profitable market for the sector. The complexity inherent to AVs forced government organisations (but also other actors in the innovation system) to collaborate more closely. In all three cases, inter-organisational learning results from such closer, formal and informal cooperation between government agencies and between them and industry and research organisations, e.g. in DS. This practice also ensured mutual understanding and improved the alignment of administrative practices. This means that close cooperation between government organisations, industry, and research centres fruitfully addresses the lack of knowledge and expertise, resulting in a networked approach to implementing the AV transition. It forms feedback loops between the stakeholders in the innovation system, facilitating and guiding future policy design and implementation.

7.3.3 Stakeholder Alignment, Centrality, and Leadership

The large quantity and variety of political, industry, academic, and societal stakeholders involved in AV innovation systems increased the difficulty to align interests and actions, especially for government organisations, and, thus, formed the third major blocking mechanism. AV developers and manufacturers, such as Nutonomy, AuveTech, or Volvo, require testing their vehicles, whereas suppliers and operators need to trial their business models, such as ST Engineering, Modern Mobility, or Holo. Research centres hope to gain funding, innovate technologies, and create lucrative spin-offs. Public agencies, following their mandates, care for the safety and security of public roads, maintenance issues, environmental standards, privacy protection, or public transportation – to name a few potentially contradicting interests. In Sweden, for example, *Transportstyrelsen,* responsible for AV safety, demanded further details into AV operations and safety mechanisms before granting a permit, whereas *Trafikverket,* which looks after road infrastructure and maintenance, was interested in getting AVs tested rapidly to gain hands-on experience (SE05, SE06). This led to misaligned efforts, processes throughout the innovation system that were not in sync, and stalled progress in testing and implementing AVs. For entrepreneurs, this caused delays, and thus, increased costs (SE09).

Singapore, Estonia, and Sweden addressed this challenge through intermediaries. Singapore established a small but high-level intermediary – an advisory body with selected experts from across the industry, academia, and government – that centrally and collectively transmitted interests and needs to the LTA. In addition, the LTA controlled which firms were allowed to test AVs in the country, reducing the overall number of actors in the innovation system (which in parts explains the low number of nodes in Singapore's AV network). In

Estonia, conversely, the purpose-oriented, catch-all AV intermediary, the AV Expert Group (and later ITS Estonia), included as many relevant actors as possible from across the innovation system. Consequently, clashes of interest could be detected early, stakeholders could learn about each other's preferences, and collaborations or coalitions could form. Several government organisations, including the Road Administration, participated in these exchanges. Similarly, in Sweden, most actors in the AV innovation system congregate in DS, the purposefully created AV forum. DS coalesces interests, lobbies, highlights differences, and mediates solutions in case of misalignments among actors, especially between government and the industry, e.g. through its policy development sub-programme[141] (SE01, SE04).

Irrespective of these strong and leading intermediaries, the three AV innovation systems differ in terms of stakeholder alignment (see Figure 7.1). Whereas the Singaporean government is central to the innovation system, the Estonian and especially the Swedish government cluster towards the network's periphery. However, the respective public agencies responsible for AVs sit more towards the core of the network and are well connected in all three countries, particularly in Estonia (see eigen centrality in Table 7.1). Therefore, policy interventions can be swift and targeted, and information can flow to policy designers and implementers. Research organisations (both universities and non-university research institutes) are positioned centrally in the network across all case study countries yet are not among the most central nodes. This results in the following dynamic: the innovation network in Singapore is mostly publicly led, whereas the AV network in Estonia is by large privately led. In Sweden, both public and private actors lead the network.

The three cases have two aspects in common regarding stakeholder alignment and leadership. First, although slightly different in nature and composition, they

[141] The purpose-oriented and most central actor in the network, DS, is not directly linked to the central government, but only via the innovation agency. This extends the path length between actors directly linked to DS (e.g. a company) and the government or its agencies. Thus, consensus-seeking or decision-making involves more actors (SE02, also cf. SE09). The central position of the LTA in Singapore, in contrast, allows it to directly take decisions and convey those to the connected network actors. At the same time, the longer path in Sweden elevates the role of DS, highlights the independence of stakeholders in the system not directly linked to the government, and allows for direct collaboration between such actors (through DS), without government interference which, in turn, can also accelerate innovation.

created a central intermediary that conjoins stakeholders, providing for the exchange of opinions, preferences, and knowledge. These fora unite actors from diverse backgrounds, allowing them to create and nurture a joint goal to which everyone contributes. The central role of these intermediaries can be spotted in the network visualisations (green arrows in Figure 7.1). Second, through such intermediaries, most system stakeholders' interests are passed on to public agencies. Not only do government organisations participate themselves, but they also actively seek the recommendations and needs of system actors (particularly in Singapore, but also in Estonia and Sweden).

Metric	**Singapore**	**Estonia**	**Sweden**
Degree (highest)	21 (LTA) 14 (CARTS) 13 (PMO)	64 (AV Expert Gr.) 32 (ITS Estonia) 29 (Road Admin.)	122 (Drive Sweden) 21 (Education Ministry) 21 (RISE)
Eigenvector centrality[142] (highest)	1.000 (LTA) 0.545 (PMO) 0.533 (RIEC)	1.000 (AV Expert Gr.) 0.952 (Road Admin.) 0.761 (Tal Tech)	1.000 (Drive Sweden) 0.320 (RISE) 0.286 (Lindholmen)
Betweenness centrality (highest)	0.464 (LTA) 0.244 (CARTS) 0.146 (Transport Min.)	0.580 (AV Expert Gr.) 0.233 (ITS Estonia) 0.105 (Technopol)	0.819 (Drive Sweden) 0.086 (RISE) 0.064 (Asta Zero)
Closeness centrality (highest)	0.569 (LTA) 0.488 (Transport Min.) 0.477 (CARTS)	0.641 (AV Expert Gr.) 0.534 (Road Admin.) 0.531 (ITS Estonia)	0.732 (Drive Sweden) 0.528 (RISE) 0.500 (Trafikverket)
Hubs (highest)	0.442 (LTA) 0.237 (PMO) 0.234 (JTC)	0.345 (AV Expert Gr.) 0.334 (Road Admin.) 0.269 (Tal Tech)	0.588 (Drive Sweden) 0.185 (RISE) 0.167 (Lindholmen)

Table 7.1: AV innovation network in Singapore, Estonia, and Sweden[143]

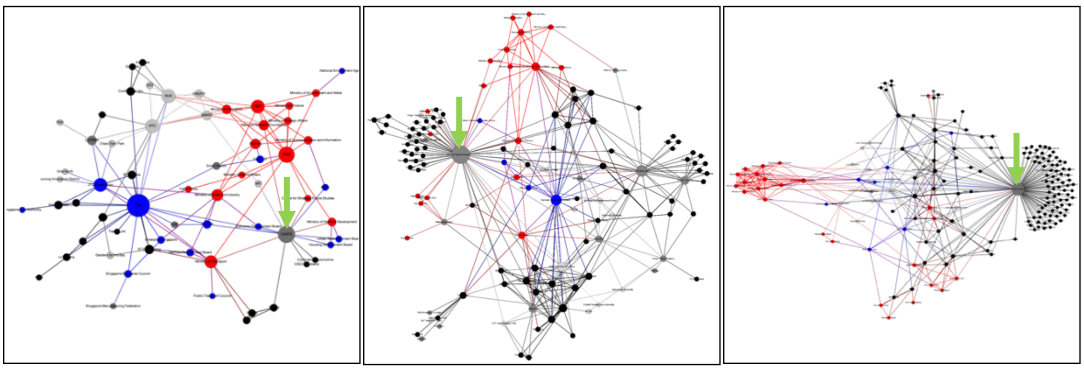

Figure 7.1: AV networks in Singapore (l.), Estonia (c.), and Sweden (r.)[144]

[142] The eigen centrality is normalised [0, 1].
[143] Source: own calculations
[144] red: government, blue: government agencies, black: private sector firms, dark grey: intermediaries, light grey: others including research organisations

Hence, stakeholder alignment through intermediaries and the central role of policy implementing agencies ensured feedback across government, industry, and research organisations, bundled interests of stakeholders, and enabled coalitions or cooperation. This practice by public agencies fostered 'knowledge development and diffusion', both technical and legal, and guided the search of AV innovation by mutually informing actors of their needs and interests. This shows in all three countries, assessing the LTA's role in Singapore, the AV Expert Group and the Road Administration in Estonia, and DS in Sweden. This means that the formation of purpose-built intermediaries, where public agencies participate, provides a fruitful approach to align the quantity and variety of stakeholders. Executive and regulatory agencies, e.g. as in Estonia and Singapore, can also take on a leading role to facilitate policy coordination. Combined, this strategy results in a networked approach to implementing the transition to AVs.

