A socio-technical governance perspective on the roles of the state in the governance of socio-technical change

The European Commission in the governance of Connected, Connective, Automated Mobility in the EU

Master thesis by Jurre Oosterwijk

MSc Public Administration – PA
MSc Philosophy of Science, Technology and Society – PSTS

University of Twente, Enschede, The Netherlands
Faculty of Behavioural, Management, and Social Sciences

EXAMINATION COMMITTEE
dr. P. Stegmaier
dr. K. Konrad
dr. F. Coenen

27-03-2023

UNIVERSITY OF TWENTE.

Abstract

This thesis studies the role of the state in the governance of socio-technical change. It is motivated by the research agenda of Borrás and Edler (2020) which calls for a more embedded approach toward the role of the state in the governance of socio-technical change. Henceforth this thesis proposes a socio-technical governance perspective based on the Multilevel Perspective and the Triple Embeddedness Framework. By integrating the MLP and TEF with the perspective of Borrás and Edler (2020) it is intended to explain the roles of the state in the governance of socio-technical change based on their embeddedness in the broader socio-technical context and the material conditions of the technological system. In doing so usage is made of a case study, which is the governance of Connected, Connective, Automated Mobility (CCAM) in the EU. CCAM is an emerging technology that integrates connective data exchange in the field of road mobility with autonomous vehicles. Based on this connective data exchange the information horizon for autonomous vehicles will be expanded, which promises to support higher levels of autonomous driving. CCAM promises to optimize road travel, which has the potential to lead to broad societal benefits. However, a comprehensive socio-technical perspective on this is lacking, which this thesis intends to provide. Because of the central role of governance in this and the specific multilevel governance context in the EU, the governance of CCAM was selected as a relevant case study. In this, the European Commission is identified as the state. The research question is "*How could CCAM change the socio-technical system for land-based road transportation in the EU, what are the roles of the European Commission in the governance of this, and how can these be explained based on their embeddedness in their socio-technical context?"* In studying the governance of CCAM in the EU, policy documents and academic literature on CCAM were read and analysed. It is concluded that CCAM has strong transformative potential for the EU on many components, ranging from industry and business models to road infrastructure. Because of the need for continuity of service based on the CCAM system requirements, the EU Single Market context, and a long expected transition period, the processes of harmonization and standardization are central. This thesis argues that to achieve the fullest benefits of CCAM based on this socio-technical context, the European Commission requires to shape the overarching framework conditions in which CCAM is intended to function while aligning the resources, capabilities, and expertise of industry actors and member states. The coordination involved in the governance on CCAM is identified as a hybrid between the hierarchical command and control governance mode and the more network-based primus inter pares mode. In these governance modes, the European Commission is identified to take different roles which can be linked back to the CCAM system requirements and Single Market context, with the process of European integration as overarching governance practice central in this. The CCAM system is viewed as an instrument to protect the Single Market and to further break down barriers between member states, leading to more European integration. But to do so, more EU coordination and integration are required which creates a self-reinforcing governance paradigm that brings CCAM towards the core of the EU Single Market context. Traditional governance mechanisms would be unsuitable to achieve this, which shows the relevance of what Kuhlmann, Stegmaier, and Konrad (2019) call governance innovation meaning that governance swings back between traditional and novel forms of governance.

Table of contents

Abstract 2

Acknowledgments 5

1. Introduction 6

1.1 Topic introduction 6

1.2 Research questions 8

1.3 Relevance and contribution of the thesis 9

1.4 Outline of thesis 10

2. Theoretical framework 11

2.1 Governance 11

2.2 The governance perspective of Borrás and Edler (2020) 13

2.3 Analytic contribution of the MLP and TEF 16

2.4 Explaining the role of the state in the governance of socio-technical change based on its socio-technical governance context 19

3. Research methodology 22

3.1 Transformative effects of CCAM in the EU 22

3.1.1 Data collection 22

3.1.2 Data analysis 23

3.2 Governance of CCAM in the EU 24

3.2.1 Data collection 24

3.2.2 Data analysis 24

4. Results 26

4.1 Sub-question 1: How could CCAM change the socio-technical system for land-based road transportation in the EU? 26

4.2 Sub-question 2: What is the governance of CCAM in the EU? 34

4.2.1 Discussion 42

4.3 Sub-question 3: Which roles does the European Commission play in the governance of CCAM in the EU? 43

4.3.1 Discussion 48

4.3.2 Roles of the European Commission 49

4.4 Sub-question 4: What is the socio-technical context in which the governance of CCAM is embedded? 50

4.4.1 MLP analysis 50

4.4.2 TEF analysis 53

5. Conclusion 57

5.1 Conclusion 57

5.2 Limitations and critical reflection 59

5.3 Recommendations 61
Bibliography 62
Appendix A: Operationalization of categories for socio-technical system of CCAM 68
Appendix B: Socio-technical system analysis 69
Appendix C: Sources used for MLP and TEF analysis 71

Acknowledgments

Where I started in 2016 with a bachelor of European Public Administration, with this thesis I now stand at the end of my 7.5-year-long journey at the University of Twente. This thesis feels like a synergy of all that I learned and experienced throughout these years. I want to deeply thank my first supervisor Peter Stegmaier for his patience, guidance, and feedback throughout the thesis process, which at points was difficult due to external circumstances. Also, I want to express my gratitude towards supervisors Kornelia Konrad and Frans Coenen who with their feedback and recommendations helped me to improve this thesis. I also would like to thank Jeroen Vonk because of the thought-provoking conversations we had during my writing breaks and the feedback provided which helped me to structure my thoughts and parts of the thesis. Throughout my research process study association W.T.S. Ideefiks was a central pillar. Not only because of the coffee and the open academic deliberative environment provided but also because I have been an active member of the board for two years. I, therefore, want to thank the past two boards and the current board of Ideefiks for their work and efforts in shaping this supportive atmosphere. Lastly, I want to thank my parents and sister for their support throughout my academic journey, which culminates in this thesis.

1. Introduction

1.1 Topic introduction

Society becomes strongly digitalized (Schroten et al. 2020: 23). When this digitalization occurs in the mobility sector it is known as smart mobility. With smart mobility, ICT applications are implemented in components of the traffic system. Between these components, digital data exchange happens intended to match their supply and demand of past and current traffic data. Because of this match between supply and demand it promises to optimize travel times resulting in more efficient usage of road space, fewer accidents, and less CO2 emission pollution (Brcic et al. 2018: 2; Schroten et al. 2020). An example of smart mobility is Connected, Connective and Automated Mobility (CCAM). Central in the functioning of CCAM are Connected Automated Vehicles (CAV) which are vehicles supported in their autonomous driving capabilities with connective data exchange based on Cooperative Intelligent Transport System technologies (C-ITS). Due to this connective data exchange with other traffic system components, the vehicle is provided with more information that it can use and adapt upon in traffic situations using its autonomous driving capabilities. The connective data exchange extends the information horizon of automated vehicles by providing extra information (Elliott, Keen, and Miao 2019: 110). Smart mobility applications like CCAM have the potential to transform the transport system (Alonso Raposo et al. 2021: 1) (Schroten et al. 2020: 19). However, according to Docherty, Marsden, and Anable (2018: 116) such imaginings are often producer-led optimistic views based on the deterministic idea that having these technologies will directly lead to their potential benefits. Therefore Docherty, Marsden, and Anable (2018) voice a more pragmatic perspective by arguing that such transitional processes are complex phenomena in which governmental actors play an important role. Multiple futures might exist for one specific technological innovation based on policy and regulations (Docherty, Marsden, and Anable 2018: 116). A similar view is shared by Schroten et al. (2020) who discuss the importance of the management of smart mobility by public authorities. Marletto (2019: 228) and Alonso Raposo et al. (2021: 13) go beyond this by also highlighting the role of industry in the efforts to incorporate smart technologies into the transport system. The actions of actors from industry and government are therefore key in the integration and functioning of such technologies in the transport system.

Socio-technical transformation or change has been studied extensively over the past decades, with different perspectives on this being in existence. The social-determinism perspective holds that social factors are what is driving socio-technical change. The techno-determinism perspective in contrast is based on the premise that the technological is the driving force in this (Gil-Garcia, Vivanco, and Luna-Reyes 2014). The co-evolutionary perspective holds the view that socio-technical change is the result of co-evolutionary dynamics between a physical environment and social structure and needs (Fox

1995: 92). This thesis takes a co-evolutionary perspective on socio-technical change. Central in the co-evolutionary view of socio-technical change taken are the actions of social actors which in their socio-technical context, consisting of social and technological factors, are what drives socio-technical change. This is known as the governance of socio-technical change. In the last decades, traditional forms of governance became obsolete and have been replaced with novel forms (Van Kersbergen and Van Waarden 2004). This led to a changing role of governments and states in these processes. According to Borrás and Edler (2020), the role of the state (comprising of public policy and governmental action) in the governance of socio-technical change is conceptually undeveloped. Hence, they call for research that takes a more embedded approach toward the roles of the state in the governance of socio-technical change.

This thesis intends to contribute to the research agenda of Borrás and Edler (2020) on the roles of the state in the governance of socio-technical change by involving a broader socio-technical perspective. Borrás and Edler (2020) identified 13 roles states can play in socio-technical change. In their approach on what drives socio-technical change, the authors focus on how social actors in their institutional context with their instruments drive social-technical change, and why the change is accepted. Even though they recognize the opportunity structures which could be presented towards social actors based on the co-evolution between technology and social structures, their framework does not take into account how the broader socio-technical context in which governance is embedded and the material conditions of technological systems can enable or constrain socio-technical change. To involve these aspects, this thesis will propose a broader socio-technical perspective that goes beyond the governance framework of Borrás and Edler (2020). In doing so usage is made of a case study, which is the governance of CCAM in the European Union.

CCAM has the potential to transform the transport system while also affecting other societal components as discussed by Alonso Raposo et al. (2021: 1) and Schroten et al. (2020: 19), therefore it is appropriate to assess it from the perspective of socio-technical change. However, a broader socio-technical perspective on the potential transformative future effects of CCAM is lacking. As discussed by Docherty, Marsden, and Anable (2018: 116), Schroten et al. (2020), Marletto (2019: 228), and Alonso Raposo et al. (2021: 13) this is dependent on the actions of social actors and how these incorporate such technologies in the mobility system, which was discussed as the governance of socio-technical change. This thesis intends to define the potential transformative effects of CCAM for the EU, the governance involved with this, and the roles of the state in this from a broader socio-technical perspective by using the Multilevel Perspective (MLP) and the related Triple Embeddedness Framework (TEF). Central in this socio-technical perspective, introduced in the theory chapter, is the notion of a socio-technical regime. A socio-technical regime consists of social actors which interact in the context of social structures and a rule system, which form a coordinating context guiding and orienting them in their actions (Geels 2005b: 449, 50). The socio-technical regime is therefore based on governance and is responsible for maintaining the stability of a socio-technical system. A socio-technical system is a configuration of elements like technologies, policy, markets, consumer practices, infrastructures, cultural meanings, and scientific knowledge (Geels 2012: 471). When changes occur in these elements or the broader socio-technical context this could lead to a socio-technical transition (Geels 2005a) (Geels 2005b: 466). Hence the socio-technical system concept will be used to define the transformative effects of CCAM and will the regime concept as part of a broader socio-technical system be used to assess the governance involved to contribute to the research agenda of Borrás and Edler (2020). Due to the specific multilevel governance context based on the EU Single Market and the transformative potential of CCAM, the governance of CCAM in the EU was selected as a relevant case study intended to contribute to the embedded understanding of the roles of the state in the governance of socio-technical change. With DIRECTIVE 2010/40/EU, the European Commission had been granted the legal capacity and the mandate to act upon the field of C-ITS and CCAM in the EU context (Commission 2010: 2). Hence, the European Commission was defined as the "state" for this case study. These considerations lead to the following research question:

"How could CCAM change the socio-technical system for land-based road transportation in the EU, what are the roles of the European Commission in the governance of this, and how can these roles be explained based on their embeddedness in their socio-technical context?"

From this research question, four different sub-questions were developed.

1.2 Research questions

Sub-question 1: *How could CCAM change the socio-technical system for land-based road transportation in the EU?*

This sub-question focusses on the transformative potential of CCAM in the EU by defining the technological system focussed upon and the socio-technical and governance requirements for this context. This is relevant since it defines the technological system in the case from a socio-technical perspective to account for its material conditions.

Sub-question 2: *What is the governance of CCAM in the EU?*

This sub-question aims to identify and describe the governance of CCAM in the EU, which started in the 1980s and will continue for the coming decades. Hence it serves as the empirical case study analysed with later sub-questions.

Sub-question 3: *Which roles does the European Commission play in the governance of CCAM in the EU?*

This sub-question analyses the case study from the previous sub-question with the perspective of Borrás and Edler (2020) to identify the roles which the European Commission as the state plays in this.

Sub-question 4: *What is the socio-technical context in which the governance of CCAM is embedded?*

This sub-question intends to capture the socio-technical context in which the governance of CCAM is embedded using the MLP and the TEF.

Making use of the four sub-questions it is aimed to answer the main research question. The sub-questions will be further elaborated upon in chapter 3, the methodology chapter for this thesis.

1.3 Relevance and contribution of the thesis

This master thesis is written for two studies: Philosophy of Science, Technology, and Society, and Public Administration. Where PSTS studies the edges and connections between science, technology, and society does PA study the role of government and governance in addressing societal challenges and creating public value. By taking a co-evolutionary approach that takes into account the interaction between the social and the technological in the governance of socio-technical change on CCAM, this thesis intends to create a synergy in its outcome which goes beyond each study program. By studying the role of the state in the governance of CCAM in the EU, this thesis is relevant for both studies since it investigates the governance of a transformative system from a socio-technical perspective and how these efforts are embedded and enabled and constrained by material technological conditions in this socio-technical context and can be explained by it. Therefore, this thesis aims to make multiple contributions to literature. First of all, it aims to contribute to the research agenda of Borrás and Edler (2020) on the role of the state in the governance of socio-technical change by integrating their governance approach with a broader socio-technical perspective. Secondly, it aims to investigate the transformative potential of CCAM from a socio-technical perspective with a focus on the EU context. CCAM is discussed as having transformative potential in literature, but mostly from an economic or market-oriented business-model perspective (e.g. Alonso Raposo et al. (2021), Marletto (2019)) or merely from the technological side (e.g. Abdelkader, Elgazzar, and Khamis (2021)). This thesis intends to go beyond this. Thirdly this thesis aims to place the case study central in a broader socio-technical governance perspective by studying the factors which influence this transformative process to explain and define the socio-technical context in which the governance processes central occur in and are embedded.

1.4 Outline of thesis

After this first introductory chapter, the next chapter will discuss the theory used. From this theoretical perspective, the analytic approach taken will be developed. The third chapter will present the research methodology used to address the sub-questions and main research question. The fourth chapter will contain the results of the sub-questions. The fifth chapter will provide an answer to the main research question, a reflection on the analytic framework and the research conducted, and points to elaborate upon for scientists and policymakers.

2. Theoretical framework

This chapter presents the theoretical framework. Hence it will discuss the analytic and theoretic lens from which the thesis is conducted. This thesis takes a socio-technical approach in its analysis of the governance of CCAM in the EU to contribute to the research agenda of Borrás and Edler (2020). The first section will open with a discussion of literature on governance to place the research agenda of Borrás and Edler (2020) and the case in a broader context. The second section will discuss their governance perspective and how the roles of the state are developed from this. The third section will discuss the analytic contribution this thesis intends to make by introducing the Multilevel Perspective and Triple Embeddedness Framework. The fourth section will develop the analytic framework used to address the main research question.

2.1 Governance

CCAM has the potential to transform the mobility system as discussed by Alonso Raposo et al. (2021: 1) and Schroten et al. (2020: 19), therefore it is appropriate to assess it from the perspective of socio-technical change. However as discussed by Docherty, Marsden, and Anable (2018: 116), Schroten et al. (2020), Marletto (2019: 228), and Alonso Raposo et al. (2021: 13) this is dependent on the actions of actors like industry and government and how these incorporate such technologies in the mobility system based on governance. Governance as a phenomena has been studied extensively in the past decades from a range of different perspectives including public management, political science, law, economics, and public administration (Provan and Kenis 2007: 230) (Van Kersbergen and Van Waarden 2004). According to Benz (2007b: 4) the term governance can be used to analyse complex patterns of collective action, and is often associated with policy-making beyond the state (Benz 2007b: 5). According to Benz (2007b: 5) governance is coordination and control in horizontal relations between actors while vertical hierarchical relationships are not excluded from being present. A governance arrangement, therefore, is a type of rule system that structures the interactions between actors surrounding a specific topic (Benz 2007b: 6). This coordination and control can happen in different forms. According to Benz (2007b: 3) different forms of coordination and mechanisms of control can be explained by “unilateral regulation in hierarchies, mutual adjustment in markets, agreement in negotiations or trust and consensus in networks and social communities”. For Benz (2007b) this is a broad conception of the term governance. On what governance is many things have been written and are many conceptions in existence. So discuss Van Kersbergen and Van Waarden (2004) nine different conceptions of governance used in different fields and paradigms.