7.3.4 Problem Formulation, Consensus, and Goal-Orientation

Stakeholders in innovation systems are motivated by different objectives. Generally, for the government and the state apparatus as a whole, these objectives should further society's well-being. For this reason, the governments in Singapore, Estonia, and Sweden have formulated the safety, security, and transport goals pertaining to AVs. The underlying missions, however, differ. The Singaporean priority rests on resolving the transport challenges in the country. A reliable, fast, efficient, inclusive, and smart technology, such as AVs, can help to achieve this goal. Persistent traffic congestion and immense pollution in high-density traffic areas are the motivation behind these goals. In addition, Singapore's government strives to develop the country into an 'innovation nation', to which the first large-scale implementation of AVs can contribute. Similarly, Estonia aims to prove itself once again as an innovation hub. Given society's general favourability of novel technologies and the promising economic benefits through additional employment and investment, the AV technology is considered a viable advancement in that direction – i.e. a market argument. Furthermore, the sustainability aspect of electric, shared, and smart vehicles that promise to replace individually owned cars in exchange for access to AVs add to their appeal. This sustainability aspect is the most strongly supported feature of AVs in Sweden. Whereas effectiveness and efficiency of smart transport and the associated cost savings naturally also appeal to Swedish transport providers and municipalities, the environmental benefits based on reduced carbon emissions of shared AVs serve as a central argument. Hence, the missions across the three countries differ slightly; however, they maintain a similar core: AVs are seen as a viable solution to mobility solutions of the future, while at the same time also carrying economic benefits.

The way these missions or gaols were formulated differed across Singapore, Estonia, and Sweden. The predominant driver of this mission in Singapore is the government, on the one hand responding to societal and political pressures related to the current problems in the transport system, and on the other eager to maintain and expand a positive reputation globally. In Estonia, the mission emerged primarily from the private sector, shaped by market dynamics after re-establishing independence (although the government contributed to the formulation of this mission). The Swedish consensus-seeking approach that dominates the public administration, overarching government mandates, and the collaborative nature across the triple helix shaped the formulation of the mission. The resulting strategic innovation programmes launched by the innovation agency, *Vinnova*, and funded by the government foster the mission further, relying on close cooperation across sectors.

The commonality across the three cases is that in each case study, government organisations cooperated with innovation system stakeholders to derive the mission – more so in Sweden, less in Estonia and Singapore. The cooperation served as a principal orientation for governments to detect interests, capabilities, potential, and possible trajectories. In all cases, several government organisations were involved in analysing the problems at stake and drafting purpose-oriented policies intended to tackle that problem.

Notably, governments often pursue multiple missions at once. In Estonia, economic development, competitiveness, and the formation of an 'innovation hub' (which is also prevalent in Singapore and partially also in Sweden) similarly shape the actors in the innovation system, including public sector organisations. In Singapore (and in parts also in Estonia), national security concerns play a vital role and, at times, may overshadow other missions. In the case of AVs, missions mostly complement each other (which is not always necessarily the case).

Hence, the joint problem formulation and consensus-based policy decisions led to a goal-oriented implementation of the AV transition in Singapore, Estonia, and Sweden. This 'common goal-orientation' affected all system functions, as it served as a guiding principle for entrepreneurs, policymakers, public agencies, and researchers when designing, interpreting, and implementing policies. This means that the mission-orientation emerged as a principal enabler of cooperation across the innovation system, between policy design and policy implementation, across government levels, and between public agencies and industry stakeholders. In other words, the respective mission is the starting point that, although not capable of resolving all issues emerging in the system, serves as common ground and induces trust on which all further cooperation can build.

7.4 Results

7.4.1 Public Sector Influence on Innovation Systems: Removing Stumbling Blocks

How and to what extent do public sector organisations influence socio-technical innovation systems? This was one of the questions this thesis aimed to answer. The primary challenges in the AV innovation systems in Singapore, Estonia, and Sweden related to uncertainties within the regulatory framework, the lack of expertise, knowledge, and capacity about the technology, as well as the multitude of stakeholders in the innovation system. A further challenge – but at the same time a part of the solution – was the formation of common goals across public agencies and beyond. By adopting the solutions outlined above, public sector organisations resolved the stumbling blocks in the system and, therefore, advanced the innovation system. The way public administrations shaped the innovation systems differed across the three case studies, however.

In Singapore, the public administration's influence is based on the LTA's mandate provided by the Ministry of Transport and the PMO. The LTA could act largely independently and could react to the needs of manufacturers and developers, as well as to the conditions in the innovation system as a whole.

Therefore, the agency's influence manifested itself, especially concerning resolving the regulatory uncertainty by allowing testing to occur, expanding the testbed, and introducing TR68. This stimulated above all 'entrepreneurial activity' and shaped the 'guidance of the search'. The strong efforts by public sector organisations also increased 'legitimacy' for AVs, helped attract domestic and foreign investors, and fostered expanding 'knowledge development and diffusion' activities. In short, Singapore's government organisations influenced five of the seven system functions strongly or very strongly (see Table 7.3).

In Estonia, it is not just the executive and regulatory agency (the Road Administration) that has a central role, but also the AV Expert Group. The participation of the Road Administration in this forum contributed to the information exchange and the sharing of expertise – knowledge that was fed back into the agency's daily operations. Hence, the Road Administration cooperates with manufacturers, although on minimal terms, leaving the majority of innovation system development to industry and research organisations. Public agencies strongly influence 'entrepreneurial activity' because the Road Administration enables AV pilots due to 'regulatory flexibility'. Otherwise, the influence of public sector organisations remains medium or low, particularly regarding 'resource mobilisation' and 'market formation', where the innovation system depends nearly exclusively on market dynamics (see Table 7.3). Nevertheless, the Road Administration's actions within the 'AV Expert Group' and 'ITS Estonia', in response to the regulatory uncertainty, substantially contributed to the advancement of the AV innovation system.

In Sweden, the public administration's influence is primarily a result of the independence and capacity of public sector organisations in the form of *Vinnova* and DS, but also the Transport Agency and the Transport Administration. Jointly, their 'capacity and independence' enabled 'entrepreneurial activity' and the 'guidance of the search' (and its direction), which is also strongly shaped by the 'common goal-orientation'. This common mission is also used to legitimise the AV technology and is a factor in convincing investors. As in Singapore and Estonia, the flexibility regarding regulations also allowed for 'entrepreneurial activity' in Sweden. Generally, the public-administrative influence is affecting the innovation system universally across most functions. Single public agencies are at no point overly dominant but are neither absent from processes within the innovation system, hinting towards the collaborative mindset that prevails in the Swedish public administration. Table 7.2 and Table 7.3 summarise these findings.

Blocking Mechanism	Singapore's Approach	Estonia's Approach	Sweden's Approach
regulatory uncertainty	• amended regulation (addendum) 'TR68'	• regulatory exemption model based on testing by the Road Administration, no new legislation for AVs	• policy lab to test possible solutions • 'Agency Arena' to exchange expertise in public agencies • iterative and dynamic application process
lack of expertise and capacity in public agencies	• advisory role of CARTS • knowledge building through cooperation of CETRAN, CREATE, SAVI and the LTA • LTA as centrally responsibly agency	• inter-organisational learning in the AV Expert Group • public agency participation in the AV Expert Group, later ITS Estonia	• formation of Drive Sweden as central AV intermediary • involvement of RISE • knowledge exchange of public agencies in the 'Agency Arena'
large variety of stakeholders involved with diverging interests	• central role of LTA as coordinator • invitation of public and private experts to serve on CARTS • common goal to eradicate traffic problems and forge a 'smart innovation nation'	• formation of AV Expert Group open to all AV actors • AV Expert Group as forum for interest formation, with government (agency) participation • common goal to form innovation hub and stimulate sustainable mobility	• Drive Sweden as central forum and representative, with government (agency) participation • common goal to foster sustainable and efficient mobility solutions

Table 7.2: blocking mechanisms/solutions across the three case studies

In sum, the influence matrix in Table 7.3. visualises the public-administrative impact on the AV innovation systems in Singapore, Estonia, and Sweden. All public-administrative elements are more or less impactful in this regard – no single element stands out in terms of influence on the innovation system. Across the case studies, public agencies affect 'entrepreneurial activity' most, first and foremost due to 'creative regulatory experimentation', but also due to the 'centrality and leadership' of public sector organisations and, especially, due to intermediaries. Similarly, the 'guidance of the search' function is heavily influenced by the public sector. Slightly less so, but still significant, is the extent to which public agencies shape the 'legitimacy' of AVs as a viable solution to the mobility challenges each country faces. We can observe that the public administration has no or only low influence on 'market formation' and 'positive externalities'. This is attributable to the early stage of the innovation system.

Interestingly, in some instances, the influence of public organisations diverges across functions and case studies. Whereas the influence of public agencies on 'knowledge development and diffusion' in Singapore and Sweden is substantial, it is hardly recognisable in Estonia, for example. In Singapore, and to some extent also in Sweden, government organisations also shape 'resource mobilisation', whereas in Estonia, this is mainly left to the market – reflecting the dominant market-based approach in the country. Overall, although public-administrative influence can be observed in all three case studies, the influence patterns do differ and depend on the previously dominant policy coordination mode.

Impact of PA elements … / **… on the TIS functions**	E1: centrality / leadership			E2: capacity / independ.			E3: creative regulatory experiment.			E4: common goal-orientation		
	SG	EE	SE	SG	EE	SE	SG	EE	SE	SG	EE	SE
F1: knowledge development/diffusion	green	yellow	green	yellow	yellow	yellow	red	red	yellow	yellow	yellow	yellow
F2: entrepreneurial activity/experimentation	green	green	yellow	green	yellow	green	green	green	green	yellow	yellow	yellow
F3: guidance of the search	green	yellow	yellow	green	yellow	green	green	yellow	yellow	green	yellow	green
F4: market formation	red	red	red	red	red	red	red	red	red	red	red	yellow
F5: resource mobilisation	yellow	red	yellow	yellow	red	green	green	red	red	red	red	green
F6: legitimacy creation	green	yellow	yellow	yellow	red	green	yellow	yellow	yellow	green	yellow	green
F7: positive externalities	red	red	red	red	red	red	red	red	red	yellow	yellow	yellow

Table 7.3: summary influence matrix for Singapore, Estonia, and Sweden[145]

Hence, although the influence of public sector organisations on the AV innovation systems in Singapore, Estonia, and Sweden differs, in all three case studies, public agencies strongly contribute to the growth and advancement of

[145] The public sector organisation influence on the AV innovation system is classified as follows: green = high, yellow = medium, red = low impact (see Section 2.2.2.5.1 in Chapter 2 for details about this classficiation). This influence matrix corresponds to and summarises the matrices depicted in each case study chapter.

AVs (Table 7.2 and Table 7.3). Public agencies mitigate uncertainties of AV regulation, contribute to knowledge exchange that increases their capacity, align stakeholders and their interests, and in parts take on a leading role (or fund a leading actor) to guide AV innovation. Without these efforts, the respective stumbling blocks would stall or slow AV innovation, possibly even preventing further advances. Answering the first research question of this study, we can conclude that although public agencies are not at the forefront of technical innovation, they contribute to the formation and development of the innovation system in substantial ways. They remove stumbling blocks and create inducing mechanisms that positively affect AV innovation.

7.4.2 Innovation System Influence on Public Agencies: Changing Coordination Modes

How and to what extent do socio-technical innovation systems influence public sector organisations? This was the second core question of this thesis. The three case studies revealed a common trend in this regard: a shift towards (or intensification of) network-oriented policy coordination in response to the challenges emerging from the AV innovation system. This is the case even though Singapore, Estonia, and Sweden, started with different policy coordination approaches – hierarchical, market-based, and network-oriented, respectively (see Figure 7.2).

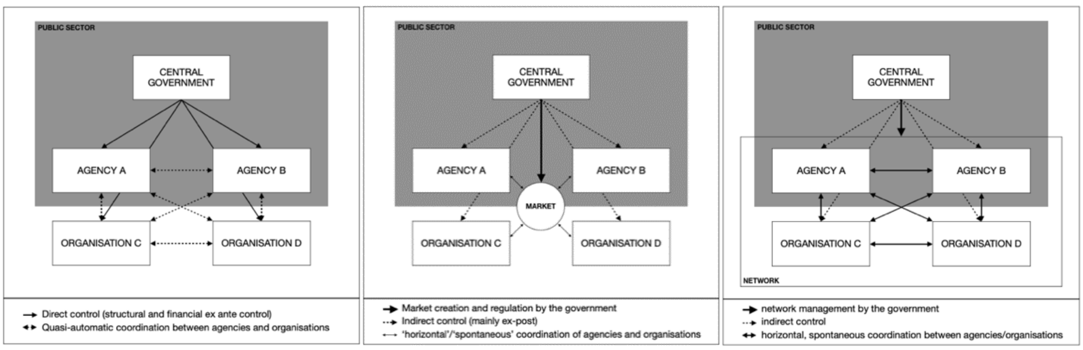

Figure 7.2: dominant coordination in Singapore (l.), Estonia (c.), Sweden (r.)[146]

[146] adapted from Bouckaert, Peters, and Verhoest (2010)

In Singapore, the LTA and the Ministry of Transport initiated the CARTS intermediary, the consultative forum where representatives from government, industry, and academia cooperate in advising the government and the LTA on AV matters. The intermediary provides the space for information exchange across government organisations, inter-organisational learning, and knowledge diffusion (cf. Aspeteg and Bergek 2020), also across the public-private divide. The cross-cutting nature of AVs triggered the LTA (and the Ministry of Transport) to re-iterate the purpose of and the objectives for AVs across government organisations, pushing and advocating for the technology, e.g. by considering AVs when discussing other policies or integrating them into the country's Transport Master Plan. The enabling of AV trials through 'regulatory experimentation' and later the passing of TR68 were the result. In addition, a common goal formed across innovation system stakeholders – including the public administration – to shape Singapore into a hub for smart technologies such as AVs. This means that the intricacies of the AV technology and its complex innovation system required Singapore's public administration to change course, adopting cooperative, purpose-oriented, and consensus-seeking practices, i.e. elements pertaining to network-oriented policy coordination. Thus, the governance approach towards AVs diverts from the dominant hierarchical mode and represents a mix between hierarchical and network-oriented policy coordination – a hierarchy-network hybrid – as Figure 7.3 represents.

In Estonia, the purpose-designed 'AV Expert Group' induced a strong collaborative incentive for stakeholders in the AV innovation system. It emerged as the best-suited forum to engage with a large number of AV actors across government, industry, and research organisations, rendering public agencies participants and – because these were co-founded by government representatives – enablers of the innovation network. This includes the Road Administration, who emerged as the responsible government agency for AV permits, charged with evaluating testing sites, vehicles, and concepts. A common goal formed among stakeholders to transform Estonia into an innovation hub with low bureaucratic hurdles and ideal testbed conditions for AV firms (among others, building on the successes in information and digitalisation technologies). This manifested in consortia to test and expand AVs, which the Road

Administration supported and approved in an effort of mutual co-optation. This means that the specificities of AVs and the unfolding innovation system compelled the public administration to turn towards collaborative, trust-based, and mutually beneficial practices, i.e. network-oriented policy coordination practices. Although the market-based dynamics common in Estonia remain strong, the network-oriented features complement and enhance AV governance. "To really achieve something of this sort, the collaboration between the public and the private sector is irreplaceable in such a small economy" (EE06). The result is a market-network hybrid coordination pattern for AVs upheld, nurtured, and expanded by the industry and research actors (see Figure 7.3).

In Sweden, the purposefully designed AV-intermediary, Drive Sweden, provides the necessary space for the large number of public and private actors in the system. It triggers collaborations, allows for the joint analysis of problems and potential solutions, and induces trust. Government agencies, including municipalities, participate in this network as well. As initiated by the Transport Agency, the 'Agency Arena' increases the understanding of the complex AV technology and allows public sector organisations to build a consensus, learn from one another, and evaluate practices informally. Collaboration and consensus-seeking are not alien to the Swedish public administration. Still, these fora are new and provide both an opportunity and an incentive for public agencies to cooperate even more closely. Such cooperation, given the possibilities underlying AVs, triggered a joint vision for the technology, nurtured by the innovation agency, pertaining primarily to an increase in efficiency, effectiveness, and environmental sustainability of (public) transport modes. This means that the nature of AVs as a complex but promising technology and the advancing, sophisticated innovation system led to the manifestation – and intensification – of the dominant network-oriented policy coordination mode in Sweden, based on cooperation, consensus-seeking, and mutual trust (Figure 7.3).

Across the three countries, the dynamic, agile, and responsive transition towards increased network-oriented coordination becomes discernible also regarding the different approaches to the triple helix cooperation across government, academia, and industry. In Singapore, we usually observe a statist model, where "the government is acting a leading role in controlling and facilitating cooperation between university and enterprises" (Mok 2015, 102). It also serves as information and knowledge bridge between academia and industry (*ibid.*). Estonia, in contrast, employs a '*laissez-faire*' model, which implies that the three actor groups operate in separate institutional spheres (Etzkowitz and Leydesdorff 2000), yet with "highly circumscribed relations among them" and strong market-based incentives to collaborate (Mok 2015, 102). Given its long cooperative tradition and collaborative culture, Sweden's model features numerous "tri-lateral networks and hybrid organisations" (Etzkowitz and Leydesdorff 2000, 111) at the nexus of government, research, and industry that are deeply entrenched into the roots of public-private interactions. Hence, the triple helix can be observed in all three countries yet still comprises different components and mechanisms.

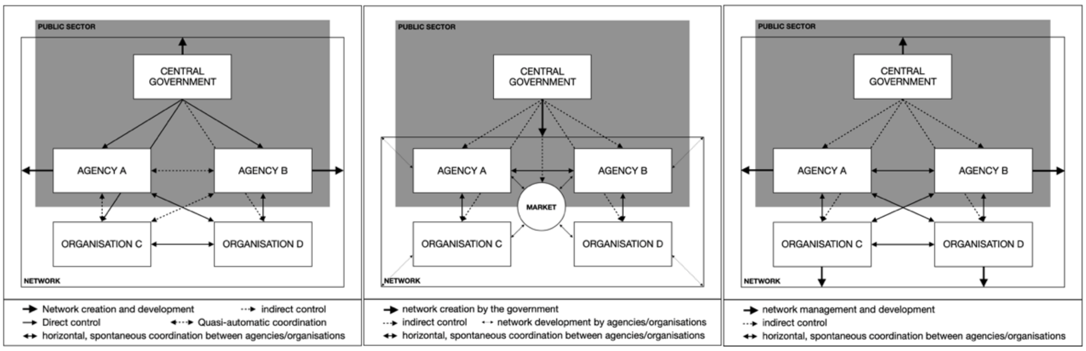

Figure 7.3: AV policy coordination in Singapore (l.), Estonia (c.), Sweden (r.)[147]