What is central in these nine conceptions is what Van Kersbergen and Van Waarden (2004: 143) call the shift from government to governance which happened in the last few decades. In this traditional forms of governance were replaced by new governance mechanisms. Traditional governance mechanisms according to Kersbergen and Van Waarden (2004, pp. 144, 152) were based on unicentric political institutions, meaning that there was one strong executive government. With the shift from government to governance, the role of these unicentric political insitutions has decreased and for a large part been replaced by different actors and institutional arrangements (Van Kersbergen and Van Waarden 2004: 143). Hence can the research agenda of Borrás and Edler (2020) be placed in a broader governance perspective on changing roles of governmental executives. One of the conceptions discussed by Van Kersbergen and Van Waarden (2004) is multilevel governance. Multilevel governance is based on different governmental levels and the involvement of both private and public actors at these levels (Van Kersbergen and Van Waarden 2004: 149, 50). Multilevel governance is often used in the context of the European Union (Hooghe and Marks 2001). Hooghe and Marks (2001) argue that due to processes of European integration, the role of the individual nation-state has decreased. The EU multilevel governance context consists of national member state governments which operate via collective decision-making and autonomously operating EU institutions like the European Commission and the European Parliament (Hooghe and Marks 2001: 2). Therefore, they argue for using a multilevel governance perspective involving supranational, national and regional levels of government when studying governance in the EU context, which is relevant for this thesis based on its focus on the governance of CCAM in the EU.

As discussed by Benz (2007b: 5), Van Kersbergen and Van Waarden (2004), and Hooghe and Marks (2001), the role of traditional governance mechanisms in policy-making and governance is changing. Especially in complex policy areas combinations of governance arrangements are present and are what Benz (2007b: 9) calls “composite” governance regimes, which combine governance mechanisms across and beyond different levels and arenas of policy (Benz 2007b: 5). Due to the nature and socio-technical requirements of the CCAM system and the multilevel EU context in which it is deployed it can be seen as a complex policy area. So can there be combinations of markets, hierarchies, and networks but also novel methods of governance based on governance innovation and tentative governance (Kuhlmann, Stegmaier, and Konrad 2019). Kuhlmann, Stegmaier, and Konrad (2019: 1092) state that the governance of socio-technical change swings back and forth between traditional and newly developing forms of governance. This is what they call governance innovation, which is driven by public and private actors alike. Examples of such governance innovations in the EU context are the Open Method of Coordination, open consultations, and networked agencies (Sabel and Zeitlin 2010). The deliberative processes involved in this resulted in a complex context of multilevel networks, which links (formal and informal) collaboration of private and public actors from different levels of government (Benz 2007a: 515).

2.2 The governance perspective of Borrás and Edler (2020)

Borrás and Edler (2020: 2) focus on the governance of socio-technical change. They understand this "as the interplay of the different ways in which agents intentionally and deliberately interact reflexively to influence, promote or inhibit transformative processes". Borrás and Edler (2020: 3) define socio-technical systems as "articulated ensembles of social and technical elements which interact with each other in distinct ways, are distinguishable from their environment, have developed specific forms of collective knowledge production, knowledge utilization and innovation, and which are oriented towards specific purposes in society and economy". Borrás and Edler (2020) motivate that the role of the state in socio-technical governance is undeveloped from a conceptual point of view. They define the state as governmental action involving both notions of government and public policy. Since government and public policy are widely defined in literature, the authors use a broad conception of the state involving different levels and forms of governmental action (Borrás and Edler 2020: 2,3). The state in their conception can consist of different governmental entities involved in socio-technical change on different levels of government, and should therefore not be confused with a nation-state or a supranational state. The state in the conception of Borrás and Edler (2020) is therefore subject to contextual factors. In their smart cities case study for example "the "state" refers primarily to local governments (municipalities), and/or city-regional departments, often indirectly encouraged by national or supranational (EU) levels" (Borrás and Edler 2020: 4). Borrás and Edler (2020) intend to go beyond the roles of the state in socio-technical governance based on the dichotomy of correcting market and system failures, or creating these.

Borrás and Edler (2020) define a typology of four different governance modes using two dimensions: whether the change was driven by public or private actors, and how hierarchical the distribution of power between the actors involved was. The first dimension focusses on the nature of the actors and the second focusses on the nature of the coordination involved. The governance modes defined are command and control, which is based on a hierarchical distribution of power and driven by state actors. Primus inter pares, which is based on a more horizontal distribution of power while being driven by state actors. Oligopoly, which is driven by non-state actors and has a hierarchical distribution of power. And self-regulation, which is driven by non-state actors and has a more horizontal distribution of power. Based on this typology, Borrás and Edler (2020) authors discuss four illustrative cases of socio-technical governance which they used to conceptualize the role of the state.

In the conceptual framework of Borrás and Edler (2020) based on Borrás and Edler (2014b), governance of socio-technical change is based on three pillars: the agents and opportunity structures driving change, the instruments used to drive change, and the legitimacy involved with the change.

With the first pillar, the authors focus on the opportunity structures which are offered towards social agents based on the co-evolution between their social context and new and emerging technologies and knowledge, and the social agents' capacity to position themselves in that institutional social context to bring alignment for system change. Hence this first pillar is based on the who and what drive change. The second pillar involves the instruments used to drive change and focusses on "the specific ways and mechanism by which agents induce change in the socio-technical system and are able to design and give direction to that change" (Borrás and Edler 2014b: 31). Where the first two pillars focus on the governance in practice, the third pillar addresses democratic and legitimacy issues related to the socio-technical change by focussing on the degree of social-acceptance on the outcomes and processes, and potential forms of social contestation (Borrás and Edler 2020: 3). Hence it focusses on why the change and the process are accepted (Borrás and Edler 2014b: 12). These three pillars are interrelated in constituting the governance of socio-technical change. In their approach, Borrás and Edler (2014b: 24) see actors both as the object and the subject of study. By studying actors in their role in the governance process, and how these are enabled and constrained by this (Borrás and Edler 2014b: 30).

Borrás and Edler (2020) identified 13 roles the state played in their illustrative case studies. For the actors involved, a broad approach was taken by including both public and private actors and their different (public, private, or joint) instruments. Hence their perspective is not bottom-up nor top-down but open to the different contextual dynamics in which it occurs. In each mode, the state was identified to play various roles, which shows the complexity of the roles which the state can play in socio-technical change. The roles of the state and their distribution amongst the different governance modes can be found below based on Borrás and Edler (2020).

- Facilitator: The state actively facilitates socio-technical change by supporting initiatives of other agents involved to make the process of socio-technical change easier.
- Lead-user: As lead-user, the state brings about market creation by shaping and co-designing socio-technical change to meet public needs.
- Initiator: The state early on identified opportunities and actively makes use of its knowledge and resources with the intention to contribute to the process of socio-technical change.
- Promoter: The state actively promotes socio-technical change by positioning itself as proponent of the change.
- Enabler of social engagement: The state takes an active role in including stakeholders in deliberative processes to shape the process of socio-technical change.
- Moderator: The state takes an arbitrary role in the deliberative process between different views and positions on the direction of socio-technical change by acting as negotiator.

- Guarantor: The state takes an active and direct role in securing operations against risks of the socio-technical change related to potential financial, security, and safety risks.
- Watchdog: The state is active in ensuring that all stakeholders in a socio-technical system act by collectively established norms.
- Observer: The state does not take an active role in the socio-technical system but watches and observes trends and developments occurring and taking place.
- Warner: The state is active in identifying and communicating potential risks on socio-technical change towards users, developers, and citizens based on its set narrative.
- Opportunist: The state seizes opportunities emerging from socio-technical change and therefore becomes active in obtaining the benefits resulting from this.
- Gatekeeper: The state takes an active role in controlling the access for agents involved with socio-technical change by creating or dissolving transformative and experimental venues.
- Mitigator: The state is active in reducing the negative externalities produced by socio-technical change.

In the command and control mode according to Borrás and Edler (2020), the state takes a moderating, promoting, initiating, and guaranteeing role besides acting as watchdog. In the primus inter pares governance mode the state takes a facilitating, initiating, promoting, and gatekeeping role besides acting as lead-user and enabler of societal engagement. In the oligopoly the state takes a gatekeeping, facilitating, and promoting role. In the self-regulation governance mode a observing, warning, and mitigating role next to acting as opportunist.

Borrás and Edler (2020) discuss that these roles are not yet fully developed nor conceptualized based on the small empirical base their research is based upon. Therefore their research agenda calls for a more embedded approach on the role of the state in the governance of socio-technical change. Borrás and Edler (2020) understand this embeddedness as the societal and socio-technical context in which state action is operating. To contribute to this research agenda, this thesis proposes a broader socio-technical perspective by integrating the Multilevel Perspective (MLP) and the Triple Embeddedness Framework (TEF) with the framework of Borrás and Edler (2014b) to account for this embeddedness in the societal and socio-technical context. The next section will explain these frameworks and their analytic contribution to the framework of Borrás and Edler (2014b).

2.3 Analytic contribution of the MLP and TEF

Both the MLP and the TEF take socio-technical regimes central in their approach on socio-technical change. A socio-technical regime consists of three elements which are socio-technical systems, social actors groups, and rules and institutions. A socio-technical system is a collection of socio-technical factors surrounding a societal function, like road transport with vehicles, regulations, and infrastructures (Geels 2005b: 466). For CCAM the vehicle is therefore embedded in a broader socio-technical context. When alterations in the context or the vehicle occur, the socio-technical configuration changes (Fraedrich, Beiker, and Lenz 2015: 3). This configuration is maintained by social actor groups that operate in the context of a rule system. This rule system guides the actor groups in their expectations, heuristics, and practices and consists of technological knowledge and capabilities, mindsets and cognitive frameworks, values, identities, and a regulatory framework (Geels 2014: 267) (Geels 2005b: 450) (Geels 2005a: 367-69) (Geels 2012: 473). The actor groups in a socio-technical regime therefore interact in the context of social structures, a coordinating rule system, and of a material socio-technical system that could enable or constrain socio-technical change (Geels 2005b: 449). Therefore, forms of coordination take place in a socio-technical regime, which was defined as governance. A socio-technical regime maintains the stability of a socio-technical system (Geels 2005a: 367-69). If the regime changes, this could over time lead to socio-technical change (Geels 2005a: 450). Where the MLP takes a macro and micro perspective on socio-technical change by studying factors influencing the regime, the TEF in turn takes a meso perspective by focussing on the environments in which the regime operates and the governance which occurs is embedded (Bodenheimer 2018: 13).

The MLP can be used to study changes and transitions in and between socio-technical systems (Geels 2005a, 2005b; Fraedrich, Beiker, and Lenz 2015; Geels 2012; Geels et al. 2016; Geels and Schot 2007). Central in this are co-evolutionary dynamics between technological and non-technological factors, or between technology and society. The MLP makes a distinction between three conceptual levels, which are the macro, meso, and micro levels, also known as landscape, regime, and niche. Co-evolution between technological and social factors occurs relatively independently at all three levels, but when these dynamics interlink a socio-technical transition could occur (Geels 2005a: 366). There is no real driving force behind transitions and changes since these are caused by dynamics and developments in and between the three different levels. Constant alignment occurs between the three levels (Geels 2004, 2011). The regime level is responsible for maintaining the stability of a socio-technical system since it mediates between the levels (Geels 2005a: 367-69). Central in this is the creation, (re)production, and refinement by social groups (Geels 2005b: 449). If the regime level changes, this could thus over time lead to a socio-technical transition (Geels 2005a: 450). A socio-technical transition can therefore be seen as regime change (Geels and Schot 2007: 399; Geels 2011: 26). Socio-technical change in the MLP perception therefore is a multi-actor process involving interactions between different groups and actors based on governance (Geels 2005b: 446). Due to changes in the broader socio-technical context, a window of opportunity could open which could lead to changes in the socio-technical regime. This broader socio-technical context in the MLP consists of niches and a landscape. In socio-technical niches technologies that deviate from the market-based status quo are developed secluded from market selection. The socio-technical landscape consists of aspects of the so-called technology-exogenous environment like macro-economics, cultural patterns, macro-political developments, and environmental aspects. These factors are at the background of technological developments, and enable or constrain socio-technical change (Geels 2005a: 366-68). Both niche and landscape put pressure on the regime. When these dynamics interlink a socio-technical transition could occur (Geels 2005a: 366). Such a process can take multiple decades (Geels 2005a).

The TEF is a framework used to define the co-evolution between industries and their environments in socio-technical change, and henceforth the governance involved. The TEF takes a meso perspective by focussing on the economic and socio-political environments in which the industry operates and is embedded. The industry is placed in two environments. The economic environment based on market pressures like supply and demand, and the socio-political environment which involves the institutional context in which the industry is located involving political pressures like legitimacy and actors like social movements and policymakers. Between the industry and the two environments, co-evolutionary dynamics occur. The industry is pressured by the external environments, but also acts strategically to these making it a bi-directional interaction. Industry is therefore triply embedded in the industry regime, the economic environment, and the socio-political environment (Geels 2014; Kungl and Geels 2018). Figure 1 shows such an industry governance regime related to a societal function based on the Triple Embeddedness Framework (TEF).

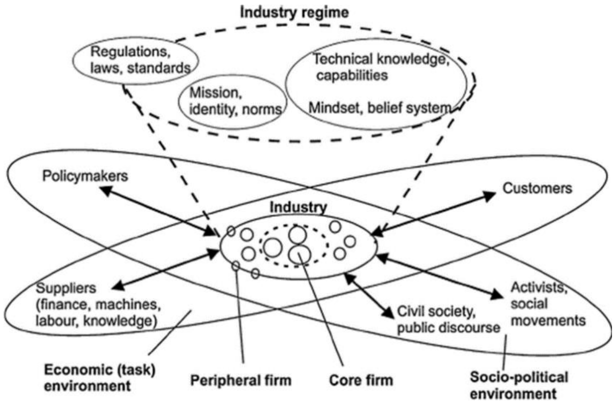

Figure 1: Triple Embeddedness Framework of industries (Geels 2014: 266)

This thesis intends to contribute to the research agenda of Borrás and Edler (2020) on the embedded roles of the state in the governance of socio-technical change. Borrás and Edler (2020) understand this embeddedness as the social and socio-technical context in which state action is operating. This explanation of Borrás and Edler (2020) however is viewed by the author of this thesis to be very socio-deterministic. So does their perspective not explain the broader socio-technical context in which governance takes place and therefore is embedded. Even though they recognize the grouping of social and technological elements in defining socio-technical systems and the co-evolution involved in this, they do not provide an explanation or framework on how the broader socio-technical context in which the governance is embedded and the material conditions of the technological system can enable and constrain the governance of socio-technical change outside of a legitimacy perspective. This is in contrast with the MLP and the related TEF which allow for taking such a broader socio-technical perspective with their focus on the regime as part of a socio-technical system involving material conditions.

So is there a difference between the opportunity structure of Borrás and Edler (2014b) and the window of opportunity used in the MLP, which even though they are similar in wording are different in their explanation. Using these the differences between both perspectives can be highlighted well. Borrás and Edler (2014b: 19) view opportunity structures based on the co-evolution between technology and new knowledge within social framework conditions which could generate opportunities for social actors to be taken, and the social agents' capabilities to position themselves in that institutional social context to bring alignment for system change. Opportunity structures are therefore based on the resources and interpretative abilities of agents. The MLP on the other hand views window of opportunities as being based on the dynamics between niche, regime, and landscape while taking into account the broader socio-technical context the regime is embedded in and how this could enable and constrain change. Nevertheless, could there be overlap between opportunity structures and the window of opportunity used in the MLP, but the framework of Borrás and Edler (2014b) lacks the explanatory capacity the MLP has in this on the embeddedness in the broader socio-technical context. The TEF allows for obtaining a more structured picture of the regime and how this is embedded in an economic and socio-political context which the MLP in turn could provide. The framework of Borrás and Edler (2014b) with its legitimacy pillar also addresses socio-political aspects, but does not go as far as the TEF and its socio-political dimension. Based on this argumentation for the analytic contribution of both perspectives, this thesis proposes a theoretical model which includes both the governance perspective of Borrás and Edler (2014b) and a broader socio-technical perspective involving the MLP and the TEF to contribute to the research agenda of Borrás and Edler (2020).

2.4 Explaining the role of the state in the governance of socio-technical change based on its socio-technical governance context

The analytic framework this thesis proposes integrates the socio-technical MLP and TEF perspectives with the framework of Borrás and Edler (2014b) to explain the roles of the state in socio-technical change based on their defined socio-technical context. A visualisation of the socio-technical governance perspective this thesis proposes is shown below.