In sum, Singapore, Estonia, and Sweden experienced similar challenges within the AV innovation system that emerged from the complexity of multi-technology solutions and socio-technical innovation in the context of mission-orientation. Although they have taken different measures to counter these challenges, they reveal a similar pattern: The policy coordination mode shifts to incorporate (or, in the case of Sweden, intensify) network-oriented elements. This includes a stronger imperative for cooperation among public organisations and between public and private stakeholders across the triple helix. This leads to improved inter-organisational learning, trust-building, in parts mutual co-optation, consensus-seeking, as well as the joint evaluation of problems, solutions, visions,

[147] in principle adapted from Bouckaert, Peters, and Verhoest (2010)

and practices. Driven by a common mission, governments hereby serve as network enablers and participants – the public administration can be seen as a system motor (cf. Suurs et al. 2010) or 'system builder' through the (more) networked coordination approach (cf. Musiolik et al. 2020; Musiolik, Markard, and Hekkert 2012). Improved coordination, thus, can be achieved through formal or informal tools, structures, and networks (cf. Alexander 1993). At the same time, each country maintained features of its original, dominant coordination regime – hierarchical in Singapore, market-based in Estonia, and network-oriented in Sweden. Hence, the resulting approaches to govern the complex AV innovation system are based on hybrid modes (in the cases of Singapore and Estonia) or result in an intensified version (in Sweden). In Estonia, this network hybrid is mostly participant-governed and led by the private sector. In Sweden, it is primarily governed by a network administrator or broker, whereas in Singapore, a central (public) lead organisation governs the network (distinction based on Provan and Kenis 2008).

This means that socio-technical innovation systems of multi-technology solutions influence the public administration to the extent that they require a change of practices that incorporate and address the principal requirements necessary to govern such a technology: removing policy-related uncertainties, enhancing knowledge capacity and learning, improving the linkages and feedback loops between policy design and implementation, as well as coping with the large number of stakeholders involved. These features can best be achieved through network-oriented policy coordination, as the case studies in this thesis demonstrated. Socio-technical innovation systems, facilitated through overarching missions, therefore, induce a transition towards network-oriented policy coordination – a networked transition towards a new socio-technical innovation. This answers the second research question.

7.5 Implications and Recommendations

This thesis reveals insights of use for those working with and for government, i.e. policymakers responsible for policy design, public administrations as implementers, and involved third parties. Likewise, the study can be insightful for those working with policies on behalf of private sector actors or research organisations. The study focused on complex socio-technical innovation systems, so-called multi-technology challenges that emerge in the context of mission-oriented innovation policies. Numerous examples beyond AVs fit into this category, such as technologies at the intersection of AI and cleantech, where machine learning increases their efficiency and effectiveness, enhancing environmental sustainability. Examples include smart electricity grids, smart electric vehicles, the digitalisation and smart automation of agriculture, or smart traffic management – and many more (cf. Herweijer et al. 2018; Herweijer, Combes, and Gillham 2019). Such technologies raise policy questions and implementation challenges regarding the regulation of components that had previously been governed and regulated separately. Now, due to their novel usage, they inflict regulatory and governance tensions, leading to questions regarding responsibility and jurisdiction on behalf of public agencies, and trigger underlap and overlap challenges of policy coordination. Hence, the insights gained in this thesis are also applicable to other multi-technology challenges.

> Recommendation I: Multi-technology innovations, or innovations that emerge in response to mission-oriented policies, should be explicitly considered in light of potential policy coordination challenges they may trigger.

The trend to further increase the complexity of innovation systems is likely to continue, as the challenges we face become more difficult to resolve, such as climate change. In most cases, this also implies a change of social behaviour, business models, or even economic and systemic structures (cf. Mazzucato 2013b, 2021). Other multi-technology innovations addressing these challenges are likely to trigger similar blocking mechanisms as emerged for AVs, including regulatory uncertainty, lack of expertise in public sector organisations (and in companies regarding the regulatory framework), and the large number of stakeholders involved. As shown, these blocking mechanisms are best prevented, countered, and resolved through collaborative, coordinated efforts based on (some) common goals across the innovation system. The network-oriented policy coordination approach is best apt to deliver such cooperative interactions between stakeholders, especially when compared to the hierarchical and market-based modes. It is the most useful coordination mode to govern socio-technical innovation systems and multi-technology innovation.

> Recommendation II: Governments, researchers, and innovators should align themselves in 'mission-oriented' networks focused on the purposeful advancement of socio-technical innovations. These networks should explicitly include those organisations responsible for implementing policies.

The thesis demonstrated that innovation policy design and implementation should be considered jointly. The state is neither a unitary actor in innovation systems nor can the policy design consistently be implemented in the intended way. The public administration engages with the innovators and entrepreneurs, in this case of AVs, on the ground – they are the face of government. Public sector organisations often have to cope with the lack of capacity and knowledge and have to decide when to exercise discretion. Simultaneously, when enacting policies and transforming policy output into a visible outcome, the public administration gains invaluable expertise and experience. This knowledge should not be lost but should instead flow back to policy designers. Creating and maintaining these feedback loops is the task of both policymakers during the policy design phase and implementers thereafter.

> Recommendation III: Innovation-related policy design should be aware of the consequences of policies during the implementation process and should anticipate potential obstacles. Feedback loops between policy implementers and policy designers provide for information exchange, sharing of expertise/experience, and testing of ideas, which improves policies.

The analysis demonstrated that one way to assure continuous interaction across the triple helix – government, industry, and research – is through the formation of intermediary organisations that can act as leaders, central fora, and coordinators of novelly formed, purpose-oriented networks (cf. Söderholm et al.

2019). In slightly different ways, Drive Sweden, the 'AV Expert Group' in Estonia, and CARTS in Singapore (although not as central as the LTA itself) embody this. They enable public sector organisations to participate in consultations and collaborative projects, which fosters feedback loops both among public agencies, and between them and innovators, and allows executive and regulatory agencies to learn about AVs. Moreover, the intermediaries triggered joint interest formation among firms, stimulated collaboration, and channelled – to some extent – constructive lobbying to the government. "It is more useful if we [Drive Sweden] go and speak to the government, rather than every firm individually", the DS chairman states (SE01). By collecting the interests of innovators, "we can speak to the government with one voice", he adds, "and can advise them what to do next" (*ibid.*). Installing collaborative organisations such as intermediaries represents a feature associated with network-oriented policy coordination[148].

> Recommendation IV: Implementing an intermediary organisation at the centre of innovation networks comprising members across government, academia, and industry strengthens and accelerates the formation of feedback loops and facilitates mutual understanding, negotiations, and policy formation.

Governing novel socio-technical multi-technology innovations stretches the capacity of public sector organisations and challenges their capabilities. Coping with a novel technology and regulating it without sophisticated knowledge about the technology as such creates an obstacle. In the case of AVs, this extended the time until a testing permit was granted. For this reason, the Swedish Transport Agency invited other government agencies involved in the permit process to participate in an 'Agency Arena'. They discussed each other's views and designed an approach for mutual learning, cross-agency cooperation, and the (partial) shift of jurisdiction – in this case, to the Transport Agency, which maintains the central role for the AV permit process in the country. The regular, roundtable-like

[148] Recently, many research projects have considered the role of intermediaries in the context of innovation, in general, and sustainability transitions, in particular (cf. Anna Bergek 2020; van Boxstael et al. 2020; Kanda et al. 2019, 2020; Kivimaa et al. 2020; Kivimaa, Boon, et al. 2019; Kivimaa, Hyysalo, et al. 2019; Mignon and Kanda 2018; Sovacool 2017).

meetings also increased trust in each other's work (SE05). Successfully implementing such an 'Agency Arena' requires the flexible interpretation of the mandate given to each agency and, thus, some degree of independence from the line ministry. Accordingly, agencies can amend their practices based on inter-organisational learning within the arena. In the best-case scenario, this helps to align public agencies along the overarching goal or mission (see below).

> Recommendation V: Establishing an 'Agency Arena' where the relevant public sector organisations come together to facilitate the governance (or regulatory) process removes bureaucratic hurdles associated with the lack of capacity, expertise, and regulatory uncertainty.

The uncertainty surrounding the misaligned regulation of AVs emerged as a key blocking mechanism for the AV innovation systems in Singapore, Estonia, and Sweden. It inhibited the further development of the technology because manufacturers and operators could initially not test their vehicles in the public space. Each country took a different route to rectify this issue. Whether through amended legislation (Singapore), an exemption model (Estonia), or a dynamic policy lab approach (Sweden), all three countries managed to enable AV testing. These approaches were implemented through different means, by various organisations, and at different speeds, yet all were shaped by the cooperation of public sector organisations with the manufacturers or operators. This means that the reduction of uncertainty relied on a joint effort between stakeholders in the innovation system, as neither side could find a solution without the other: the regulatory and executive agencies had to learn about AVs, innovators had to learn about the legal framework. Hence, the flexibility and adaptability of the regulatory framework depended on the openness and willingness to understand regulation (by firms) and the technology (by public agencies).

> Recommendation VI: Public agencies should be provided with a mandate from the government flexible enough to accommodate novel technologies and should be open to learning about such, e.g. through collaboration with other agencies, technology experts, industry, or researchers.