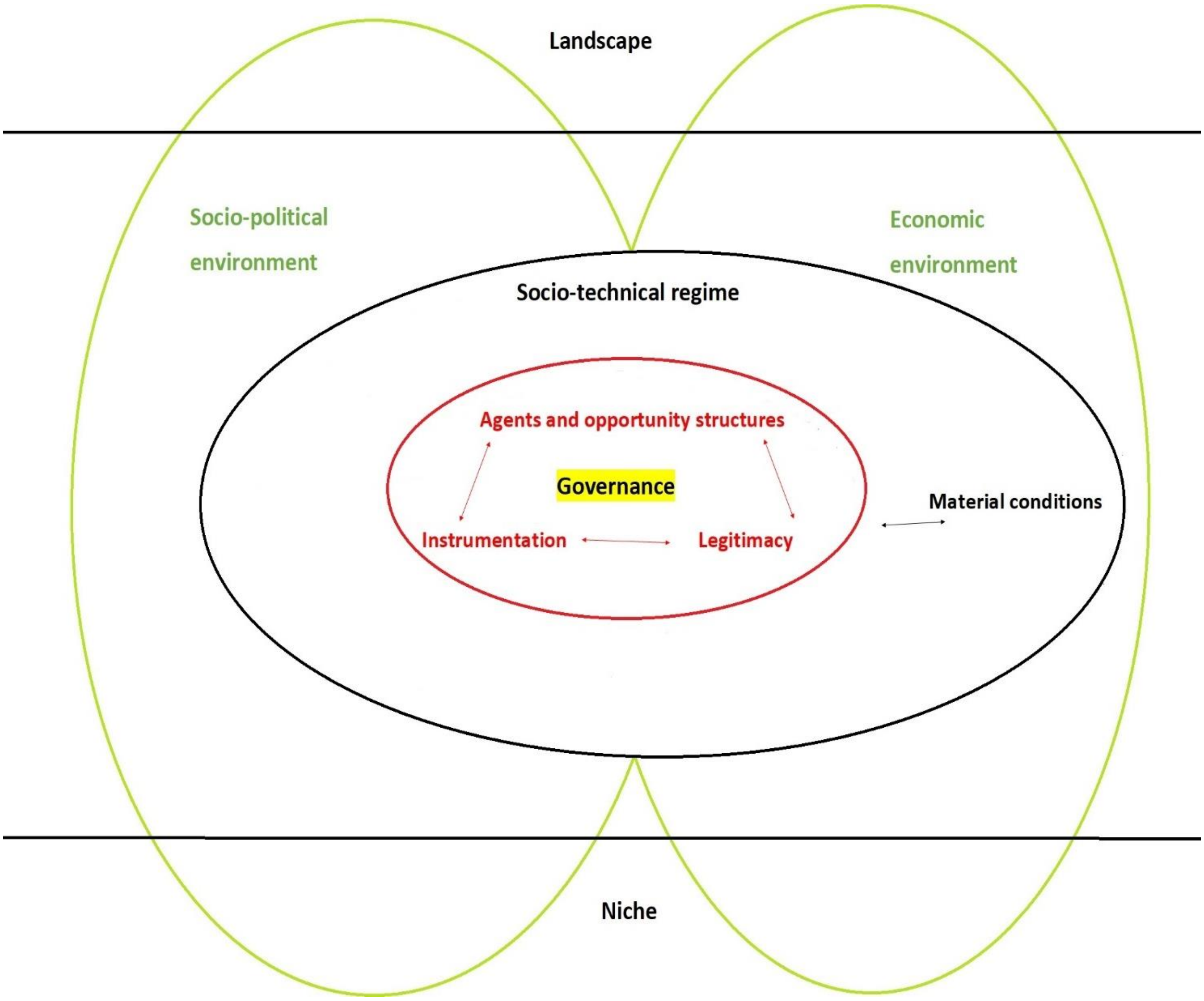

Figure 2: The analytic framework proposed

Central in this framework is governance, which this thesis studies. Governance is highlighted in yellow and is located in the middle of the red circle which intends to represent the framework of Borrás and Edler (2014b) and its three components. This is included in the framework since it is the foundation of the research agenda of Borrás and Edler (2020) on the roles of the state, which this thesis intends to contribute to. In black, the MLP is visualized, with governance being placed in the middle of the socio-technical regime since governance takes a central role in this. The regime in turn is placed in the middle of the other two MLP levels, which are the Landscape and Niche. Governance is also connected with the material conditions of the socio-technical regime, which this thesis intends to take into account. By including the MLP in this model it is aimed to define the broader socio-technical context the regime is embedded in and the material conditions of the technological system and how these enable or constrain socio-technical change. The TEF is visualized with green rounded shapes, one for the economic environment and one for the socio-political environment. By including the TEF it is aimed to obtain a meso-perspective on the regime and how this is embedded in a broader socio-economic and political environment. With this analytic socio-technical governance perspective it will be aimed to investigate the research question, with the MLP and TEF perspectives aiming to account for the socio-technical context in which the governance of the socio-technical regime is embedded.

Doing so usage is made of a case study, which is the governance of CCAM in the EU. Due to the nature and technical requirements of the CCAM system and the multilevel EU context in which it is deployed, it can be seen as a complex policy area. Following Benz (2007b) there can therefore be combinations of markets, hierarchies, and networks but also novel methods of governance based on governance innovation as discussed by Kuhlmann, Stegmaier, and Konrad (2019). Since this thesis uses the analytic framework of Borrás and Edler (2014b), it will also follow their broad interpretation of agents driving socio-technical change by including public, private, and joint efforts and the involved governance instruments by including both state-led policy instruments and socially led-instruments.

Borrás and Edler (2020) have a broad definition of the state involving different levels and forms of governmental action and public policy. What should be viewed as the state is therefore contextual and can be used to define actors from different levels of governmental action. Because of the multilevel governance context of the EU, different “states” could therefore be identified dependent on which level or region is focussed on which limits the epistemic value of the specific roles the “state” can play in the governance of socio-technical change in practice. Therefore, it was decided to focus upon a clearly defined “state” for this thesis. With DIRECTIVE 2010/40/EU, the European Commission had been granted the legal capacity and the mandate to act upon the field of C-ITS and CCAM in the EU context (Commission 2010: 2). Therefore the European Commission (EC) was defined as the “state” in the governance of CCAM. Involving the conception of Borrás and Edler (2014b) on actors driving change and governance instruments used in this allows for taking a broad perception in studying the governance of CCAM in the EU and the socio-technical governance context in which this occurs. In the next chapter the research methods which are developed based on this analytic framework will be discussed to assess the governance of CCAM in the EU and the roles the EC plays in this, and how these can be explained based on their socio-technical context.

3. Research methodology

In this chapter, the research methodology used to conduct the research to provide an answer to the main research question the sub-questions will be presented based on the in the previous chapter discussed analytic framework. The research was conducted in two main phases, data collection and data analysis. Data collection focussed on two components, the transformative effects of CCAM in the EU context and the governance of CCAM in the EU. The data collection for both components was conducted separately. Data analysis focussed on analysing the data collected. The first section will discuss the data collection, data analysis, and sub-questions for the first component. The second section discusses the data collection, data analysis, and sub-questions for the second component. To address the main research question, the outcome of the analyses conducted to address the sub-questions have to be integrated which will be done in the conclusion.

3.1 Transformative effects of CCAM in the EU

3.1.1 Data collection

Data collection for the transformative effects of CCAM in the EU was required to be able to answer the first sub-question, which as discussed is: *How could CCAM change the socio-technical system for land-based road transportation in the EU?* This sub-question is of relevance for this thesis since it intends to define the technological system central in the case under study from a socio-technical perspective to account for the material conditions of the socio-technical regime component of the analytic framework. The usage of the word 'could' was done because of the uncertainty which exists around the future practice of CCAM based on its management by public authorities, its incorporation in the mobility system, and the expected transition period. Therefore, it should be viewed as a discussion of trends and potentials on how the CCAM system could develop in practice based on a structured analysis of literature.

To collect data for this sub-question inspiration was taken from the 8 categories of which the socio-technical system for land-based road transportation by Geels (2005b: 446) consist, as can be seen in figure 3.

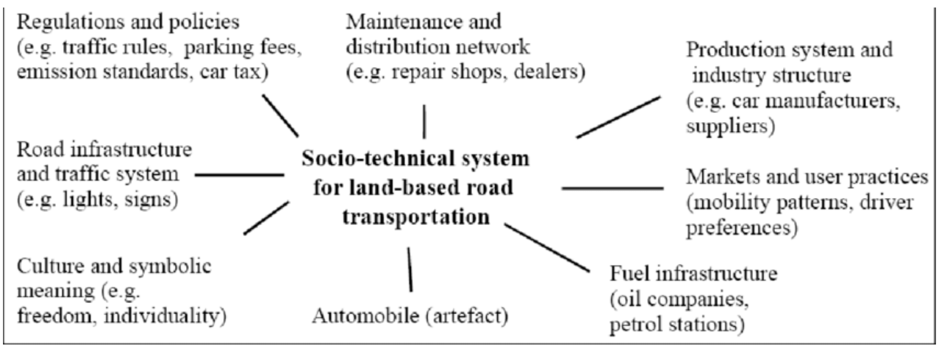

Figure 3: Socio-technical system for land-based road transportation (Geels 2005b: 446)

These were however not taken over directly since after its publication many technological developments have occurred based on digitalization and sustainable transport (Schroten et al. 2020: 21) (Commission 2017: 4). Irwin and Kossoff (2015) made the categories of Geels (2005b: 446) more explicit, but did not include these novel developments. The operationalization of the categories adapted towards CCAM can be found in Appendix A, with the proposed socio-technical system for land-based road transportation in figure 4.

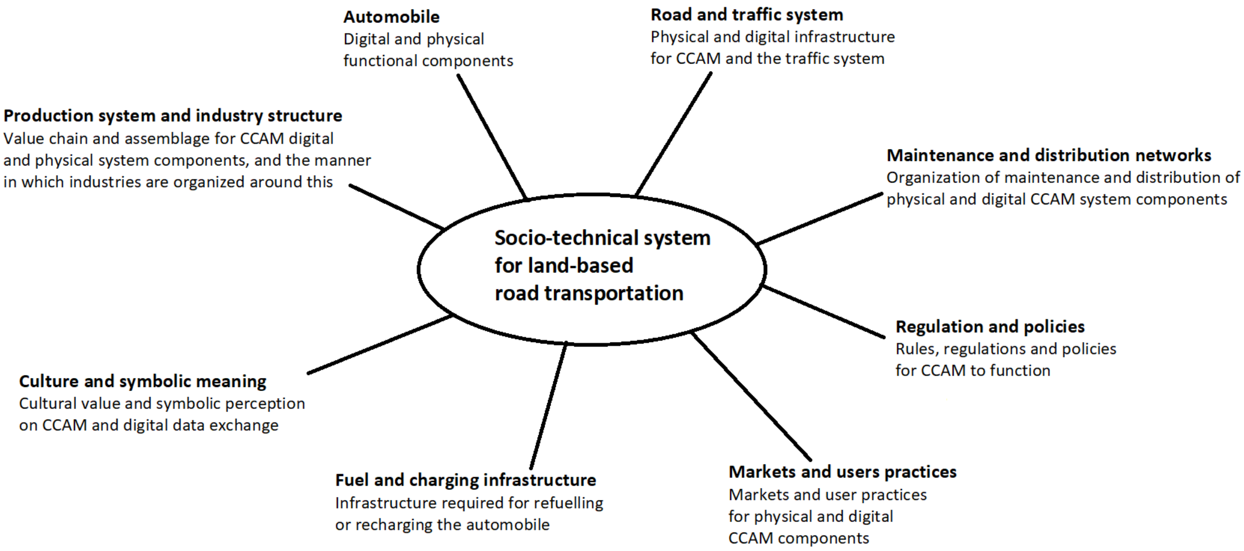

Figure 4: The proposed socio-technical system for land-based road transportation

Based on these categories data was searched. In finding data, Scopus, Web of Science, Google, and Google Scholar were used. Search terms used to identify literature are connected automated mobility, automated mobility, C-ITS, smart mobility, transformation, and socio-technical. Next to this structured search, a more explorative approach was taken to target specific categories of figure 4 due to the explorative nature of the sub-question or to go more in depth, especially related to more technical components of CCAM.

3.1.2 Data analysis

The data collected with the methods described in the previous section was analysed to answer sub-question 1. To analyse and categorize the data, the categories of figure 4 were used based on the analytic framework and the role of sub-question 1 in this. To support this analysis, usage was made of the ATLAS TI programme. This is a software application that can be used for qualitative data analysis. All selected literature was uploaded to this application in which codes were created based on the categories of figure 4. Relevant text parts were coded based on this operationalization. The coded data were then combined for each category and reanalysed to be able to provide a valid discussion for each category on how CCAM will or could affect this. This selection was based on the researchers' interpretation of the data. The read and analysed literature can be found in Appendix B.

3.2 Governance of CCAM in the EU

3.2.1 Data collection

The governance of CCAM is relevant since it is an important stepping stone for sub-questions 3 and 4. Data collection was conducted by addressing sub-question 2, which represents the governance component of the analytic framework. This sub-question aims to identify and describe the governance of CCAM in the EU. Since this thesis makes usage of the framework of Borrás and Edler (2014b) and Borrás and Edler (2020), it will also follow their broad interpretation of the governance of socio-technical change in terms of actors involved, public and private, and the actions and instruments used, public, private or joint. Governance by Borrás and Edler (2020: 2) is conceptualized "as the interplay of the different ways in which agents intentionally and deliberately interact reflexively to influence, promote or inhibit transformative processes". To collect data, a broad approach was taken in line with the conceptualization of Borrás and Edler (2020). For this policy documents, reports, strategies, declarations, regulations, websites, roadmaps, and academic articles on CCAM, C-ITS, ITS, automated mobility, mobility, road transport, and EU policy were read. Due to the integrated approach taken at the EU level between cooperation, connectivity, and automation, efforts on ITS and C-ITS are understood as foundations for CCAM.

3.2.2 Data analysis

The data collected was analysed to answer sub-questions 3 and 4. Sub-question 3 aims to analyse the governance from the perspective of Borrás and Edler (2014b) to identify which roles the European Commission as the state plays in this based on the 13 roles by Borrás and Edler (2020). Sub-question 4 question aims to structure the presented governance using the MLP and the TEF to account for the socio-technical context in which the governance of CCAM is embedded.

3.2.2.1 Sub-question 3: Which roles does the European Commission play in the governance of CCAM in the EU?

This sub-question aims to analyse and define the governance collected with sub-question 2 from the perspective of Borrás and Edler (2014b), therefore intending to capture this component of the analytic framework to identify which roles the European Commission as the state plays in this based on the 13 roles by Borrás and Edler (2020). Since CCAM was identified as a complex policy area the "composite" governance regime concept of Benz (2007b) was taken into consideration to structure and simplify the presented governance. This was done to provide a valid but also readable overview in line with the presented governance to identify the different roles the EC plays based on Borrás and Edler (2020). First, it was investigated whether different phases of governance could be demarcated based on the two dimensions of different governance modes by Borrás and Edler (2014a). It was however concluded that there could be in terms of hierarchy involved, but that these would not be that different terms of governance mode. Besides that, taking small parts as object of study as part of the broader narrative and the path dependency involved with this would lead to repetition and less deepened outcomes which was expected to have negative effects on the validity of the outcomes of this thesis. Henceforth it was decided to discuss selected governance initiatives from the presented governance of CCAM. The selected governance initiatives were analysed with the three dimensions used by Borrás and Edler (2014b) which are the distribution of capabilities of actors and opportunities structures, the policy instruments used, and the legitimacy involved. Based on this the governance mode was identified while also taking into account the existence of hybrid arrangements since these modes are ideal models. Based on the governance mode identified and the analysis it was then assessed which of the roles Borrás and Edler (2020) identified in this mode could be identified or not, after which this was done for the roles not identified by Borrás and Edler (2020).

3.2.2.2 Sub-question 4: What is the socio-technical context in which the governance of CCAM is embedded?

This sub-question aims to structure the presented governance of sub-question 2 using the MLP and the TEF to account for the socio-technical context in which the governance of CCAM is embedded. Hence it intends to capture the socio-technical dynamics involved with the governance based on the socio-political and economic environments these are embedded in based on the analytic framework. Socio-technical change according to the MLP is based on complex dynamics between three conceptual levels which are niche, regime, and landscape. An MLP analysis was conducted of the collected data of the presented governance to identify the socio-technical dynamics involved. This was then structured based on the TEF to define the socio-political and economic environments the regime is embedded in using identified literature on EU governance. The read and analysed sources can be found in Appendix C.