The study showed that the orientation towards a common goal across public sector organisations (and beyond) directed policy design and implementation in an overarching manner. This reflects the mission-orientation from which the policies regarding smart mobility, and thus also AVs, in Singapore, Estonia, and Sweden emerged (although the missions in the three countries differed and did neither specify nor prescribe a particular technological solution). The existence of this common goal facilitated the decision-making process, for example, when enacting discretion, when interpreting regulatory frameworks, and when agreeing to participate in non-traditional and non-institutionalised arrangements, such as the 'AV Expert Group' (Estonia) or the 'Agency Arena' (Sweden). With the increasing complexity of socio-technical innovation systems, the existence of such a mission, from which a common goal can be derived, becomes a facilitator and a guide for administrative alignment throughout the policy implementation process.

> Recommendation VII: Policy design should be based on an overarching mission that is clearly communicated across government organisations and the broader innovation system, which can serve as guidance when making decisions and administratively enacting a policy during the implementation process.

* * *

Overall, public sector organisations implement innovation policy and are at the front line of governing multi-technology solutions or other socio-technical innovations that emerge from mission-oriented policies. They particularly affect regulation, agenda-setting, and 'legitimacy creation' for a technology and, thus, can hinder or enable 'entrepreneurship', 'resource mobilisation', and 'knowledge development' for a technology. That is why public agencies should be considered when drafting innovation-related policy and should be included in the analysis of innovation systems. The dichotomous relationship between policy design and policy implementation can be overcome through feedback loops between both spheres. These can be ascertained, for instance, through the creation of specific mission-oriented agencies or intermediaries and through the incorporation of a variety of stakeholders – a challenge common to socio-technical innovation systems, which the network-oriented policy coordination approach is best suited to resolve.

> Recommendation VIII: Governments and public sector organisations should strive to implement network-oriented policy coordination features (or hybrids thereof) when facing the challenge of governing complex, mission-oriented socio-technical innovation, as it is the most suitable approach to accommodate the commonly emerging challenges.

7.6 Future Research Trajectories

This thesis investigated the extent to which public sector organisations, through their approach to policy implementation and coordination, influence the development of socio-technical innovation systems. It also explored the inverse causality, i.e. how socio-technical innovation systems affect the practices of public administrations. Although AVs might have developed without such pertinent public sector influence, it can hardly be assumed that socio-technical innovations of this magnitude and potential impact could develop in a politico-administrative vacuum.

In this light, despite its relevance, especially the ‘agency’ of public sector organisations in innovation systems had been insufficiently understood and inadequately captured conceptually and empirically. In response, the thesis links insights, concepts, and analytic tools from the public administration and innovation studies literature, including policy coordination, innovation policy, mission-oriented innovation, institutional change, and innovation systems. Conjoining them resulted in introducing the ‘TIS+’ analytic framework used for the empirical analyses of the three case studies in Singapore, Estonia, and Sweden. It allows understanding the role of public agencies within the processes relevant to shaping and coordinating innovation system functions. Its conceptual logic based on systems thinking captures the missing dynamics and provides a reliable tool for researchers. The ‘TIS+’ framework can be used beyond the remit of socio-technical and multi-technology innovation. In fact, any innovation system analysis may benefit from analysing the role of public sector organisations in detail. Several additional questions arise from the findings in this study – questions that go beyond the scope of this thesis. Hence, the theoretical and empirical conclusions of this thesis, especially the analytic tools provided, can build the stepping stone for future research in the fields of public administration and political economy, on the one hand, and innovation studies, on the other.

First, this thesis opens up several questions in the field of **public administration**. The analyses in the three case study countries have shown that the state is not a unitary actor and that different public sector organisations can have different kinds of influence on innovation systems. Scholars should consider this aspect in more depth. What are the influences that various public-administrative organisations can have? What are the mechanisms and instruments that embody this influence? How do policy outcomes differ depending on the implementation strategy chosen? What about other 'capacities' of public administrations, for instance, analytic, management, or delivery capacities (cf. Lodge and Wegrich 2014)? In doing so, researchers can bridge the gap between policy design and policy implementation and can show how feedback loops from the public administration to the policymakers can be established, maintained, and improved. Empirical insights into best practice examples of backward integrating the design-implementation dichotomy could yield helpful lessons for practitioners and innovators alike. Similarly, the governance network literature can benefit from these insights (cf. Klijn, Steijn, and Edelenbos 2010). Policy coordination approaches should not be neglected either. As this study showed, countries respond differently to similar challenges (cf. Karo and Kattel 2016b). Consequently, different coordination modes manifest themselves in different implementation practices. Are there other policy areas or policy problems that benefit from one over another coordination mode? Although this thesis focused on innovation and innovation policy, similar questions can be asked about other policy areas, adding meaningful layers to applied policy analyses.

The international dimension of cooperation and coordination through international fora will be a fruitful area for future research as well, possibly making this research also attractive for scholars of International Relations. Enterprises, research organisations, and in parts also government organisations in Singapore, Estonia, and Sweden – and beyond – already show signs of international cooperation, which might be expanded in the future (cf. Drive Sweden 2021b; Lam 2020; SOHJOA Baltic 2019; Tambur 2018). This will affect the innovation system and governance practices across countries.

Second, in the **innovation studies** scholarship, the 'TIS+' framework can support future studies that pay closer attention to the role of public sector organisations. The transitions literature, focusing on sustainability transitions, for example, could benefit from this insight, as the TIS framework is commonly used in this field, yet the particular role of the public administration is usually not addressed. AVs have proven to be a prime example of multi-technology challenges. Future research could investigate to what extent the findings from Singapore, Estonia, and Sweden concerning AVs hold true also in other countries with different politico-economic contexts, where the technology is also being developed, e.g. in the US, the UK, Germany, Israel, Japan, or South Korea. Can the same shift towards network-oriented policy coordination be observed? Are regulatory uncertainty, lack of experience and expertise, and lack of inter-organisational linkages and learning across a large number of stakeholders also the key problems inhibiting policy and implementation coordination in other countries? Likewise, analysing other multi-technology innovations in the same three case study countries (and/or others) might be insightful. Can similar dynamics be observed, for instance, for smart electricity grids, electric vehicles, or smart agriculture? Looking more deeply into innovation systems and their development over time, it may help to distinguish between resolving blocking mechanisms and preventing them, as the latter approach might further reduce the time an innovation system takes to develop. A closer look at public agencies and their ability to avoid bottlenecks from emerging, e.g. regulatory misalignment, might therefore be advisable.

Scholars of innovation policy should ask further questions relating to policy implementation and coordination. Innovation policy is not always a prescribed policy domain, as many countries pursue policies across other domains, such as research and education, environment, transportation, economics, etc. and then combine innovation-related policies to render an ‘innovation package’. In this process, scholars may ask: What role do distinct public-administrative organisations play? Mission-oriented innovation policy (or similar approaches) is considered as a viable strategy to overcome some of the most pressing global challenges with the state taking on a more ‘entrepreneurial’ role (cf. Mazzucato 2013b). The role of public administrations in formulating, designing, and implementing such missions and the practices regarding *how* the state can be more entrepreneurial should not be neglected. This is especially key given the complexity underlying mission-oriented, socio-technical innovation, which usually includes a large set of stakeholders and can have far-reaching knock-on effects across the socio-economic system. Scholars should pay attention to the tactics that governments use to align and coordinate public organisations (and beyond) with missions – similar to what the Swedish case showed in the context of sustainable, smart, and efficient mobility solutions. How do public administrations shape missions, and how do missions change the behaviour of public organisations? Is the network-oriented coordination mode generally most apt to govern sustainability and mobility missions, as demonstrated in this thesis? And which coordination modes are most suitable for governing other missions? In this light, policy design and policy implementation should be considered jointly (this is not to say that separate analyses are never useful), especially to analyse stumbling blocks pertaining to implementation. Additionally, similar questions should be asked about less complex innovations. Are dominant coordination modes also affecting innovations that are less difficult to govern? Do these also trigger shifts in coordination approaches? If so, can a pattern be detected? And if not, why not?

The competition, alignment, and complementarity of missions when governments pursue multiple missions at once is another trajectory for future research. How can this be done while ascertaining the advancement of all missions? What role do public agencies play in devising and implementing them? And how can different missions be coordinated, both in terms of policy design and implementation?

Combined, these academic fields and most questions raised in this section would benefit from a more longitudinal approach. As indicated in several parts of this thesis, some of the observed shifts towards network-oriented coordination as well as the resulting influences and effects might be temporary. The governments in Singapore and Estonia, for example, are responding to the complexity inherent to AVs by including network-oriented coordination features in their approach to governing this technology. This shift (or intensification) only applies to the governance arrangement for the socio-technical innovation in question, in this case, AVs. It may be that this shift also applies to other complex technologies or even other policy areas, but this needs to be confirmed and requires further research. All other interaction arrangements that are shaped by the dominant policy coordination mode may remain intact. Hence, the thesis does not conclude that coordination patterns shift as a whole across the entire public administration regarding all policy domains. Scholars should, therefore, ask how permanent such institutional changes or shifts really are? Will public sector organisations revert to the (dominant) coordination patterns that previously defined their interaction?

In sum, the bridging of public administration, political economy, and innovation studies, in general, and the 'TIS+' framework, in particular, provide multifaceted grounds for further research concerning coordination challenges, socio-technical innovation systems, the transitions towards sustainability, the governance of multi-technology innovations, and mission-oriented, socio-technical innovation (policy).