4. Results

4.1 Sub-question 1: How could CCAM change the socio-technical system for land-based road transportation in the EU?

Automobile or vehicle

The vehicle will be severely altered with CCAM. It will be integrated with two complementary systems, automated driving and connective data exchange making it a Connected Automated Vehicle (CAV) (Sharma and Zheng 2021: 5; Commission 2018: 11). Therefore these can be understood as "connected computers on wheels" (Platform 2017: 107). Central in the functioning of CAV is connective data exchange (Abdelkader, Elgazzar, and Khamis 2021: 3). Enabling in the functioning of CAV are Intelligent Transport System (ITS) applications which are ICT applications like sensors, transmitters, and receivers implemented in components of the transport system (Schroten et al. 2020). Automated driving is based on the implementation of an Automated Driving System, ADS. This ADS involves a combination of hardware components and artificial intelligence and replaces, parts, of the human role in driving (Li, Ota, and Dong 2018: 6814) (Soteropoulos et al. 2020: 64) (Chan 2017: 213) (Sharma and Zheng 2021: 5). To provide the ADS with data the vehicle is implemented with ITS technologies like sensors, cameras, radar and lidar (Sharma and Zheng 2021: 8, 9) (Abdelkader, Elgazzar, and Khamis 2021: 13) (Llatser et al. 2019: 1). The degree of automation is defined by the Society of Automotive Engineers (SAE) (Chan 2017; Soteropoulos et al. 2020) (SAE 2021b, 2021a). This division consists of six different levels based on the level of automation involved. With levels 0-2, the driver remains in control while with levels 3-5, decision-making responsibilities on driving tasks related to perception, planning, control, and navigation in a stepwise manner are adopted by the vehicle (Dokic, Müller, and Meyer 2015: 2) (Soteropoulos et al. 2020: 66, 67). The higher the SAE level, the more the ADS can process, recognize, adapt, and act upon increasingly complex traffic situations based on the AI involved by executing both lateral (direction) and longitudinal control (speed) of the vehicle while avoiding collisions and crashes with detected objects like vulnerable road users like pedestrians (Soteropoulos et al. 2020: 66, 67) (Elliott, Keen, and Miao 2019: 128) (Sharma and Zheng 2021: 8) (Nitsche, Mocanu, and Reinthaler 2014: 3).

An ADS is designed to function in specific circumstances. SAE (2021a) defines this as the Operational Design Domain. The more complex the ODD the more sophisticated the ADS and data have to be for safe driving. Therefore, it covers facets like geographical, roadway, environmental, traffic, and temporal conditions (Soteropoulos et al. 2020; SAE 2021a). The local ODD has a strong effect on the autonomous driving capabilities of the vehicle based on these conditions due to the data the ADS can take into account, e.g. road lining highlighted or visibility of traffic signals or signs (Soteropoulos et al. 2020: 65, 68; Nitsche, Mocanu, and Reinthaler 2014) (ERTRAC 2019: 6). A city for example is a different ODD then a highway, due to its complexity based on the differentiation of street spaces and a larger number of other road users (Soteropoulos et al. 2020: 65).

To provide the ADS with extra information, connective data exchange comes into play. CAV in that sense are different than Automated Vehicles (AV) because of this connective data exchange (Sharma and Zheng 2021: 6,7). Instead of one autonomous vehicle, vehicles in CCAM become part of a larger network in which data is exchanged between other vehicles and road infrastructure. This is known as V2X communication, with V being the vehicle and X being everything (Botte et al. 2019: 1). Based on the data exchange, vehicles in CCAM can interact and share information which these can jointly act upon allowing higher levels of automation (Llatser et al. 2019: 120). The data exchange between vehicle and road infrastructure can expand the ODD, and the automation involved, by providing the ADS with extra digital information which conventional road infrastructure is unable to provide due to for example snow or other local factors influencing this (Amditis et al. 2019: 311-19) (Inframix 2019: 24-31).

This requires wireless data exchange (Elliott, Keen, and Miao 2019: 111). Two types of communication technologies are involved in positioning and communication (Jako et al. 2019: 139). Accurate information on vehicle position is required to provide the vehicle and other vehicles with accurate locational information for collision-free driving. Communication is then required to exchange this information. Both reinforce one another in their functioning based on a so-called hybrid communication approach (Platform 2017: 12) (Amditis et al. 2019; Jako et al. 2019; Zlocki et al. 2019; Commission 2017; Elliott, Keen, and Miao 2019). GNSS and GPS can be used for positioning. For communication, the cellular telephone network with 4G or 5G internet connections, radio frequencies, and short-range communication technologies like Wi-Fi could be used (Jako et al. 2019: 139) (Commission 2017: 43). Vehicles therefore have to be implemented with these applications. This requires standardized communication based on interoperability and compatibility (Llatser et al. 2019). Interoperability means that components can exchange information and can act on that information (IEEE 1991). Compatibility means that the various technologies as parts of one system are sharing compatible hardware and operating systems and therefore can cooperate (ACE n.d.). Both can be seen as key to creating the aimed for continuity of service. Another technological development that is occurring in the automobile industry is that of zero-emission vehicles, as indicated by the GEAR 2030 report of Commission (2017). Therefore CCAM and electrification of vehicles are expected to go hand in hand, as argued by McCauley (2017) leading to more changes of the vehicle due to the replacement of an internal combustion engine with an electric motor (Commission 2017: 28).

Road and traffic system

Due to changes to the vehicle, CCAM will also alter the road and traffic system. Road infrastructure requires to be changed due to its role in the digital system of connective data exchange. Road infrastructure in CCAM consists of digital and physical components, therefore it is what Lytrivis et al. (2018: 4) call hybrid road infrastructure (Amditis et al. 2019: 311). Figure 5 shows 4 infrastructural components, roadside units, traffic management and information, cloud services, and cellular network.

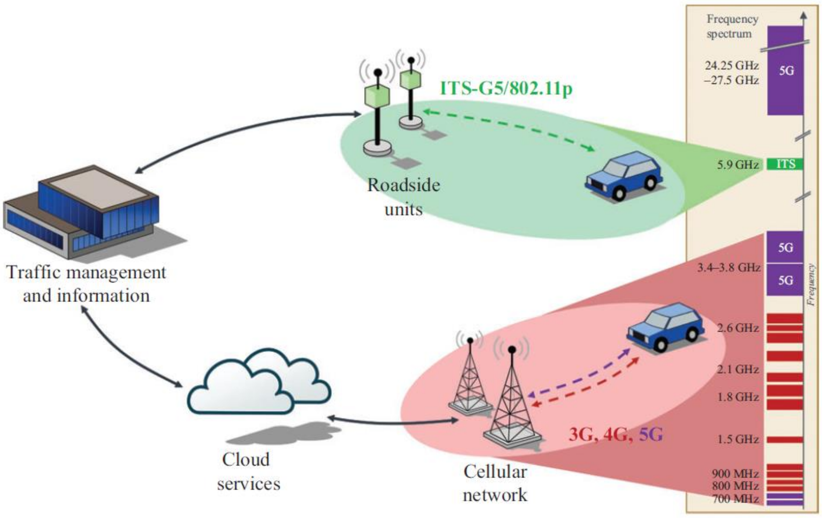

Figure 5: CCAM infrastructure (Bohm 2019: 27)

- Roadside units provide services to road users to facilitate traffic flow, like matrix signs and traffic lights (Amditis et al. 2019: 310). These are equipped with communication and sensorial technologies to identify traffic conditions. Roadside units can communicate with vehicles or could function as relay stations communicating information received from vehicles to other components (Lytrivis and Amditis 2012: 249).
- Traffic management is a public authority or road operator which is responsible for managing traffic conditions (Lytrivis and Amditis 2012: 450). In doing so traffic management is responsible for digital data handling (Amditis et al. 2019: 311). Because of the dynamic nature of data usage, traffic management in C-ITS is known as dynamic traffic management (Kotsi, Mitsakis, and Psonis 2020) (Geels 2007: 142).
- Telephone networks are used for long-range communication based on 4 or 5G telephone networks. Cellular networks are privately owned by telephone service providers (Jako et al. 2019: 156).
- Cloud services are services on the internet, and are therefore virtual (Frankenfield 2020). Cloud services, which are owned by service providers, in CCAM can further enhance traffic

perception based on digital maps by providing accurate information on traffic signs, lane topology, weather conditions, and emergency stop zones (Amditis et al. 2019: 311,15,18).

Not all infrastructure can support CCAM. ISAD (Infrastructure Support levels for Automated Driving) is a division of five levels of infrastructure based on the support it can provide to automated driving (Amditis et al. 2019) (Erhart et al. 2020). The higher the level, the more the infrastructure can support automated driving. Where Level E does not support automated driving, does Level A. Level A is based on cooperative driving, which means that infrastructure and the traffic information centre can guide vehicles in their movements to optimize traffic flow. Hence level A can be seen as supporting CCAM (Amditis et al. 2019: 311-19) (Inframix 2019: 24-31). Since CCAM requires continuity of service both physical and digital infrastructure require standardization based on interoperability and compatibility (Commission 2021a: 27, 42; Festag 2014: 1) (Platform 2017: 85, 86). CCAM in this manner will have a strong transformative effect on European road infrastructure (Amditis et al. 2019: 309).

Llatser et al. (2019) discuss two examples of how CCAM could function and change the traffic system, via collective perception and cooperative manoeuvrer coordination. With collective perception, V2X communication extends vehicles' information horizon by sharing and integrating information send out by other vehicles or road infrastructure. With cooperative manoeuvrer coordination, vehicles can cooperate and coordinate in specific manoeuvrers like highway merging with a high traffic density. Examples of both can be found in figure 6. A possible scenario for example is that when lane markings become less visible due to weather conditions or other circumstances like oil an ADS is no longer able to identify these. Digital data exchange can provide this information (Amditis et al. 2019: 311-19).

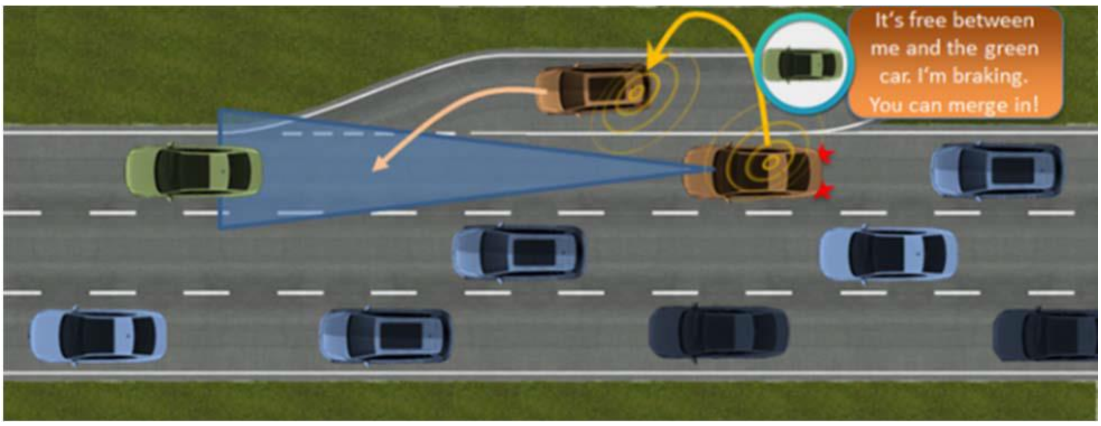

Figure 6: Functioning of CCAM based on collective perception and cooperative manoeuvrer coordination (Llatser et al. 2019: 122)

By enhancing road capacity CCAM promises to minimize traffic congestion (Sharma and Zheng 2021: 22). Traffic congestion leads to an unoptimized usage of road space which in turn leads to increased social costs (Metz 2018; Hensher and Bliemer 2014; Mondschein and Taylor 2017; van Woensel and Cruz 2009; Council 2020). However as discussed by Alonso Raposo et al. (2021) CCAM could also potentially lead to an increase in travel congestion because of an increased demand for road travel based on its incorporation into the mobility system (Alonso Raposo et al. 2021: 13) (Schroten et al. 2020: 14). As discussed it will take time before CCAM is fully deployed which will lead to a mixed traffic situation in which there is co-existence between CAV and conventional vehicles (Commission 2021a: 9, 18) (Commission 2018: 10) (Sharma and Zheng 2021: 13). Alonso Raposo et al. (2021: 12) discuss that when the penetration rate of CAV is high, and digital infrastructure is reliable enough conventional infrastructure might not be required anymore. Besides that, no new roads could have to be built.

Regulation and policies

ERTRAC (2019: 9) defines traffic regulations as "the concrete constraints under which a vehicle is allowed to move on the road, covering aspects like speed, allowed vehicle characteristics like width, height, weight and permissible movements like lane change, right/left turn, overtaking, etc." Traffic regulations therefore shape how the transport domain is regulated and organized (Inframix 2019: 9). Without a regulatory legal framework, CCAM therefore cannot function. For CAV traffic rules and regulations have to be adapted. For CCAM data exchange is required. This data exchange contains information on the location, origin and destination, vehicle, and trip. This data could be privacy sensitive, but also brings further security risks like misuse of data or hacking (Sharma and Zheng 2021: 17, 18) (Abdelkader, Elgazzar, and Khamis 2021: 21) (Jako et al. 2019). Both could influence traffic in such a manner that harm is done. Regulations are therefore required on privacy and security but also on responsibility. As discussed by Bohm (2019: 37) it should be clear among the different system component owners and developers who is responsible for which types of informational messages. An example used is which organization is responsible for providing speed information, the road authority, the digital map provider, the car manufacturer, or a mix of these. Therefore a centralized security certification policy is required to ensure the validity and trustworthiness of messages between different stakeholders (Bohm 2019: 28). A regulatory framework is required to coordinate between the different stakeholders involved. The actor responsible for the maintenance of roads and infrastructure is a road operator (Williams 2008: 1), but as discussed in the previous section components of the CCAM system are owned by different actors (Schroten et al. 2020: 111, 12). Therefore CCAM will require changes to the transport

governance framework on multiple levels since its functioning is based on the local context in which its implemented (Fraedrich, Beiker, and Lenz 2015: 8) (Brcic et al. 2018: 3).
Since it is the task of a public authority to be involved with transport governance according to Docherty, Marsden, and Anable (2018), CCAM is a form of public service provision (Botte et al. 2019; Hartley 2005). Regulation and policies therefore provide the overarching conditions in which CCAM is envisioned to function, which therefore will have to be adapted based on the previously discussed effects. This regulatory framework should include all components of the system involving (road) safety, security, data exchange, and responsibility but also the mixed traffic situation which is expected for the coming decades (Horizon et al. 2020; Santoni de Sio 2021) (Sharma and Zheng 2021). To maximize the output of CCAM, not only policy is required on the earlier mentioned components but also to guide public and private actors in their (financial) investments and on social acceptance which is an important condition for the deployment of CCAM according to Alonso Raposo et al. (2021: 3) (Marletto 2019: 224; Commission 2021a: 13).

Markets and user practices

CCAM has strong potential to change market and user practices. So do Sharma and Zheng (2021: 15) state that CCAM will disrupt several industries. How this will happen remains however uncertain and is dependent on how the technology is incorporated into the societal system of automobility (Marletto 2019: 228). So do Fraedrich, Beiker, and Lenz (2015) discuss three complementary scenarios on how automated driving could develop, including a change from personal car ownership to a more platform service-based personal transportation usage. This Mobility as a service is in EU policy documents discussed as an innovative business model based on CCAM (Commission 2021a: 14, 20) (Commission 2017: 21). Alonso Raposo et al. (2021) discuss the 10 sectors which will be most affected economically by CCAM including the automotive, telecommunication, transport, medical, electronics and software sectors but also the insurance industry which shows the wide effects of CCAM. How this will come to be remains uncertain. What however can be noted is that new actors will become involved with the transport market like traffic data providers, the telecom service industry, and original equipment manufacturers related to ITS. Hence the market in digital data in traffic will likely grow because of the data-rich environment created with the CCAM system (Abdelkader, Elgazzar, and Khamis 2021: 2). Market practices will therefore change, but how this will be remains uncertain based on its incorporation in the mobility system as discussed by Marletto (2019) and the actual penetration rate of CAV as discussed by Sharma and Zheng (2021). This penetration rate as discussed by Alonso Raposo et al. (2021: 3) will also depend on user acceptance of the technology.

This will also be the case for user practices. If business models on personal transportation change, this also will change how users make use of them (Alonso Raposo et al. 2021; Fraedrich, Beiker, and Lenz 2015). The biggest effect CCAM will have on user practices is the fact that these are not required to drive them. The social practice theory holds that a specific social practice is built on three elements: the material element on which the social practice is based, the meaning which is given towards the social practice, and the competencies necessary to do the practice. A change in one of the three elements affects the social practice as a whole (Shove, Watson, and Spurling 2015). An example of such a study for automobility is the effect of the electrification of cars on the social practice of driving as discussed by Ryghaug and Toftaker (2014). Due to changes in the material element, which in this case is the vehicle, the competencies necessary are also altered. This in turn could enhance accessibility, by making CCAM available to travelers without a driver's license like children, disabled people, and elderly (Sharma and Zheng 2021: 11, 12).

Cultural and symbolic meaning

All discussed in the previous section will have an effect on how the automobile and its usage in society are culturally viewed and understood. So could CCAM lead to a decrease in personal car possession (Marletto 2019: 222). Driving a vehicle that is personal property is likely having a different symbolic meaning than making usage of a service as motivated by the change in attitude towards car usage based on the electrification of vehicles identified by Ryghaug and Toftaker (2014). Such a similar effect could in this case also happen. Since the role of the driver as a controller shifts towards a more passive passenger role with CCAM, these can spend time on other things during traveling (Commission 2018: 3). This could affect the symbolic meaning of being in a car from a means of travelling to a moving working spot. Since CCAM is based on the usage and collection of data which could be personal, it could also be viewed as a privacy liability if the regulatory frameworks required are not functioning (Sharma and Zheng 2021: 17). A similar thing could be said about security if examples occur of CCAM being hacked.