7.7 Concluding Remarks

Riding on an AV is, indeed, an extraordinary experience and can feel exceptional. Knowing how the AV technology has developed in Singapore, Estonia, and Sweden, we learned that it is not the blinking sensors, flickering screens, or any other technical component that make it so. Instead, it is the fact that so many challenges could have derailed the advancement of the technology – from regulatory uncertainties to the lack of expertise and the tension between stakeholders. Yet they did not.

AVs have arrived at where they are today (at least in the selected case study countries, but also beyond) because of the remarkable development of an early-stage innovation system. Innovators, entrepreneurs, researchers, and other experts provided the technology and novel business models in these innovation systems. However, the central stumbling blocks were resolved due to the collaborative role of public sector organisations. This thesis has shown that public agencies can make or break essential processes in socio-technical innovation systems, such as stimulating 'knowledge development', incentivising 'entrepreneurship', 'guiding the direction' of the innovation trajectory, 'creating legitimacy' for a novel technology, 'mobilising resources', and even 'forming markets'. In short, they can help to accelerate innovation dynamics.

Most interestingly, the common observation across the three cases is a shift or an intensification of the networked policy coordination mode. The tools and mechanisms inherent to this approach of coordinating policies and public organisations, such as the establishment of intermediaries, the collaboration of the public and the private sector, the transfer of jurisdiction between government agencies, a common approach to analysing problems and finding solutions, consensus-seeking based on trust, or the enabling role of public agencies, have been commonly observed in the three innovation systems concerning AVs. They form a central part of the explanation why Singapore, Estonia, and Sweden are at the forefront of AV development globally. Socio-technical transitions from one technology to another, as this thesis shows, are best governed through this networked approach. Hence, a *socio-technical transition* that responds to a mission or challenge necessitates an *administrative transition* towards networked policy coordination. Public agencies embody, guide, and implement this shift – a shift that enables the continuous feedback between policy design and implementation and, therefore, ascertains the successful implementation of innovation policies and the fulfilment of missions.

'*Networked transitions*', hence, implies a twofold conclusion: As this thesis showed, socio-technical transitions, especially when involving complex, multi-technology solutions, require a transition towards (or intensification of) network-oriented policy coordination. Network-oriented coordination is best suited to accommodate the challenges likely to emerge within the innovation system. Consequently, this approach indirectly also provides coordination for the system stakeholders affected by the transition across the triple helix, e.g. through intermediaries, certain policies, or other mechanisms discussed in this thesis. In sum, '*networked transitions*', therefore, imply the networked character of coordinating the innovation system as such, and the public administration, in particular. The transition ought to be '*networked'* in socio-technical and public-administrative terms. Combined, this answers the principal research question of this thesis: How do public sector organisations and socio-technical innovation systems mutually shape each other, particularly in the context of mission-oriented policies?

This role of public sector organisations in innovation systems should be considered in the future – by policymakers, policy implementers, innovators, and researchers alike. For this reason, this thesis also provided an extension to the TIS framework, which includes the role of the public administration, called 'TIS+'. Future research may rely on this framework to investigate AVs or similarly complex socio-technical innovation in other cases. Academically, the intersection of public administration, innovation studies, and political economy not only provides for a promising field of future research but can also teach us how to better govern socio-technical transitions.

Finally, this thesis offered a different and novel view on innovation system analyses and the challenges that the governance of socio-technical innovation in the context of mission-oriented policies triggers – conceptually, analytically, and empirically. "When you change the way you look at things, the things you look at change" (Max Planck in Die ZEIT 2021, 31). Accordingly, I hope that this thesis can help to render fruitful insights leading to a win-win situation for policymakers, policy implementers, innovators, entrepreneurs, researchers, and the public alike such that we can better achieve the missions we set ourselves in the future.

Appendices

Appendix 1: Main Actors in AV Innovation Systems

Singapore

Organisation	Organisation Type	Role in (AV) Innovation Ecosystem
Agency for Science, Technology, and Research (A*STAR)	agency/statutory board	• supports RD&D organisations • focuses on manufacturing, healthcare, urban solutions/sustainability, and the digital economy • reports to Ministry of Trade and Industry
Campus for Research Excellence and Technological Enterprise (CREATE)	research	• managed by and part of NRF • focuses on cutting-edge, interdisciplinary RD&D in areas of strategic interest • space for international research collaboration, among others for AVs (includes US, CH, DE, UK, IL, CN)
Centre of Excellence for Testing and Research of Autonomous Vehicles (CETRAN)	research	• located at NTU • co-funded between NTU, LTA, and JTC • tests AVs before permits are handed out • cooperates with LTA to derive AV standards • maintains a test circuit at CleanTech Park
Committee on Autonomous Road Transport Singapore (CARTS)	intermediary	• set up by the Ministry of Transport • comprises AV experts from across governance organisations, industry, and academia • meets bi-annually to derive conclusions about AV strategy and future policy suggestions
Economic Development Board (EDB)	agency/statutory board	• responsible for economic planning, investment strategies, and global outreach • reports to Ministry of Trade and Industry
Enterprise Singapore	agency/statutory board	• supports small and medium enterprises, also start-ups • is the national standards accreditation organisation • reports to Ministry of Trade and Industry
GovTech	agency/statutory board	• responsible for implementation of digital technologies in governance organisations • oversees Smart Nation infrastructure development • reports to Prime Minister's Office
Jurong Town Corporation (JTC)	agency/statutory board	• property developer responsible for the Jurong District • responsible for One-North and CleanTech Park areas where AV testing takes place • reports to the Ministry of Trade and Industry

Land Transport Authority (LTA)	agency/statutory board	• transport regulator, issues AV trial permits • central executive agency for transport/AVs • co-runs AV pilots with industry/research partners • reports to Ministry of Transport
Ministry of Information and Communication	government	• manages communication and information technologies and associated infrastructures • line manages among others these statutory boards: Cybersecurity Agency, Data Protection Commission
Ministry of Trade and Industry	government	• generally responsible for economic, industrial, trade, and other related policies • houses the 'Futures and Strategy Office' and the 'Future Economy Planning Office' • line manages among others these statutory boards: EDB, JTC, SDC, A*STAR, and Enterprise Singapore
Ministry of Transport	government	• manages air, land, and sea transport • line manages these statutory boards: LTA, Public Transport Council, Transport Safety Bureau
Nanyang Technical University	research	• world-class research-intensive university with an all-encompassing teaching curriculum, focused on technology-specific subjects • houses CETRAN
National Research Foundation	research/statutory board	• guides national strategy for RD&D activities • funds strategic RD&D programmes • reports to Prime Minister's Office
National University of Singapore	research	• world-class research-intensive university with an all-encompassing teaching curriculum
Prime Minister's Office	government	• central government executive, oversees/ guides all other government organisations • line manages among others: GovTech
Sentosa Development Corporation (SDC)	agency/statutory board	• property developer responsible for Sentosa Island, where some AV testing occurs • reports to the Ministry of Trade and Industry
Singapore Autonomous Vehicle Initiative (SAVI)	other	• set up by LTA and A*STAR • oversees test-beds for AV pilots • supports and reports to CARTS
Singapore-MIT Alliance for Research and Technology (SMART)	research	• founded by MIT and NRF, based at CREATE • space for collaboration between Singaporean and US researchers, including on AVs • spin-off Nutonomy emerged from SMART
Smart Nation Singapore Programme	other	• government initiative to harness digital solutions and smart technologies • run by GovTech and the Smart Nation and Digital Government Group at the Prime Minister's Office

Estonia

Organisation	Organisation Type	Role in Innovation Ecosystem
Enterprise Estonia	agency (foundation)	• supports Estonian companies to grow and to expand export capabilities and destinations • serves as innovation agency • coordinates foreign investment in Estonia
Estonian Research Council	agency (foundation)	• funds research projects in universities and beyond • coordinates research efforts across Estonia
ITS Estonia	intermediary	• brings together industry/research/government actors • organises bi-monthly roundtables to exchange ideas • advocates collaboration and coordination across actors
KredEx	agency (foundation)	• provides credits, loans, and venture capital to businesses
Ministry of Economic Affairs and Communication	government	• responsible for economic growth and development • cooperates with other ministries and with EU organisations concerning economic matters • responsible ministry for innovation, entrepreneurship, transportation, information technology, energy, and construction (among others)
Ministry of Education and Research	government	• responsible for research and development • placed policy coordination staff in several other ministries regarding RD&D • directly funds some research projects
Ministry of Finance	government	• responsible for state finance and the budget process, including the budgets of other line ministries
Municipality of Tallinn	(local) government	• approves AV testing on its public roads
Prime Minister's Office	government	• responsible for the overall coordination of government activities across the cabinet • the strategy unit devises strategic development plans to enhance Estonia's economic competitiveness and coordinates government policies on a general level
Road Administration	agency	• executive agency that manages all aspects regarding terrestrial transportation, such as roads, traffic, public transport, etc. • responsible for approval of AVs before they are tested on public roads (incl. examination) • reports to the Ministry of Economic Affairs and Communication
Tallinn Technical University	research	• actively pushes AV research • tested an AV on its campus • produces spin-offs in the AV sector • advises other innovation actors
University of Tartu	research	• actively pushes AV research • is involved in AV tests across Estonia • advises other innovation actors