The cultural and symbolic meaning of CCAM could also be altered based on the potential benefits it could have. So does Commission (2021a: 32) state that "It aims to exploit the full systemic benefits of new mobility solutions enabled by CCAM: increased safety, reduced environmental impacts, and inclusiveness". The inclusiveness of CCAM as Alonso Raposo et al. (2021: 1) discuss is in the fact that it would allow "underserved users like aging populations, people with mobility impairments and people without a driving license to access new mobility options". The statement from the European Commission (2021a: 32) inherently contains the viewpoint that the current situation is unsafe, unsustainable, and not inclusive and that with CCAM it will become (more), safe, sustainable, and inclusive thus showing a change in cultural and symbolic meaning. CCAM could also lead to a new conception of values like freedom. As discussed by Sager (2006: 469, 70), freedom and mobility have become interlinked in the last decades. The personal autonomy experienced by car users to on their terms travel from point A to B might due to CCAM and accompanying business models change, and be experienced as a limitation of their autonomy and therefore their freedom. Even though CCAM could lead to more inclusiveness, increasing the autonomy and freedom of certain groups, it could limit the experienced freedom of others therefore requiring a new conception of freedom in the field of personal mobility.

Fuel and charging infrastructure

CCAM in essence will not change the fuel and charging infrastructure required. However, as discussed CCAM and zero-emission vehicles are expected to go hand in hand. This will require alterations to the fuel infrastructure related to 'refuelling' like the electric grid and fuel stations (Marletto 2019: 227). Besides that, based on the infrastructural CCAM system components discussed earlier C-ITS technologies have to be implemented.

Production system and industry structure

CCAM will disrupt industries and markets and will due to the integration of connective data exchange and automated mobility both the technological requirements for infrastructure and the vehicle change. As discussed by Commission (2017: 21) the increased connectivity will have severe effects on the whole automotive value chain. This is further discussed by Commission (2017: 26-30) in which the value chain stretches "from suppliers of raw materials, basic components, and materials, to manufacturers of parts, service providers, vehicle manufacturers, dealers and the aftermarket sector." Due to changes to the vehicle and infrastructure, new materials and production processes are required. CCAM will require new skills and changes in the workforce because of increased digitalization and the involvement of AI and machine learning (Sharma and Zheng 2021: 16). So does Alonso Raposo et al. (2021: 13) stress the workforce evolution associated with CCAM. The production system and industry structure for vehicles and infrastructure will also be changed because of the involvement of new market entrants like original equipment manufacturers from the hard and software markets and established actors which were not involved with transport before like Telecom companies (Commission 2017: 6) (Marletto 2019: 225).

Maintenance and distribution networks

CCAM as discussed will require new skills and changes in the workforce for vehicles which affects how personnel is trained for maintenance and repairing but also on aspects like addressing cyber security (Commission 2017: 22, 30, 31). Since road infrastructure becomes more digitalized, it also has different requirements for maintenance than conventional infrastructure which might not be required anymore at all (Alonso Raposo et al. 2021: 12). This therefore will likely affect how road management is conducted. Since CAV are expected to become safer, it can be assumed that these require less reparation (Alonso Raposo et al. 2021: 12). The earlier discussed changes in markets and business models also affect how repair shops and dealerships operate based on sales and ownerships (Alonso Raposo et al. 2021: 12).

4.2 Sub-question 2: What is the governance of CCAM in the EU?

The governance of CCAM in the EU starts in the 1980s with the PROMETHEUS project. PROMETHEUS short for "Programme for a European traffic with highest efficiency and unprecedented safety", which ran from 1987-1994 can be seen as the first major European effort on CCAM. Funding for this R&D project was provided by EUREKA, a pan-European organisation founded in 1985 involving the EC and member states, aiming to foster competitiveness and market integration by financing joint European research and development projects. The PROMETHEUS project involved a broad range of stakeholders like research institutes, automotive industry, electronics industry, traffic engineers, and traffic authorities from different European countries (EUREKA n.d.-a) (Festag 2014: 166) (Zlocki et al. 2019: 4; EUREKA n.d.-b) (Maurer 2016: 4). The research output of PROMETHEUS already made use of autonomous driving based on visual guidance involving digital machine vision, which is still the main method used today (Kröger 2016: 59, 60). These first-generation prototypes were however far from market selection but provided valuable input on further developments by being precursors for modern driver assistance systems (Zlocki et al. 2019: 4) (Kröger 2016: 59, 60).

In 1992 the EC published the white paper: *The future development of the common transport policy* with the under title *A global approach to the construction of a Community framework for sustainable mobility*. In the white paper, EC states the need to strengthen EU transport by realising a more integrated and intermodal transport network because of a growth of transport. However, this growth was unevenly spread on different transport modes, with most occurring via road or rail which put pressure on these infrastructures (Commission 1992: 6, 7). This in turn would lead to other negative effects like congestion, pollution, and accidents (Commission 1992: 7,8,9). Henceforth investments in transport had to occur to make the transport system more efficient and accessible. Amongst other measures the white paper discusses the need for a coherent transport R&D approach that finds cooperation with other EU R&D organizations like the discussed EUREKA (Commission 1992: 71). The period after this was therefore followed by many R&D projects which focussed upon enabling technologies for CCAM like sensors, positioning, and localization technologies but also on communication and connectivity which were triggered by the availability of GPS and Wi-Fi (Zlocki et al. 2019: 10) (Festag 2014: 166) (Leinmuller and Mittal 2019: 169). Many of these projects were funded by the EC which recognized the potential benefits of such technologies, under the European Fifth Framework Programme (FP5), Sixth Framework Programme (FP6), Seventh Framework Programme (FP7), and the Competitiveness and Innovation Framework Programme (CIP) (Festag 2014: 1) (Leinmuller and Mittal 2019: 169) (Zlocki et al. 2019: 9-12) (Kotsi, Mitsakis, and Psonis 2020: 2-5) (Meng et al. 2018: 2, 3). Examples of such projects are Safespot, COOPERS, and CVIS which all focussed upon different C-ITS applications and were conducted across and by member states in consortia of stakeholders, like ERTICO (Safespot n.d.; McDonald 2008; CVISproject n.d.; Commission n.d.-b).

In 2001 the EC published the white paper *European transport policy for 2010: time to decide*. It discusses that even though efforts were put in to integrate and harmonize the EU transport network with the 1992 white paper, more needed to occur. So was there still an uneven growth between different transport modes, with road transport being the dominant method. This was viewed as undesirable because of the accompanying congestion, and the negative external effects of road transport on the environment, public health, and deaths occurring because of accidents. Traffic congestion was starting to threaten the competitiveness of the European economy (Commission 2001: 7). To address the problems the white paper discusses a wide range of instruments focussing on further integrating different modes of transport by taking away barriers between different member states, and therefore increasing the interoperability of the transport system. To achieve this the white paper discusses innovations like C-ITS to focus upon in funding programmes because of their promises to optimize road transport and henceforth decrease congestion and the accompanying negative external effects (Commission 2001: 119-22).

In 2008 the EC with the ITS Action Plan (COM (2008) 886) recognized that ITS applications were taken up slower than expected in a fragmented and uncoordinated order. This led to a broad range of different national, regional, and local solutions without harmonization, which would be undesirable for the EU Single Market based on the required continuity of service (Commission 2008: 4) (Commission n.d.-c). Therefore, consultations with public sector representatives, industry, and other stakeholders like road operators were conducted which resulted in priority areas to be further addressed with specific actions and periods. These action areas aimed to create interoperability, cooperation between stakeholders, solve privacy and liability issues, continuity of traffic management services, and traffic safety (Commission 2008: 9). Interoperability in the context of CCAM means that data exchange should uniformly take place across borders, transport modes, generations, brands, and manufacturers which ensure that there is a so-called continuity of service (Commission 2016a: 9) (Platform 2017: 98) (Commission 2018: 13) (Commission 2021a: 28). In general, this intends that CCAM should be able to function across all 27 EU member states based on the Single Market. Central in this was the view that ITS should be treated as a means and not an end. To address these priority areas the preferred policy option for the EC was to concentrate on enabling actions and applications to in an indirect manner coordinate and support the deployment and development of ITS with a Committee consisting of member state representatives and the addition of an advisory group consisting of industry representatives (Commission 2008). The motivation of the EC behind this was that it will be the most effective "in particular regarding cooperation and the potential to speed up agreements on particular issues hampering ITS deployment and to bring about harmonised deployment of ITS throughout Europe" (Commission 2008: 62).

To provide a legal base for these actions the EC preferred to use a directive. This would allow for recognizing the different levels of ITS usage and deployment while also leaving the EC with the power and responsibility in cooperation with the ITS Committee of member states to define technical details required to support the implementation of the directive (Commission 2008: 6). Therefore, the action plan also contained the proposal for DIRECTIVE 2010/40/EU: *on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport.* To further support this in 2009 the EC with Mandate m/453 for C-ITS standardisation gave European standardization organizations ETSI, CEN, and CENELEC the mandate to analyse, identify, and create the requirements for European standards of and for C-ITS communication (Commission 2021a, 2009).

In 2010 the aforementioned directive was adopted by the European Parliament and the Council of the European Union based on the ordinary legislative procedure. This directive defined four priority areas that had to be addressed:

- The first priority area addresses the optimization of road, traffic, and travel data usage
- The second priority area addresses the continuity of service for traffic and freight management ITS
- The third priority area addresses road safety and security ITS applications
- The fourth priority addresses the linkage between the vehicle and transport infrastructure

In the directive, the necessity of innovative measures to deal with increasing congestion and rising energy consumption as a result of EU economic growth and the mobility requirements of citizens were discussed as motivators (Commission 2010). The directive provided the Commission with the legal capacity "to adopt the specifications necessary to ensure the compatibility, interoperability and continuity for the deployment and operational use of ITS for the priority actions" (Commission 2010: 2) (Commission 2021a: 133, 34). The directive since then has been supplemented with delegated acts on road safety, traffic information, legal, and technical frameworks to ensure interoperability of services (Platform 2017: 8) (Commission 2021a). The directive states that member states should take the necessary measures to meet the requirements set by the Commission on the priority areas and that they should report their process to the Commission based on self-declaration (Commission 2010) (Commission 2019) (Commission n.d.-d).

In 2011 the Amsterdam Group was created. The goal of this strategic alliance was to facilitate information exchanges between stakeholders involved in the field of C-ITS by clearing barriers for deployment and facilitating dialogue on deployment results (Group n.d.). The Amsterdam Group consists of the Car2Car Consortium of industry actors, CEDR which is the European organisation for national road administrations, ASECAP which is the European association of toll road operators, and POLIS which is the European cities and regions network (Botte et al. 2019: 3) (Car n.d.-b). Testing on C-ITS also continued. So was DRIVE C2X a testing project funded with FP7 and coordinated by Daimler which aimed to create a reference for cooperative driving in Europe by bringing together seven national test sites to create a harmonized testing environment and system of C-ITS in which it was successful (C2X 2015). Also, in 2011 the EC published the white paper: *Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system*. In this white paper vision zero is discussed, which aims to lower the amount of traffic-related deaths and injuries. Driver assistance systems and cooperative systems were discussed as technologies to further deploy to achieve this (Commission 2011: 21).

In 2014 the EC making usage of the directive created the platform for the deployment of Cooperative Intelligent Transport Systems in the European Union (C-ITS Platform) which is an expert group consisting of member states, C-ITS value chain stakeholders like public authorities, vehicle manufacturers, suppliers, service providers, and telecom companies. This deployment platform aimed to create a common vision amongst stakeholders and to provide policy recommendations for the Commission for later deployment of C-ITS in the EU (Commission n.d. ; Kotsi, Mitsakis, and Psonis 2020) (Platform 2017). So were deployment efforts set up across member states like the C-ITS Corridor and Nordic way which are respectively focussed upon the motorway corridor from Rotterdam via Frankfurt am Main to Vienna (C-ITS Corridor) and the Nordic region (Nordic Way) (Car n.d.-b) (NordicWay n.d.; Kotski, Mitsakis, and Tzanis 2020: 5). In these projects mostly was focussed upon the exchange of information which can be used to enhance foresighted driving and therefore awareness (Sjoberg et al. 2017: 91; Car n.d.-a). Also in 2014, the SAE published its earlier mentioned 6 levels of automation (SAE 2021b). In 2015 the EC adopted the *Digital Single Market strategy*, which “aims to make this transformation work for people and businesses, while helping to achieve its target of a climate-neutral Europe by 2050.” Part of this strategy is to make Europe the most connected continent by 2030. Central in this is to break down barriers for cross-border online activity by harmonizing rules for connectivity services like 5G, which as discussed could be used for V2X communication on which CCAM is based (Commission n.d.-a; Eurostat 2018; Commission 2015). To encourage collaboration between the telecom and automotive industry on the usage of 5G for connectivity in automobility, the EC facilitated round-table meetings. These resulted in the creation of the European Automotive-Telecom Alliance and the 5G Automotive Alliance (5GAA), both of which are collaborative efforts of actors from both the automotive and telecom industries (Commission 2017: 42) (ACEA 2016) (5GAA n.d.; EATA n.d.).

With the Declaration of Amsterdam of 2016, EU transport ministers urged the EC to develop a shared European strategy on CCAM to facilitate, in coordination with member states and industry, the deployment of an interoperable system based on continuity of service and to maximize the output of public and private efforts to grasp the societal benefits of such systems (Commission 2016a: 3) (Commission 2018: 6) (ministers 2016). Therefore later in 2016, based on the outcomes and recommendations of the first phase of the C-ITS Platform and after the urgence of the ministers for coordination, the Commission prepared and created *A European Strategy on Cooperative Intelligent Transport Systems (C-ITS)* which aims for cooperative, connected and automated mobility (CCAM) in the European Union (Commission 2016a). This strategy aimed to serve as an overarching framework and developed a centralized EU-wide platform to converge the different efforts and investments undertaken to facilitate international cooperation on open road testing of C-ITS and to link up with pre-deployment activities on regulatory legal frameworks on privacy and security and the harmonization of security and communication standards (Commission 2021a: 5) (Commission 2016a: 3) (Commission 2018: 6) (ministers 2016). To link and coordinate the diffused deployment projects, the C-ROADS initiative was set up in 2016 by the EC and member states to work together and share knowledge from a learning doing based approach making usage of Horizon 2020 funding (Commission 2016a: 10) (Commission 2021a: 156) (Botte et al. 2019: 2, 9). The earlier discussed C-ITS Corridor initiative for example under C-ROADS was linked with other C-ITS corridor projects from Belgium, France, and the UK (Zlocki et al. 2019: 11). Most of these member state conducted projects took place on and beyond the Trans European Transport Network, which is an initiative aimed to close gaps, remove bottlenecks and to take away technical barriers on European infrastructure in the broadest sense (Commission 2017: 42; n.d.-f). In the European Space Strategy, the usage of satellite navigation systems like Galileo and EGNOS are discussed to further support connected automated driving (Commission 2016b: 3).

In 2017 the EC adopted the Strategic Transport Research and Innovation Agenda (STRIA) (Alonso Raposo et al. 2021: 2). In this agenda seven priority areas were identified related to innovations in transport, of which many can be understood as being linked to CCAM.

1. Cooperative, connected and automated transport
2. Transport electrification
3. Vehicle design and manufacturing
4. Low-emission alternative energy for transport
5. Network and traffic management systems
6. Smart mobility and services
7. Infrastructure

(Commission n.d.-e).

In September 2017 the C-ITS Platform released its final report in which is stated that all members of the platform "believe that the ultimate goal is the full convergence of all developments under Cooperative, Connected and Automated Mobility (CCAM) (Platform 2017: 8). This was followed in October 2017 by the GEAR 2030 report released by the EC which is aimed to ensure that the EU has the most innovative, competitive and sustainable automotive industry of the 2030s and beyond. To achieve this the relevance of the automotive industry for the EU is discussed, and developments that are viewed as challenges to be grasped and overcome:

- New technologies and business models
- Climate goals, environmental and health challenges
- Societal changes and changes in the way that consumers access, purchase and use cars
- Globalisation and the rise of new players
- Structural change for the labour market due to zero-emission vehicles and increasingly automated driving

In the report, zero-emission vehicles and automated driving are discussed as technological developments which have transformative potential. The report, which is based on input from the C-ITS platform, underlines the necessity for coordination on the European level to grasp the full benefits of CCAM (Commission 2017: 4) (Commission 2016a: 4).

As a result of this, the EC in May 2018 adopted the communication *On the road to automated mobility: An EU strategy for mobility of the future* in which it using funds from the Connecting Europe

Facility announced its intention to create "one single EU wide platform grouping all relevant public and private stakeholders to coordinate open road testing and making the link with pre-deployment activities" on CCAM (Commission 2018: 9). This previously happened with different projects like CATRE, SCOUT, and ARCADE (ERTRAC 2019: 23).