Sweden

Organisation	Organisation Type	Role in (AV) Innovation Ecosystem
City of Gothenburg	government	• municipality of Gothenburg, involved in an AV trial • needs to confirm the pilot permit
City of Stockholm	government	• municipality of Stockholm, involved in an AV trial • needs to confirm the pilot permit
Drive Sweden	intermediary	• strategic innovation programme by Vinnova • central forum for autonomous and smart transport • >130 members from across Sweden (and beyond) including firms, research organisations, and government agencies • runs, initiates, and supports projects for AV testing • acts as marketplace and network hub for AV actors
Formas (Swedish Research Council)	agency	• cooperating with Vinnova to fund strategic innovation programmes like Drive Sweden
Lindholmen Science Park	intermediary	• science park in central Gothenburg, where an AV trial takes place • houses Drive Sweden, a part of RISE, and other stakeholders involved in the AV innovation system
Ministry of Education and Research	government	• oversees RISE and public universities • minister participates in the NIC
Ministry of Enterprise and Innovation	government	• oversees the innovation agency (Vinnova) • minister participates in the NIC
Ministry of Finance	government	• distributes finance through the budget allocation process • drafts mandate letters to government agencies • minister participates in the NIC
National Innovation Council (NIC)	intermediary	• consists of senior politicians, industry representatives, and professional/academic experts • guides Sweden's innovation policy informally through advice to the government • convenes 3-4 times annually (temporarily suspended)
Prime Minister's Office	government	• most visible government figure, advocates for AVs • signals AV intentions with international partners • coordinates cabinet meetings and mediates consensus-seeking approach to policy design • chairs the National Innovation Council

RISE	research	• Sweden's central research institute operating across the country in various disciplines • supports Vinnova, Drive Sweden, and other government agencies in their work, e.g. regarding regulation (through policy labs)
Swedish Energy Agency	agency	• cooperating with Vinnova to fund strategic innovation programmes like Drive Sweden
Transport Administration (*Trafikverket*)	agency	• central road administration, responsible for maintenance and road infrastructure • participant of the 'Agency Arena' • included in the board of Drive Sweden
Transport Agency (*Transportstyrelsen*)	agency	• central transport regulator, also responsible for regulating AV trials • initiator of the 'Agency Arena' on AV regulation
Vinnova	agency	• organises strategic innovation programmes • receives funds from the government and spends them on innovation-related activities • central focus point for innovation in Sweden • launched mission-oriented innovation programme

Appendix 2: List of Interviews

This list contains the anonymised participants of semi-structured interviews. The interview codes used in this thesis denote their respective contribution.

Singapore (11)

Code	Date	Interviewee Role	Organisation	Location	Format
SG01	08.02.2019	Technology Lawyer	Asian Development Bank	from London, UK	video call
SG02	14.02.2019	Technology Strategist	Prime Minister's Office Singapore	from London, UK	video call
SG03	19.02.2019	Professor	University College London	from London, UK	phone
SG04	19.03.2019	Professor/Deputy Director; prv. Head of Future Strategy	National Univ. of Singapore; Ministry of Transport	from London, UK	video call
SG05	02.05.2019	Foresight Analyst	Future Agenda	London, UK	in person
SG06	07.05.2019	AV Researcher	Campus Research Excellence & Technological Enterprise Singapore	from London, UK	video call
SG07	07.05.2019	Professor of AVs; AV start-up co-founder	National Univ. of Singapore; Nutonomy	from London, UK	video call
SG08	17.05.2019	Deputy Manager	Land Transport Authority Singapore	from London, UK	video call
SG09	23.05.2019	Senior Science Officer	Singapore-UK Chamber of Commerce	from London, UK	video call
SG10	24.09.2019	Managing Director	ST Engineering Systems	from London, UK	video call
SG11	30.10.2019	AV Researcher	National Univ. of Singapore	from London, UK	in writing

Estonia (10)

Code	Date	Interviewee Role	Organisation	Location	Format
EE01	17.01.2020	Project Leader; Senior Researcher	SOHJOA AV Project; Tallinn Technical University	from London, UK	video call
EE02	21.01.2020	Professor	Tallinn Technical University	from London, UK	video call
EE03	23.01.2020	Programme Manager	Municipality of Tallinn	from London, UK	video call
EE04	27.01.2020	Chief Technical Specialist	Road Administration	from London, UK	video call
EE05	31.01.2020	Director Technical Dept.	Road Administration	from London, UK	video call

EE06	03.02.2020	Senior Advisor	Ministry of Economic Affairs & Communication	from London, UK	video call
EE07	07.02.2020	CEO	ITS Estonia	from London, UK	video call
EE08	02.03.2020	Professor	University College London	London, UK	in person
EE09	11.03.2020	CEO	AuveTech	from London, UK	video call
EE10	12.03.2020	Chair AV start-up CEO	AV Expert Group Modern Mobility	from London, UK	video call

<u>Sweden (22)</u>

Code	**Date**	**Interviewee Role**	**Organisation**	**Location**	**Format**
SE01	20.02.2019	Managing Director	Drive Sweden	from London, UK	phone
SE02	01.03.2019	Deputy Director General	Vinnova	from London, UK	video call
SE03	08.03.2019	Senior Researcher	RISE	from London, UK	phone
SE04	08.03.2019	Programme Manager	Vinnova	from London, UK	video call
SE05	21.03.2019	Department Head	Transport Agency (*Transportstyrelsen*)	from London, UK	video call
SE06	25.03.2019	Chief Strategist	Transport Administration (*Trafikverket*)	from London, UK	video call
SE07	25.03.2019	Public Administration Advisor and Director	Ministry of Finance and National Innovation Council	from London, UK	video call
SE08	29.03.2019	Managing Director	Nobina Technologies	from London, UK	video call
SE09	27.06.2019	Professor	Chalmers University	Montreal, CA	in person
SE10	06.09.2019	CEO	Holo (Autonomous Mobility)	from London, UK	video call
SE11	06.09.2019	Senior Researcher	RISE	from London, UK	video call
SE12	06.09.2019	Professor	Stockholm School of Economics	from London, UK	video call
SE13	12.09.2019	AV Researcher and Project Advisor for AV Trucks	Stockholm School of Economics and Scania	Gothenburg, SE	in person
SE14	12.09.2019	Senior Advisor	Urban Transport Authority Gothenburg	Gothenburg, SE	in person
SE15	12.09.2019	Programme Head	Transport Administration (*Trafikverket*)	Gothenburg, SE	in person
SE16	12.09.2019	AV Operator	Holo (Autonomous Mobility)	Gothenburg, SE	in person
SE17	19.09.2019	CEO	Gothenburg Parking Administration	from London, UK	video call
SE18	19.09.2019	Head of Sustainability	Gothenburg Parking Administration	from London, UK	video call

SE19	24.09.2019	KRABAT Programme Manager	Drive Sweden	from London, UK	phone
SE20	01.10.2019	Head of Transport Office	Municipality of Stockholm	from London, UK	phone
SE21	10.10.2019	Head of Innovation	Urban Transport Authority Gothenburg	from London, UK	video call
SE22	10.10.2019	Director of Traffic	Urban Transport Authority Gothenburg	from London, UK	video call

Appendix 3: Semi-Structured Interview Questions

This list includes the questions used to structure the interview process. The list is split into three sections, as explained in Chapter 2. The purpose of semi-structured interviews is to leave room for an open discussion based on the answers provided by interviewees. Note that not all questions have always been asked to every interviewee. This depends on the progress of each interview.

Phase 1: Personal questions and general, politico-economic context questions

Focus	Questions
personal	Can you briefly summarize your role in your organisation? What is the role of your organisation in the context of innovation in your country?
politico-economic context	How does the general economic context affect innovation in your country? How does the political context affect innovation in your country?
innovation/AVs	Would you describe your country as an innovation nation? What makes your country a strong innovator? Have you ever been on an AV?

Phase 2: Specific structural and functional TIS questions

Focus	Questions
S1: actors	Who are the main actors involved in the AV network? Who coordinates these actors involved? Are there actors who would like to be involved but are not? Why? Are there actors who inhibit the development of the AV technology? Why?
S2: interaction	Where/how do actors meet? How do stakeholders communicate? How does knowledge flow between different types of actors?
S3: infrastructure	What infrastructure do actors rely on? What additional infrastructure is needed for the AV technology? Which existing infrastructure needs to change? Are there infrastructure elements that inhibit the technology?
F1: knowledge development/diffusion	Where do actors source their knowledge from about AVs? Which RD&D activities do you observe regarding AVs? What RD&D is needed to enhance the technology further? Who funds this RD&D? Are there any mechanisms that allow the technology to spread? Are there international collaborations to improve the knowledge about AVs?
F2: entrepreneurial activity	Which activities by established and newcomer firms do you observe? What is missing or needed to expand the market? What are the use cases for the technology? How do you expect the opportunities for firms to develop in the future?