In June 2019 the Single Platform for Open Road Testing and Pre-Deployment of Cooperative, Connected, Automated and Autonomous Mobility was set up by the EC based on its intention to create one single wide EU platform. This CCAM Platform consisted of representatives of stakeholder groups like member states, EU institutions, industry, users, regional authorities, and research organizations and was aimed at providing advice and support to the EC (Commission 2021a: 32, 84). Also, in 2019 the EC released a report in which an evaluation was made of how member states acted upon the implementation of Directive 2010/40/EU, and its delegated regulations on the set priority areas. The conclusions are drawn that most member states make good progress with the implementation of C-ITS, but that "this work would certainly benefit from better coordination, involving all member states and covering all specifications, to federate all these efforts towards a harmonised ITS digital infrastructure across the EU" (Commission, 2019, p. 15).

In 2020 the EU's road safety framework for 2021-2030 was published. In this document is discussed that technological innovations like connectivity and automation have the potential to contribute to 'Vision Zero', which is the goal to have zero fatalities and serious injuries by 2050 on European roads (Commission and Transport 2020: 7). This vision zero is further elaborated upon in the resolution on this framework by the European Parliament in which is focussed upon three components: safe vehicles, safe infrastructure, and safe road use. In this document is discussed that the EU should continue working on CCAM, but that attention is required for the expected mixed traffic situation and safety for vulnerable road users like cyclists and pedestrians. Besides that it highlighted that road infrastructure might be required to be upgraded (Parliament 2022).

The Covid-19 pandemic had significant effects on European mobility as discussed in the *Strategy for Sustainable and Smart Mobility* published by the EC in December 2020. This strategy expresses the vision that mobility and transport are central to EU society, and that it brings benefits but also produces negative external effects. The most challenging of these are the reduction of emissions and accompanying sustainability. The document states that "a coordinated European approach to connectivity and transport activity are essential to overcome any crisis" (Commission 2020: 1). To achieve this the focus should be on "greening mobility" and digitalization. The effects of these measures should be inclusive to all by ensuring affordability and accessibility. Therefore a fundamental transformation is required (Commission 2020: 1,2). Besides that it discusses the importance of multimodality for a resilient transport system (Commission 2020: 7). The strategy also recognizes that the pandemic has reinforced changes in mobility patterns and consumer behaviour due to an increase of digitalization in daily lives like teleworking (Commission 2020: 8). CCAM and C-ITS are discussed as instruments to achieve such a mobility system (Commission 2020: 13). In April 2021 the European Climate Infrastructure and Environment Executive Agency took over the programmes on CCAM which earlier were conducted under the Connecting Europe Facility like the C-ROADS initiative (Commission and INEA n.d.). The CCAM Platform released its final report in September 2021 in which its pre-deployment activities were summarized. It was concluded that the outcomes could be deepened and discussed the under Horizon-funded CCAM Partnership as its successor.

The goal of the CCAM Partnership ongoing partnership set up in June 2021 between industry (automotive, telecommunications, ICT, insurance, maintenance), research, mobility providers, civil society, local and regional governments, national ministries, and road authorities is to create a more user-centred and inclusive mobility system, to increase road safety, to reduce congestion and to reduce the environmental impact. This has to be achieved via a collaborative effort at the European level to remove barriers and contribute to the acceptance and efficient deployment of automation technologies and services (Partnership n.d.-c). To do so the efforts of the CCAM partnership are structured around 7 interlinked clusters:

- Large-scale demonstrations of technologies via pilot projects or living labs
- Vehicle technologies based on automation or communication
- Validation of CCAM systems
- The integration of the vehicle into the transport system based on connectivity and communication
- Key enabling technologies like AI, Big Data, and cyber security
- Societal aspects and user needs
- Coordination to exchange knowledge and learn lessons

The different clusters all come together in the main actions of the CCAM Partnership which are large-scale demonstrations with pilots and living labs to achieve the deployment readiness of CCAM. The actions of the CCAM Partnership are focussing on three phases. The first phase from 2021 to 2024 is aimed at “developing the building blocks”. The second phase from 2025 to 2027 aims at further developing the technological maturity of the technologies involved in CCAM. The third phase from 2028 to 2030 aims to have trails in living labs all over Europe (Partnership n.d.-c, n.d.-b, n.d.-a)

In October 2021 a study on the “Future of the EU Automotive Sector” was published after request by the European Parliament. In this study is discussed that European carmakers jointly are working on vehicle automation (Blumenthal and Csernatoni 2022) (Brown et al. 2021). The study discusses how the EU automotive sector can be leading in the twin green and digital transition (Brown et al. 2021: 23). Also in that month, the EC organized a workshop on a common European mobility data space. The goal of this data space is “to accelerate the digital transformation of the European transport sector and to fully reap the benefits of data for the sector and for society at large”(Commission, E4, and B4 2021: 2). The EC “will therefore support the development of an architecture and common design principles, building blocks and tools to support the convergence of governance and infrastructure” (Commission, E4, and B4 2021: 2). During the workshop a presentation was given in which was discussed that the digital transformation depends on data availability, access, and exchange. The Mobility Data Space therefore aims to provide EU regulations on the data market (Commission 2021b: 22). This could be seen as relevant for CCAM due to the data exchange involved.

On the 6th of July 2022, the Vehicle Safety Regulation came into force. This regulation was adopted by the European Parliament and the Council of the European Union after a proposal made by the EC. In this regulation is discussed that certain advanced driver assistance become mandatory for new vehicles. The regulation, based on UN rules, provides the Commission with the power to adopt the legal framework to approve automated vehicles of level 3 and higher for the Single Market. Therefore it will cover components like testing procedures, cyber security, and data recording rules (Commission 2022b, 2022a; Parliament and Union 2022).

4.2.1 Discussion

The identified governance of CCAM in the EU is an ongoing process that started in the 1980s with the PROMETHEUS project until The Vehicle Safety Regulation of 2022. In the decades after PROMETHEUS, many governance actions and instruments in the public, private, or joint domains were taken and used leading up to now. Where the output of the PROMETHEUS project was still in a clear R&D phase, the Single Market in 2022 with The Vehicle Safety Regulation opened up for vehicles with autonomous driving capabilities in which the driver does not require to be hands-on all the time (Commission 2018: 3). This shows the developmental process on CCAM which occurred throughout the decades. Efforts on CCAM specifically have only been happening in the last couple of years, but its deployment and developmental processes as discussed have been going on much longer due to the integrated approach taken (Commission 2016a: 3). The decision to focus on CCAM is a deliberate choice made by a wide variety of stakeholders, which therefore shows it is widely supported (Platform 2017: 8). To achieve this coordination is viewed as key. Besides that standardization, harmonization, and convergence efforts can be identified (Commission 2008: 4)

(Commission n.d.-c; Commission, E4, and B4 2021: 2). It must be noted that in the governance of CCAM many different R&D projects were identified, which could not all be discussed. A distribution of these can be found in Zlocki et al. (2019) and Kotski, Mitsakis, and Tzanis (2020).

4.3 Sub-question 3: Which roles does the European Commission play in the governance of CCAM in the EU?

PROMETHEUS, Safespot, COOPERS, and CVIS

The PROMETHEUS project involved stakeholders from different industries, research institutes, and traffic engineers and authorities from different European countries. It was based on R&D via a collaborative partnership effort. EUREKA, involving both EC and member states, provided funding aiming to foster EU innovation and competitiveness. Besides the project aimed at efficient and safe transport as indicated by the name of the project. Agents driving change are the EC and member states by providing funding via Eureka, which is their instrument used so that the PROMETHEUS partnership could conduct their R&D project. Hence the actors involved in PROMETHEUS are agents as well, with their instruments of change being their shared expertise and collaborative effort leading to the research output on CCAM. The opportunity structure, therefore, is based on the potential benefits of CCAM to foster innovation and competitiveness in the EU and the promises of efficient and safe transport. The legitimacy involved, therefore, are the broad benefits for EU society. The same things can be said about the Safespot, COOPERS, and CVIS projects with the main difference being the larger quantity in which R&D projects were conducted via the different framework programmes.

ITS Action Plan, Directive 2010/40/EU and evaluation

With the ITS Action Plan in 2008, the EC recognized that the slow, fragmented, and uncoordinated uptake of ITS could endanger the Single Market. Due to the formal role of the EC in the Single Market, it took action. Consultations with ITS stakeholders were conducted to identify priority areas that required further elaboration. Instead of a strong top-down role, the EC decided to in an indirect manner coordinate and support deployment and development by focussing on enabling actions and applications, since it holds the belief that this would be the most effective. To provide a legal base for this a directive was adopted by the European Parliament and the Council of the European Union. In the directive, a strong formal responsibility was given to member states, since these should take the necessary measures to meet the requirements set by the EC and also were required to report their progress to the EC based on self-declaration. Hence it can be seen as a clear example of the principle of subsidiarity in practice, which states that action should be taken at the lowest level of governance if this is the most effective, even though it is based on formal roles which point in the direction of a hierarchy (Benz 2007b: 6, 7). Industry was involved in this in an informal advisory role. When the progress of member states was evaluated in 2019, it was concluded that most member states make good progress with the implementation of the priority areas set but that more coordination would still be beneficial.

It can be argued that this is based on governance innovation (Kuhlmann, Stegmaier, and Konrad 2019). In the EU context, these are open consultations, networked agencies and the OMC (Sabel and Zeitlin 2010). By having conducted consultations with ITS stakeholders, the EC used governance innovation. Besides, it can be argued that the formal interaction between EC and member states is based on the OMC. On the EU level common guidelines were created which member states have to comply with. Due to the involvement of self-reporting and the lack of legal sanctions when these were not achieved it can be argued that this is based on the OMC. So, the main agent driving change in this is the EC, which gave formal responsibilities to the member states which therefore also are agents. The instrument of change in this is the directive since it puts responsibilities on the member states to comply with its priority areas. The EC viewed this to be the most effective. To do so, usage was made of the OMC. The legitimacy involved is based on the protection of the Single Market to gain the full benefits of ITS. To do so the EC took action based on its formal role in it, which is its opportunity structure. Therefore, similar things can be said about Mandate m/453 for C-ITS standardisation.

Amsterdam Group

The Amsterdam Group is a strategic alliance between public and private stakeholders, to share knowledge and to take away barriers for C-ITS deployment by facilitating dialogue. Agents driving change are the Car2Car Consortium of industry actors, CEDR which is the European organisation for national road administrations, ASECAP which is the European association of toll road operators, and POLIS which is the European cities and regions network. The opportunity structure is based on the policy framework created by the EC, and the role and expertise of these actors. Therefore, the main instruments are the willingness to collaborate and their relevant expertise to support the deployment and integration of C-ITS in the EU mobility system. Due to the informal nature of the Group in the formal system of governance, legitimacy is not of main concern in the formal sense. However, by aiming to gain the full benefits of C-ITS, it intends to generate full societal benefits.

The future development of the common transport policy, European transport policy for 2010: time to decide, Roadmap to a Single European Transport Area and the Digital Single Market Strategy

These four policy documents released by the EC are aimed to strengthen the European Single Market by taking away barriers and to further integrate different modes of transport, or to facilitate data exchange so that this could happen. In these, the role of technology is discussed as a possible instrument to address these. This becomes most apparent with the Roadmap to a Single European Transport Area in which the Commission expressed the vision to create a competitive, resource efficient, and safe transport system based on a Single European Transport Area. Driver assistance systems and cooperative systems were discussed as instruments to contribute to this. The driver of change in these is the Commission, which by expressing its vision with the publication of the white papers (the instrument) provided directions for its future policy on which member states and industry could position themselves. It is legitimized by the formal role of the Commission in the Single Market.

European Automotive-Telecom Alliance and the 5G Automotive Alliance (5GAA)

To foster collaboration between the car and telecom industries because of the envisioned usage of 5G in CCAM and broader connectivity in transport, the EC facilitated round-table meetings. These resulted in the creation of two network organizations, the EATA and the 5GAA consisting of stakeholders from both industries. The main agent governing change in this is the EC which by using its role of keeper of the Single Market (instrumentation) brought together relevant industries to protect this Single Market and obtain the benefits of 5G in automotive connectivity (legitimacy). Both network organizations are also agents driving change due to their expertise and willingness to cooperate to maximize the output of CCAM and 5G connectivity.

C-ITS Platform

The C-ITS Platform was an expert group created by the EC in 2014 to provide policy recommendations for the deployment of CCAM. It consisted of member states and C-ITS value chain stakeholders like public authorities, vehicle manufacturers, suppliers, service providers, and telecom companies. To create it the Commission used its legal powers based on the directive. Hence the C-ITS Platform requires to be viewed in the context of this directive, meaning that it was intended to provide advice on the priority areas set and to protect the Single Market while obtaining the benefits of CCAM. The main agent driving change is the EC, which used its legal powers to achieve the aforementioned goals by letting itself be informed by an expert group.

Declaration of Amsterdam

With the declaration of Amsterdam, European transport ministers urged the EC to develop an overarching strategy on C-ITS in consultation and coordination with member states and industry to gain the full benefits of such systems by ensuring continuity of service. Following this the Commission using the C-ITS Platform created *A European Strategy on Cooperative Intelligent Transport Systems* which aims for CCAM. This strategy served as an overarching framework from which deployment, testing, harmonization, and standardization efforts were conducted. To coordinate and link the previously diffused deployment and testing projects, C-Roads was created by both the EC and member states. Hence diffused projects like the C-ITS Corridor (Rotterdam, Frankfurt, Vienna) and Nordic Way (Nordic region) were linked in this broader overarching framework to share knowledge and to foster learning. It was funded by the EC via Horizon 2020 funding. What is interesting in this is the bottom-up interaction central. Where member states with the aforementioned directive gave the EC the mandate to act to ensure continuity of service, these now called up the Commission to take more action and to coordinate more. In the context of the potential agent-principal problem between member states and EC due to the OMC, this can be seen as peculiar and shows that the relationship is not based on an object and a subject but can be reciprocal. So, the main agents driving change are the transport ministers. Their main instruments are their shared expertise and experience based on which they understood that more coordination was required to ensure continuity of service, which at the same time are also the opportunity structure and legitimacy. By doing so the Commission took action, making it an agent as well, based on its legal powers due to the directive.

Strategic Transport Research and Innovation Agenda, On the road to automated mobility: An EU strategy for mobility of the future, the GEAR 2030 report, and the Common Mobility Data Space workshop

These three documents were all published by the EC. Hence this is the main agent involved with change. The opportunity structure was the protection of the Single Market and competitiveness by focussing on innovations like CCAM which could provide benefits for EU society and the role of the Commission in this. By publishing and adopting these documents the EC created its intentions on what the change should be aiming for, how this ought to be achieved, and why. Coordination was an important pillar. Hence it provided clarity for industry and member states so these could adapt to it. Besides that, the EC made itself accountable by publishing these. The Commission took a similar role by hosting a workshop on the Common Mobility Data Space, in which it expressed its intentions on regulating the data market and therefore the connective data exchange involved with CCAM.

CCAM Platform and CCAM Partnership

Based on the intention to coordinate the deployment of CCAM, the EC created the Single Platform for Open Road Testing and Pre-Deployment of Cooperative, Connected, Automated and Autonomous Mobility. Better known as the CCAM Platform, this expert group had the goal to provide the Commission with advice on how to approach pre-deployment of CCAM. The CCAM Platform was funded by the Commission with funds from the Connecting Europe Facility and consisted of stakeholders like member states, EU institutions, industry, users, regional authorities, and research organizations. The CCAM Platform was eventually succeeded by the CCAM Partnership. The CCAM Partnership, which is still ongoing, was co-funded by the EC. Where the CCAM Platform focussed on pre-deployment, the CCAM Partnership focusses on deployment activities via a learning-based approach by sharing knowledge to identify and break down barriers. The EC can in both be seen as the main agent driving change in these governance constellations by shaping the circumstances in which these can operate by providing funding and setting the overarching framework based on the directive and the requirements of coordination and continuity of service. The other stakeholders involved in both the Platform and Partnership therefore in this context to provide the Commission with advice. Even though both are based on the regulatory framework shaped by the Commission, there is no hierarchical nor market dynamic visible.

Resolution on EU's road safety framework for 2021-2030: Strategy for Sustainable and Smart Mobility, and the "Future of the EU Automotive Sector" study

The European Parliament also was involved with driving change as identified. So did it come with a resolution on the aforementioned Strategy for Sustainable and Smart Mobility by the EC, and did it request a study on the future of the EU Automotive Sector. The role of the European Parliament in the governance is limited, although it did adopt the directive which provided the EC with the mandate to act. By adopting the resolution and requesting the study it made efforts to shape and influence the governance of CCAM by providing reflection and insights, even though it did not have a legal role besides adopting the directive and its delegated regulations.

The Vehicle Safety Regulation

The European Parliament and the Council of the European Union adopted this regulation after a proposal by the EC. The main actor driving change, therefore, is the EC which acted based upon its mandate granted by the directive. After the adaptation of the Regulation, level 3 and higher automated vehicles would be allowed on roads in the Single Market. Besides that, does it describe under which conditions this would be. Hence the Commission used its legal powers to ensure the competitiveness of the Single Market and the potential benefits of CCAM.

4.3.1 Discussion

When assessing the identified governance, it can be argued that the main agent driving socio-technical change is the European Commission. Based on the mandate granted to it by the European Parliament and the Council of the European Union, better to be understood as the member states, it therefore had a legitimate role to ensure that the Single Market is protected by aiming for continuity of service and that the full public and private benefits of CCAM would be gained. As discussed, these goals were widely shared amongst relevant stakeholders, and based on the specific governance context of the Single Market the EC is the agent to act upon this based on its opportunities and capabilities. In this it used different instruments like providing funding, facilitating dialogue between stakeholders to create consensus, informing other stakeholders about the to-be-taken course, letting itself be informed by experts, and shaping the circumstances in which industry and member states can deploy CCAM. Overall the governance identified can be seen as based on flat interactions, even though there is a hierarchy based on the directive. Maggetti (2015) makes a distinction between 'hard' and 'soft' governance, with the first one being based on traditional binding methods of EU governance like the community method and the ordinary legislative procedure and the latter one being based on new modes of governance which are non-binding like the OMC. As discussed, the directive was based on the OMC and therefore binding and a form of 'hard' governance. However, in its functioning, it is very non-binding because of the lack of clear deadlines set for member states and sanctions in the case these were not met. This was identified as the OMC, which as discussed is a method used to coordinate policy based on mutual learning between actors involved and the identification of best practices. Throughout the governance this can be identified, with many of the initiatives focussing on learning, sharing knowledge, and bringing down barriers for CCAM. Hence it can be argued that the governance of CCAM involves governance innovation as discussed by Kuhlmann, Stegmaier, and Konrad (2019) because the OMC is used as an instrument. Based on the four modes of governance of Borrás and Edler (2020) the primus inter pares seems to be the most fitting for this case since it is driven by state actors and even though there is a formal distribution of power this is in practice very horizontal. However, this formal power distribution is there and is based on formal rules and regulations. Hence the command and control mode also seems to apply. Therefore, it is argued that in practice it is a hybrid of the primus inter pares and command and control modes.

4.3.2 Roles of the European Commission

This section intends to define the roles of the EC based on the previous section which could conclude that the governance mode by Borrás and Edler (2020) of the governance of CCAM is a hybrid of primus inter pares and command and control. In these modes, the state takes different roles according to Borrás and Edler (2020: 6). So is it facilitating, initiating, promoting, moderating, guaranteeing, enabling social engagement, and acting as lead-user and watchdog.

- The EC acts as facilitator in the governance of CCAM by supporting initiatives of other agents involved to make the process of socio-technical change easier. Examples of these in the governance are the different funding provisions by the EC and the round table meetings conducted with the automotive and telecommunication industries. But most importantly the EC was facilitating by creating the overarching regulatory framework and conditions in which the efforts towards socio-technical change by the other agents should occur.
- Whether the EC is lead user of CCAM is a matter of perspective based on the technological system, however it can be seen as initiating market creation. The EC is aiming to ensure the competitiveness and harmonization of the Single Market while maximizing the public and private outputs of CCAM. Besides, Docherty, Marsden, and Anable (2018: 117) discuss twelve reasons why state involvement is required in transport governance, which therefore legitimizes the change and role the EC takes in this.
- The EC acts as initiator in the case of CCAM, since it in the 1980s already identified the potential benefits of systems like CCAM by providing funding for the PROMETHEUS project. Since then, this has not been changed based on the other examples of funding provided by the EC, and the facilitating role it played.
- The EC acts as promoter of socio-technical change by actively discussing the necessity of the CCAM system and motivations and benefits in its policy documents.
- By facilitating round table meetings, and by letting itself be informed by expert groups (e.g., C-ITS Platform) the EC is actively involving other stakeholders and therefore acts as enabler of social engagement.
- How far the EC acts as moderator between different political positions on CCAM is unclear. However, it can be seen as aiming to get all stakeholders on the same line as indicated by the previous roles. This especially comes apparent with the ITS Action Plan.
- By providing a regulatory framework on CCAM based on both connective data exchange and automated vehicles, the EC acts as guarantor by securing operations against safety and security issues of CCAM.

- The EC also acts as watchdog, by ensuring that other stakeholders act by collectively defined norms based on the creation of standards for C-ITS communication, the regulatory legal framework of CCAM, and the conditions set by the Single Market.

These are the roles identified based on the hybrid governance arrangement of primus inter pares and command and control, but it must be noted that these are ideal models. So could the EC potentially act as observer, warner, opportunist, gatekeeper, and mitigator. It can however be argued that the EC does not act as an observer, since it takes an active role instead of waiting and seeing what happens. Next to that the EC also does not act as a gatekeeper since it does not actively control access for other actors as indicated by initiatives like the Amsterdam Group and the functioning of CCAM which falls outside of its direct scope of influence, even though it limited access with regards to providing funding. Also, it does not act as a warner, since it is actively aiming to minimize the potential hazards of CCAM by taking these into account in its regulatory framework. Therefore it also does not act as a mitigator since it is actively trying to prevent negative effects of the socio-technical change from happening by coordinating this. Borrás and Edler (2020) discuss the opportunist role as taking up the opportunity from arising socio-technical change. However, this is not happening in this case since the EC actively supports the process of socio-technical change based on its potential. Henceforth it is not taking up opportunities arising, but aiming to make its potential come through.

4.4 Sub-question 4: What is the socio-technical context in which the governance of CCAM is embedded?

4.4.1 MLP analysis

What can be identified is that niche developments are putting pressure on the regime. These are technologies part of CCAM like Automated Driver Assistance Systems and the accompanying developments of AI and machine learning, improvements in telecommunications and ICT, ITS developments in sensorial and locational technologies, and an overall increased connectivity (Kröger 2016: 42) (Commission 2008: 5) (Commission 2011: 22, 23) (Platform 2017: 19) (Commission 2015: 9) (ministers 2016: 3) (Commission 2017: 8,9,19) (Commission 2021a: 17, 18) (Commission 2016a: 3). Accompanying these technological developments are changes in business models and mobility services which could be disruptive towards the current mobility system like MaaS (Commission 2016a: 2) (Commission 2017: 8, 9) (Commission 2018: 2) (Commission 2021a: 13). These niche developments can be closely linked to landscape developments. So are two main technological developments happening on the macro-economic level the so-called twin digital and green revolutions towards the global market is changing (Commission 2020: 26). Due to changes on the global market, e.g. the rise of new players like China and an overall increase of globalization, the EU is at risk of lagging since growth is stagnating (Commission 2017: 8,9,19). For the EU and its industry to stay competitive on the global economy in terms of its mobility and transport ecosystem and to maintain at the top of the automotive market, which it has the ambition to do so, innovation is required (Commission, E4, and B4 2021: 6) (Commission 2017: 19) (Commission 2021a: 15) (Commission 2018: 3) (Commission, E4, and B4 2021: 6). Mobility and transport and the automotive industry are key for EU society and the functioning of its internal market, for the freedom of its citizens to travel but also for economic growth and job creation and employment (Commission 2011: 4) (Commission 2017: 7). Hence it can be argued that these macro-economic developments are pressuring the regime to change. Based on the landscape forces involved and their linkages with niche technologies the governance regime in the EU opted to deploy CCAM, which shows the window of opportunity.

However, that is not all of what is happening and influencing the governance of CCAM. As discussed the EU decided to take an instrumental approach towards CCAM (Commission 2008: 9). Hence CCAM can be placed in a broader EU perspective related to other challenges and developments requiring to be addressed. These can be viewed in the context of minimizing social costs based on the negative external effects of road transport and mobility. A landscape development mentioned earlier is the green revolution, which is based on minimizing the effects of global warming and climate change. This means the global efforts to reduce emissions of greenhouse gasses produced by transport and mobility (Commission 2021a: 13). This is formalized with the Paris Accords of 2015, in which the need to decarbonize was highlighted (Commission 2017: 35). The EU internally set the goal in the Green Deal to have cut the emission of greenhouse gasses from transport and mobility in 2050 with 90% (Commission, E4, and B4 2021: 19) (Commission, E4, and B4 2021: 6). To achieve this the need to cut fossil fuels, and therefore to decrease oil dependence, can therefore be identified in the governance of CCAM as putting pressure on regime actors. So are both zero-emission vehicles and CCAM specifically identified as promising innovations to focus upon as indicated by the GEAR 2030 report of Commission (2017). Due to the promises of CCAM to make transport and mobility more efficient, this is expected to lead to a more energy-efficient mobility system with fewer emissions and pollution which likely also will have a positive effect on the health of EU citizens and lower social costs (Commission 2011: 4) (Commission 2021a: 15). Climate change and the need to make transport and mobility more sustainable therefore is a landscape development influencing the governance of CCAM.

The technological promises of CCAM can also be linked to other landscape developments. Because of economic growth and changing mobility preferences of citizens road pressure has increased (Commission 2010: 1). This leads to traffic congestion, which brings negative external costs because road capacity is insufficient to handle all traffic (Metz 2018: 494). This therefore leads to a stagnation of traffic flow, causing delays and longer travel times which negatively affects travel comfort (Metz 2018; Hensher and Bliemer 2014; Mondschein and Taylor 2017; van Woensel and Cruz 2009) (Meng et al. 2018: 2; Zlocki et al. 2019). This not only leads to an unoptimized emission of greenhouse gasses and other pollution, negatively affecting both sustainability and public health, but also has a strong economic dimension since transport and mobility are of vital importance for the competitiveness of the EU Single Market and industry (Commission 2011: 4) (Commission 1992, 2001). With traffic congestion supply chains can be derailed and transport costs increased. Traffic congestion also increases the chance of traffic accidents to occur (Mondschein and Taylor 2017: 65; Council 2020; van Woensel and Cruz 2009; Van Meerkerk, Verrips, and Hilbers 2015). In the EU there was a stagnating trend in terms of road safety, with more accidents and road fatalities occurring as a result of this (Platform 2017: 19). As a result of this Vision Zero, the ambition to have zero road fatalities in 2050, was defined. This was linked to the economic goals by displaying the ambition to have the EU be world leader in safe and secure transport (Commission 2011: 11) (Commission 2021a: 13). Since CCAM could minimize human error and promises to optimize traffic flow, CCAM was decided to focus upon in the governance identified based on the occurrence of a window were landscape and niche developments meet (Commission 2018: 9) (Parliament and Union 2022: 5). These landscape developments are therefore disruptive by nature since they force change.

Other landscape developments occurring are a growing accessibility gap between centre and peripheral regions and a changing population due to aging (ministers 2016: 3) (Commission 2011: 4,5,13) (Commission 2021a: 15). Therefore, there is a growing demand for a socially inclusive, fair and multimodal transport and mobility system. Due to the growing accessibility gap specific areas are becoming increasingly difficult to be reached with public transport modes, while an aging population is expected to go hand in hand with a decrease in driving abled population (Leinmuller and Mittal 2019: 161). CCAM is viewed to support such a mobility system since it does not require to be driven, which serves elder and disabled persons, and the overall connectivity involved could link it to other mobility options creating a connective intermodal network of mobility options (Commission 2020: 3) (Commission 2021a: 15) (ERTRAC 2019: 45). The Covid pandemic has further shown the necessity for such a system (Commission 2020: 22). Not only did this limit the freedom of EU citizens, but also showed the importance of a well-functioning and resilient transport and mobility system and its importance for the EU economy and industry and its jobs and competitiveness (Brown et al. 2021: 6, 23) (Commission, E4, and B4 2021: 19). Connectivity and transport of vital importance for the functioning of the Single Market, which is highlighted by the Covid pandemic (Commission 2020: 1).

4.4.2 TEF analysis

Based on the MLP analysis in the previous section it can be concluded that the governance of CCAM is based on complex dynamics involving simultaneous niche and landscape forces that put pressure on the regime. Since these niche and landscape forces are complementary to one another windows of opportunity are opened which the social regime actors involved in the governance of CCAM are acting upon. What can be noted is that the effects of traffic congestion and the need for an intermodal transport system and the potential for technology to address these were already discussed by Commission (1992). Hence it can be concluded that the governance of CCAM should be viewed as one narrative. When structuring this based on the TEF it can be concluded that both the socio-political and economic environments are very much integrated and also affecting another. So are landscape developments both socio-political and economic of nature, which shows that these are intertwined. Global developments based on sustainability, climate change, increased digitalization, and overall globalization put pressure on the EU economy to innovate and invest to ensure its competitiveness. This can be closely linked to the socio-political environment in the EU involving increased traffic congestion, accidents, and fatalities, an increasing accessibility gap, and a changing demand for mobility services due to an elder population. As was identified connectivity and transport are two key dimensions for the functioning of the Single Market, however, these would be negatively affected by the discussed socio-political factors which further reinforces the need to invest and innovate. To address these issues and to protect the Single Market it was decided by a wide variety of stakeholders to focus on digital innovation in the transport and mobility and automotive domains leading up to Connected, Connective, and Automated Mobility.

Due to the system requirements of CCAM and the Single Market context continuity of service is required. Fragmentation would therefore be problematic for the Single Market since it undermines this continuity of service and because of the effects CCAM could have on the value chain and job security of EU industry (ministers 2016: 3) (Commission 2008: 25) (Commission 2017: 49). Harmonization and coordination at the EU level between EC, member states, industry, and other stakeholders is therefore vital to take away barriers, which is where the Single Market is built on, but also to address new problems which could arise on security, privacy, liability, data usage, ethics, public support and the expected period of co-existence (ministers 2016: 3; Commission 2017: 49). A policy area which can be seen as similar of that of CCAM is on telecommunications. Both are digital systems that require interoperable data exchange based on compatible infrastructure to obtain the required continuity of service for the Single Market. So do Cave, Genakos, and Valletti (2019: 51) discuss that harmonization and further integration of the European market between the EU member states are the two main challenges in this, which is similar in the situation of CCAM. However, CCAM in contrast requires a more sophisticated governance and regulatory framework because of the linkage involved between connectivity and automated mobility.

Egan (2016: 259) discusses that technical harmonization and standardization are at the core of the European Single Market, which is not intrinsic to CCAM based on the example of telecommunications. So, in that sense, it can be claimed that the overarching regime practice is the further European integration by strengthening the Single Market. This can be seen from two different perspectives. CCAM is viewed as an instrument to strengthen the Single Market based on the connectivity involved, which due to the connections made leads to more integration, and the competitiveness value it could bring to this because of its promises. On the other hand, more integration is required to ensure that CCAM can function in the Single Market because of the Single Market by harmonization, standardization, and taking away barriers. Besides that can CCAM be connected to other EU projects like the deployment of 5G, which could be used for CCAM, the Digital Single Market, which regulates the data exchange involved with CCAM, and the Single European Transport Area which aims to eliminate barriers between different modes of transport and national systems to create a European intermodal mobility and transport system (Commission 2011: 10) (Commission 2015: 3) (Commission 2011: 10). So, in that sense it is a self-reinforcing process, as also indicated by the Single Market Acts published by the EC in 2011 and 2012 which amongst other things focus on transport (Cini and Pérez-Solórzano Borragán 2016: 418). CCAM as a system therefore is part of other EU infrastructural systems. In the book *Europe's Infrastructure Transition* by Høgselius, Kaijser, and van der Vleuten (2015) a discussion is made on the development of different systems of European infrastructure and which role these played in the process of European integration. The authors argue that by creating new infrastructures and connections the groups behind these had a strong impact on the current practices, economics, and politics of Europe (Høgselius, Kaijser, and van der Vleuten 2015: 315). Besides that, the authors were also able to conclude that infrastructures are often interlinked, based on vertical connections, and have become internationalized which means that these are going beyond national borders via so-called horizontal connections (Høgselius, Kaijser, and van der Vleuten 2015: 356). As discussed CCAM goes beyond national borders and is linked to and based on different infrastructural systems meaning that it can be placed in the broader narrative presented by Høgselius, Kaijser, and van der Vleuten (2015).

When linking the governance of CCAM with the developmental process of the Single Market, it can be argued that both are heavily intertwined. The PROMETHEUS Project was set up in 1987, which was in a period in which the idea to remove trade barriers amongst EU countries and thereby creating an internal market was established. PROMETHEUS was funded by EUREKA, founded in 1985, which aimed to foster competitiveness and market integration amongst EU countries. Market integration and the removal of trade barriers are closely intertwined, which therefore provide indications to the socio-political and economic zeitgeist in which the first efforts on CCAM and the "Single Market Project" are embedded (Phinnemore 2016: 19). This is further indicated with the Schengen Treaty which was, even though outside of the EU framework, established in 1985 amongst the Benelux countries, France and West-Germany intended to create a community free of border controls amongst their internal borders (Lelieveldt and Princen 2015: 104) (Ucarer 2016: 283) (Cini and Pérez-Solórzano Borragán 2016: 417). In the scope of the EU framework, the Single European Act was adopted in 1986 which introduced different competencies and instruments to increase the economic and social cohesion between member states by removing non-tariff barriers. The deadline for the completion of this Single Market was set on the 31st of December 1992 by the SEA and the 1992 Programme (Lelieveldt and Princen 2015: 16) (Phinnemore 2016: 19) (Hooghe and Marks 2001: 1). The 1992 Programme was the Commission's programme and timetable for the implementation of the Single Market (Egan 2016: 261). Also in 1992, the EC published the white paper *The future development of the common transport policy* which can be seen as the start of an overarching EU policy on CCAM. This timing in 1992 provides another indication for the socio-political context in which the governance of CCAM is embedded regarding the development of the Single Market. The process of European integration continued with the Maastricht Treaty of 1991, which amongst other things introduced the principle of subsidiarity, and the treaty of Amsterdam of 1997 which introduced the Schengen Treaty into the EU framework (Phinnemore 2016: 20-25) (Cini and Pérez-Solórzano Borragán 2016: 417) (Ucarer 2016: 286).