	Are there any obstacles to market entry? Are new firms encouraged to enter the market? Are there mostly national or also international firms emerging in the market? Are there start-ups forming, or is it mostly established companies? How high is the risk for (new) companies in this market?
F3: guidance of the search	In which policy framework does the technology develop? What are the political or legal barriers and enablers? How does the media report about the technology? How does the government communicate about the AV technology? How do firms communicate about the AV technology? How do academic organisations communicate about the AV technology? Who is pushing the technology, who is blocking it? How is the technology regulated?
F4: market formation	How does the market for the technology look like? What are the respective market shares per firm? What is needed for the market to grow? What are the strategies of market players? Which role does the government play in this market? Is there a demand for the AV technology? Is there sufficient supply to manufacture AVs or to run AV services?
F5: resource mobilisation	Where do resources for the AV technology come from? How big are these resources? (actual amounts, people, infrastructure) How large/small are the resources firms mobilise? Which resources are needed to enable the success of the AV technology? Where does the investment come from otherwise, and why? Are there sufficient human resources to cater for the expansion of the technology?
F6: legitimacy creation	Which legitimacy does the technology have? Who is using the technology and why? Does the public widely accept the technology? What is the political opinion about the technology?
F7: positive externalities	Do we observe knock-on effects across the economy/society? Are there changes to the labour market or knowledge development? Does the AV technology cause any positive/negative effects?
E1: centrality and leadership	Is any public organisation leading the efforts to promote the AV innovation system? Is any gov. organisation more central than others, and why? Is the most central actor also the leading actor? What are the central gov. actors doing to support the AV technology? Are there individuals in agency X who led these efforts?
E2: capacity and independence	How independent is agency X from its line ministry or the government in general? How flexibly does this agency interpret its mandate? What happens if agency X overreaches its competences? Can this agency fulfil its responsibilities concerning the AVs? Do they have the necessary knowledge, expertise, workforce, budget, legitimacy, etc.? How does this agency source knowledge regarding the AV technology? How respected is agency X among society and others in the innovation system?

E3: creative regulatory experimentation	Which regulatory framework governs the AV technology, and who enforces that? To what extent is the regulator allowing deviation from these regulations? What are the mechanisms that enable this deviation? Which pilots/trials exist under these regulations? How is the regulator planning to proceed regarding these regulations in the future? How is the government planning to proceed regarding these regulations? Are there any regulations that block the development of the AV technology? How have eventual stumbling blocks been resolved, and who is taking the initiative? How does the regulator interact with the private sector and academia regarding AVs?
E4: common goal-orientation	Is there an overarching goal behind the development of the AV technology? Who stands for this goal, and if there are opposing goals, who stands for which goal? How are contradicting goals aligned across government organisations? Have any goals already been achieved, and if so, how? How are these goals supported otherwise, and what additional efforts exist? How will society benefit from these goals?

Phase 3: Open-ended discussion question and room for further conversation

Focus	**Questions**
AV-related	Where do you see AVs in your country in the future, in 5-10 years? Are AVs a solution to the challenges your country is facing?
formalities	Could you confirm once more that you agree to use the data you just provided for research purposes, as indicated in the consent form? Is there anyone else you have in mind who I should speak to about this topic?
open-end	Is there anything else on your mind regarding AVs that we have not discussed? Is there anything else that you would like to add?

Appendix 4: List of Events Attended

The following list contains the events attended that informed this study. This includes academic conferences, AV workshops, AV and AI-focused events, AV-related fayres, and AV-focused online events (due to the SARS-COV-19 pandemic).

#	Date	Event Name	Location
1	June 2017	Innovation Growth Lab (NESTA)	Barcelona, ES
2	April 2018	University Sustainability Alliance	Berlin, DE
3	June 2018	9th International Sustainability Transitions Conference	Manchester, UK
4	December 2018	Innovation Growth Lab Research Workshop (NESTA)	London, UK
5	May 2019	4th Network of Early Career Researchers in Sustainability Transitions Conference	Lisbon, PT
6	May 2019	Future Agenda AV Workshop	Frankfurt, DE
7	June 2019	CogX – Festival of AI & Emerging Technology	London, UK
8	June 2019	10th International Sustainability Transitions Conference	Ottawa, CA
9	June 2019	4th International Conference of Public Policy	Montreal, CA
10	September 2019	Drive Sweden Forum	Gothenburg, SE
11	May 2020	5th Network of Early Career Researchers in Sustainability Transitions Conference	Zurich, CH (online)
12	June 2020	CogX – Festival of AI & Emerging Technology	London, UK (online)
13	June 2020	European Forum for Studies of Politics for Research and Innovation Conference	Utrecht, NL (online)
14	August 2020	11th International Sustainability Transitions Conference	Vienna, AT (online)
15	August 2020	Tallinn Autonomous Vehicle Conference	Tallinn, EE (online)
16	September 2020	Drive Sweden Forum	Gothenburg, SE (online)
17	November 2020	Sweden Innovation Days	Gothenburg, SE (online)
18	January 2021	Drive Sweden Forum	Gothenburg, SE (online)

Appendix 5: Glossary

Agency: "The capacity of an actor to act" (Geels 2020, 3).

Directionality: "Deliberate orientation of social or technological change towards fulfilling particular objectives or goals" (European Environment Agency 2019).

Capability: The resources available to individuals, organisations, and the wider system as a whole that are required to fulfil a particular task (Wu, Ramesh, and Howlett 2018).

Capacity: "The set of skills and resources – or competences and capabilities – necessary to perform policy functions" (Wu, Ramesh, and Howlett 2015, 166).

Centrality: The extent to which organisations are more or less central within the innovation network, defined by how closely connected actors are within the innovation network.

Collaboration: "An interaction between participants who work together to pursue complex goals based on shared interests and a collective responsibility for interconnected tasks which cannot be accomplished individually" (McNamara 2012, 391).

Cooperation: "An interaction between participants with capabilities to accomplish organisational goals but chose to work together, within existing structures and policies, to serve individual interests" (McNamara 2012, 391).

Coordination: "The instruments and mechanisms that aim to enhance the voluntary or forced alignment of tasks and efforts of organisations within the public sector. These mechanism are used in order to create a greater coherence, and to reduce redundancy, lacunae, and contradictions within and between policies, implementation, or management" (Bouckaert, Peters, and Verhoest 2010, 16)

Feedback loop: "The mechanisms (rule or information flow or signal) that allow a change in a stock to affect a flow into or out of that same stock" (Meadows 2008, 187).

Goal-orientation: The orientation towards particular overarching goals in the innovation network that provides a direction for the behaviour of system stakeholders.

Grand challenge: Global, societal challenges, such as climate change, digitalisation, or sustainable development that are too complex to be approached through single or top-down policy initiatives and instead require "new constellations of actors and their concentration" (Kuhlmann and Rip 2018, 450).

Independence: The extent to which an organisation can perform their tasks free from pressures or guidance of other organisations, e.g. from the government or line ministries. This includes the flexibility to show discretion and interpret policies based on an organisation's mandate.

Innovation: "The process by which [a new socio-] technology is conceived, developed, codified, and deployed" (Brooks 1980, 67), and also commercialised and introduced into markets.

Innovation(-related) policy: "Actions by public organisations that influence innovation processes" (Edquist 2011, 1728).

Intermediary: "Actors and platforms that positively influence […] processes by linking actors and activities, and their related skills and resources, or by connecting transition visions and demands of networks of actors" (Kivimaa, Boon, et al. 2019, 1072).

Leadership: The extent to which organisations exercise leadership over other actors in a system and whether this corresponds to an active influence, e.g. through agenda setting, command and control mechanisms, oversight, initiative, funding arrangements, or coordinative activities.

Mission-oriented innovation systems: "Networks of agents and sets of institutions that contribute to the development and diffusion of innovative solutions with the aim to define, pursue, and complete a societal mission" (Hekkert et al. 2020, 76).

Multi-technology: Technologies that comprise a set of complex, interacting sub-technologies of diverse characters catering a multitude of socio-technical purposes (cf. Markard 2018).

Network: "(More or less) stable patterns of cooperative interaction between mutually dependent actors around specific issues of policy (or management)" (Bouckaert, Peters, and Verhoest 2010, 44)**.**

Policy design: "The deliberate and conscious attempt to define policy goals and to connect them to instruments or tools expected to realize those objections" (Howlett, Mukherjee, and Woo 2015, 291; see also Peters 2018b)**.**

Policy implementation: "The effort, knowledge, and resources devoted to translating policy decisions into action [through] a set of activities" (Howlett 2019, 407; see also O'Toole 2000).

Public administration: Mostly public (and sometimes private) organisations responsible for the implementation of policies, and at times also for the evaluation and feedback of policy impact into the policy design process.

Socio-technical system: "The configuration of elements (technologies, markets, policies, user practices, cultural meanings, manufacturing) that underpin the fulfilment of societal functions such as mobility, heating, shelter, and sustenance" (European Environment Agency 2019).

System: "A set of elements or parts that is coherently organised and interconnected in a pattern or structure that produces a characteristic set of behaviours, often classified as its 'function' or 'purpose'" (Meadows 2008, 188).

Technology: The "knowledge of how to fulfil certain human purposes in a specifiable and reproducible way" (Brooks 1980, 66).

Technological innovation system: "The actors, networks, and institutions that tenable the emergence of novel technologies" European Environment Agnency 2019, 152).

Sustainability transition: "A fundamental and wide-ranging transformation of a socio-technical system towards a more sustainable configuration that helps alleviate persistent problems such as climate change, pollution, biodiversity loss, or resource scarcities" (European Environment Agency 2019).

Triple helix: The combined reference to government, industry, and academia (Etzkowitz and Leydesdorff 2000), who collaborate in order to solve particular problems or achieve particular tasks.

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