The linkage between CCAM and European integration can again be shown with the "Lisbon Strategy" which aimed at improving the economic power of the EU by turning it into the global leader in knowledge-based economy in terms of competitiveness and dynamisms (Zeitlin 2005: 1) (Egan 2016: 264). The governance of CCAM was defined as based on learning, sharing knowledge, and bringing down barriers for the functioning CCAM, involving the OMC. And the OMC is a result of the "Lisbon Strategy". Even though CCAM was not first incentivized based on environmental policy, but on traffic efficiency and road safety as indicated by Commission (1992), this throughout the governance identified started to play a more prominent role. Environmental policy has not been one of the main policy areas in which the EU operated before 1993. Even though the Commission adopted several Environmental Action Programmes, the fifth adopted in 1993 represented a shift in focus. So did the fifth introduce the notion of sustainable development and explored novel manners of environmental policy integration. This environmental policy integration intends to integrate an environmental dimension in new policy areas, like transport, agriculture, and energy. All these sectors produce greenhouse gas emissions, which required strong intersectional cooperation and coordination to address which led to a cross-sectoral policy integration in which different policy areas were linked (Benson and Jordan 2016: 325-33). The governance of CCAM has a strong environmental dimension based on this environmental policy integration. Based on the MLP analysis this was identified as a landscape development, but it therefore also is an intrinsic part of the socio-political and economic context in which the governance of CCAM is embedded. Since the governance of CCAM was identified as based on the OMC, governance innovation is henceforth central in the practices and cognitive framework of the regime which because of the "Lisbon Strategy" and its connection with the single market can therefore be linked towards the process of European integration. This TEF analysis therefore strengthens the argument that the identified process of European integration is the overarching regime practice in the governance of CCAM.

5. Conclusion

5.1 Conclusion

This thesis addressed the research question “How could CCAM change the socio-technical system for land-based road transportation in the EU, what are the roles of the European Commission in the governance of this, and how can these roles be explained based on their embeddedness in their socio-technical context?”. Foremost this research question intended to contribute to the research agenda of Borrás and Edler (2020) on the roles of the state in the governance of socio-technical change, by taking a more embedded approach than their framework by including the broader socio-technical context and the material and digital conditions of the socio-technical system. This was done by using the MLP and TEF perspectives which were intended to account for this broader explanatory context the governance of CCAM in the EU is embedded based on the socio-technical governance perspective taken. Besides, it was intended by addressing this research question to present a comprehensive socio-technical perspective on the transformative effects of CCAM in the EU context which goes beyond the identified main perspectives on business models or the technological physical and digital components of the system.

To address this research question usage was made of four sub-questions, which intended to measure different components of the main research question. The first sub-question addressed the transformative potential of CCAM on the socio-technical system for land-based transportation in the EU, by studying how this could affect different components of the socio-technical system. Based on this can be concluded that CCAM would have strong transformative effects on many parts of the EU. Not only would it lead to material changes in the vehicle and the broader system of automobility, but also would require a more sophisticated governance and regulatory framework because of the linkage involved between connectivity and automated mobility. Examples of this are involved with data exchange and data handling and the overarching question of responsibility, the standardization of roadside infrastructures, and the potential business models with which CCAM could be deployed like mobility as a service and the whole socio-institutional and technological framework surrounding this. CCAM is required to function in diverse ODD contexts, which all require a type of governance. The second sub-question focussed on the governance of CCAM in the EU context, which was identified based on a literature review following the analytic perspective of Borrás and Edler (2014b). It was identified that the governance of CCAM started in the 1980s and is still occurring. The intention behind it is to deploy an interoperable system of Connected, Connected, Automotive Mobility (CCAM) across the European Union. This vision is motivated by the promises that CCAM will contribute to European society by leading to improved road safety, increased efficiency of road transport, reduced emissions, improved accessibility, and ensuring the competitiveness of the EU industry. In this CCAM is treated as an instrument to achieve other ends. The vision is based on two main components, automated driving, and connected driving. In essence, both are independent technological systems, but public and private stakeholders in the EU decided to take an integrated approach since they hold the belief that "cooperation, connectivity, and automation are not only complementary technologies, they reinforce each other and will over time merge completely" (Commission 2016a: 3). Interoperability in the context of CCAM means that data exchange should uniformly take place across borders, transport modes, generations, brands, and manufacturers which ensures that there is a so-called continuity of service. This intends that CCAM should be able to function across all 27 EU member states due to the Single Market. The Society of Automotive Engineers expects that fully automated vehicles will become available on the European market in 2030, but before this fully diffuses will take time (Commission 2018: 3). Therefore, a transition period is expected of multiple decades in which there is a mixed traffic situation with co-existence between CAV and conventional vehicles. This has been going on for the past decades and involves different stakeholders like the EC, member states, and the car and telecommunications industries. The third sub-question analysed the governance of CCAM with the framework of Borrás and Edler (2014b) to identify the roles of the EC as the state in this. It was concluded that the EC as the state acts as initiator, promoter, enabler of social engagement, moderator, guarantor, and watchdog based on the identified hybrid governance mode of primus inter pares and command and control. In the governance of CCAM the OMC was identified to be an instrument often deployed. Hence the governance of CCAM is an example of governance innovation as discussed by Kuhlmann, Stegmaier, and Konrad (2019). The fourth sub-question then intended to define the socio-technical context in which the governance of CCAM, and therefore these roles, are embedded in making usage of the MLP and TEF based on the analytic approach taken. With the MLP analysis was identified that the process of European integration by strengthening the Single Market was the overarching regime practice in the governance of CCAM. The TEF analysis strengthened this argument based on the socio-political and economic environments the governance of CCAM and therefore the roles of the EC as the state are embedded The findings of the sub-questions have to be integrated to provide an answer to the main research question.

When assessing the roles of the EC based on the MLP and TEF analyses and the involvement of the material conditions of CCAM in line with the research question and used analytic framework, it can be concluded that these roles can be explained because of the material and digital requirements of the CCAM system and the Single Market based on the need for continuity of service to obtain the full benefits of the CCAM system with regards to the discussed socio-political and economic environments. To do so a strong top-down method of governance based on hierarchical relations would not be beneficial (command and control), but letting it be self-regulated by the market or by a few strong industry actors (oligopoly) would also be counter-productive because of the expected lack of coordination involved with this. Therefore, a balance between strong regulation and more collaborative efforts was required to achieve this based on the identified hybrid governance mode. To obtain this the EC had to foster the innovation process and accompanying market development of CCAM. To do so it required the knowledge, technical capabilities, and necessary investments of member states and industry which needed to be aligned, coordinated, and enforced to obtain the fullest synergy and benefits. Hence the EC acts as initiator, to foster market development and innovation in order to gain full benefits of CCAM because of the broader socio-technical context and the material and digital conditions of CCAM. Promoter because of the instrumental approach the EC takes towards CCAM to address these issues. To achieve this, it required the knowledge and capabilities of other actors, for which it had to enable social engagement. To ensure that these other actors could conduct their efforts as part of the governance of CCAM the EC had to provide the overarching regulatory framework to minimize risks (guarantor) and to enforce these (watchdog). Before this could happen, it had to align different positions on the governance of CCAM and to act as moderator based on its position in the Single Market. These roles can be placed in the broader process of European integration which was identified as overarching regime practice, in which both the socio-political and economic environments can be placed with the main example being the policy integration involved with environmental policy. This becomes apparent because of the material and digital conditions of the CCAM system and the Single Market which require interoperability and continuity of service. As discussed, the Single Market is based on technical harmonization and standardization, which summarizes both the socio-political and economic environments. Henceforth a harmonized and interoperable market environment is to be created via the instruments used and the roles taken by the EC as the state, which leads to a governance paradigm focussing on European integration. Traditional governance mechanisms would be unsuited to achieve these aims, which therefore shows the relevance of governance innovation based on its prevalence in this case.

5.2 Limitations and critical reflection

Borrás and Edler (2020) called for research that takes a more embedded approach on the roles of the state in the governance of socio-technical change. To contribute to this, this thesis took a broader socio-technical perspective by including the MLP and TEF to account for the broader socio-technical context the governance is embedded in and the material conditions of the socio-technical system. This approach was defined as a socio-technical governance perspective. A first observation this thesis makes is that the state takes more diverse roles in the governance of socio-technical change than the dichotomy of correcting market and system failures, or creating these. Henceforth it can be seen as contributing to the research agenda of Borrás and Edler (2020) by affirming their observation. However, this thesis intended to go beyond their framework by not merely identifying and describing these roles as the authors did, but to provide the broader socio-technical context these roles are embedded in and the material conditions of the socio-technical system as extra explanatory factors.

Based on its conclusions drawn, it can be argued that the socio-technical governance approach taken by this thesis presents a framework that could be used to enhance the embedded understanding of the roles of the state in the governance of socio-technical change. When assessing the findings of sub-question 3, which follows the framework of Borrás and Edler (2020), individually than it can be concluded that these are less in-depth in comparison when sub-question 4, the MLP and TEF analyses, is added. By having involved this broader socio-technical perspective, the more complex dynamics in the context in which governance is embedded become apparent leading to a deeper understanding of how and why the roles of the state are what they are and why. Regarding the ideal modes of governance used by Borrás and Edler (2020) and the identified hybrid mode between primus inter pares and command and control for the case, it can be argued that when studying governance more reflection on the possible hybrid forms of governance in line with the “composite” governance regime of Benz (2007b) and the tentative governance and governance innovation of Kuhlmann, Stegmaier, and Konrad (2019).

The main challenge for this thesis was to integrate frameworks that fitted both the PA and the PSTS programs and to structure these around a technological system. That this would be based on the governance of socio-technical change and involve a form of C-ITS was known in an early phase of the process. Regarding the C-ITS many changes had occurred. Where first was started by focusing on the discussed C-ITS Corridor it was becoming apparent that this had to be seen as part of the broader CCAM development and the context and framework in which this was embedded in the EU. This change can be seen as a strong expansion of the case under study which also increased the complexity of the research due to earlier written parts becoming irrelevant, or less relevant, based on the technological system central and the context in which this occurred. To continue first a reorganization of information and understanding had to occur before it could be continued. By taking such a qualitative approach certain limitations can be identified. Yu, Jannasch-Pennell, and Digangi (2011: 736) state that reliability for qualitative research is based on consistency and replicability. By being transparent which steps were taken and which epistemic choices were made this thesis aims to account for the reliability of the results based on the consistency of methods and replicability of these. By haven taken a sceptic and reflective mindset toward the data during analysis it was aimed to minimize the risk of researcher bias (Babbie 2013: 410). However, these are mostly based from a general perspective on such an approach. When applying this to the perspective taken in this thesis certain limitations can be identified. Difficulty was found in the broad approach toward the governance of socio-technical change taken by Borrás and Edler (2014b). Following this, a vast collection of literature consisting of a diverse range of sources was analysed. However, structuring these led to problems concerning the trade-off between validity and comprehensibility in digesting the main narrative in the broad collection of sources that represent the governance of CCAM. Besides, does the inclusion of the MLP and the TEF in explaining the roles not define a direct causal relationship but merely the broader socio-technical context in which these are embedded, which was important to keep note of during the research. By being aware of these threats towards validity and reliability, and by describing the methods used for the Atlas TI programme, which was not the most efficient in analysing, it was intended to take care of these.

5.3 Recommendations

This thesis can make multiple recommendations for policy-making and future research. Its findings and the approach taken might be most suitable from a policy analysis perspective. By analysing governance processes as part of a broader socio-technical context, the meaning and understanding of instruments used in these processes might therefore be expanded. This will provide enhanced reflection for policy analysis in science and policymaking alike, for example based on the governance innovation concept, which could enhance the reflectivity of actors involved with such practices on the roles and actions prevailing in governance. Where this thesis focussed on the supranational EU level, further research could focus on lower levels of governance and the roles of “the state” in this. So could a comparative study be made on how different member states approach the socio-technical governance of CCAM in the context of the overarching framework shaped by the EC, and how this can be explained in under their socio-technical and institutional contexts while taking into account the hybrid governance modes. The framework of Borrás and Edler (2020) and their broad perception of the state allows for this. Based on the identified transformative effects of CCAM multiple recommendations for further research could be identified. What would for example the effect be of CCAM on the social practice of using an automobile? How can CCAM for example be best integrated into the local context of a smart city following Brcic et al. (2018) and which roles should the state take in this to achieve this? This brings many questions and challenges which can be elaborated upon, both from a governance or socio-technical perspective.

Bibliography

5GAA. n.d. 'ABOUT 5GAA'. https://5gaa.org/about-5gaa/about-us/.

Abdelkader, Ghadeer, Khalid Elgazzar, and Alaa Khamis. 2021. 'Connected Vehicles: Technology Review, State of the Art, Challenges and Opportunities', *Sensors*, 21: 7712.

ACE. n.d. 'Systems Integration and Compatibility '. https://aceproject.org/main/english/et/etd01e.htm.

ACEA. 2016. '37 leading companies join forces in European Automotive-Telecom Alliance'. https://www.acea.auto/press-release/37-leading-companies-join-forces-in-european-automotive-telecom-alliance/.

Alonso Raposo, María, Monica Grosso, Andromachi Mourtzouchou, Jette Krause, Amandine Duboz, and Biagio Ciuffo. 2021. 'Economic implications of a connected and automated mobility in Europe', *Research in Transportation Economics*: 101072.

Amditis, Angelos, Panagiotis Lytrivis, Evdokia Papanikolaou, Anna Carreras, and Xavier Daura. 2019. "Road infrastructure taxonomy for connected and automated driving." In *Cooperative Intelligent Transport Systems: Towards high-level automated driving*, 309-25. Institution of Engineering and Technology.

Babbie, Earl. 2013. *The Practice of Social Research* (Cengage Learning Wadsworth).

Benson, David, and Andrew Jordan. 2016. 'Environmental Policy.' in Michelle Cini and Nieves Pérez-Solórzano Borragán (eds.), *European Union Politics* (Oxford University Press: Oxford).

Benz, Arthur. 2007a. 'Accountable Multilevel Governance by the Open Method of Coordination?', *European Law Journal*, 13: 505-22.

———. 2007b. 'Governance in Connected Arenas – Political Science Analysis of Coordination and Control in Complex Rule Systems.' in D. Jansen (ed.), *New Forms of Governance in Research Organizations,* (Springer Dordrecht).

Blumenthal, Marjory, and Raluca Csernatoni. 2022. 'Computers on Wheels: Automated Vehicles and Cybersecurity Risks in Europe', Accessed 06-10. https://carnegieeurope.eu/2022/03/24/computers-on-wheels-automated-vehicles-and-cybersecurity-risks-in-europe-pub-86678.

Bodenheimer, M. 2018. *Beyond Technology: Towards Sustainabiliy Through Behavioral Transitions*

Working Papers "Sustainability and Innovation" (Fraunhofer ISI).

Bohm, Martin. 2019. "Deployment of C-ITS: a review of global initiatives." In *Cooperative Intelligent Transport Systems: Towards high-level automated driving*, 21-40. Institution of Engineering and Technology.

Borrás, Susana, and Jakob Edler. 2014a. 'Chapter 1: Introduction: on governance, systems and change.' in, *The Governance of Socio-Technical Systems: Explaining Change* (Edward Elgar Publishing).

———. 2014b. 'Chapter 2: The governance of change in socio-technical and innovation systems: three pillars for a conceptual framework.' in, *The Governance of Socio-Technical Systems: Explaining Change* (Edward Elgar Publishing).

———. 2020. 'The roles of the state in the governance of socio-technical systems' transformation', *Research Policy*, 49: 103971.

Botte, Marilisa, Luigi Pariota, Luca D'Acierno, and Gennaro Nicola Bifulco. 2019. 'An Overview of Cooperative Driving in the European Union: Policies and Practices', 8: 1-25.

Brcic, Davor, Marko Slavulj, Dino Šojat, and Julijan Jurak. 2018. "The Role of Smart Mobility in Smart Cities." In *Fifth International Conference on Road and Rail Infrastructure*, 1601-06.

Brown, David, Michael Flickenschild, Caio Mazzi, Alessandro Gasparotti, Zinovia Panagiotidou, Juna Dingemanse, and Stefan Bratzel. 2021. "The Future of the EU Automotive Sector." In. Luxembourg: European Parliament

C2X, DRIVE. 2015. 'DRIVE C2X The European reference for cooperative driving', Accessed 30-06. https://www.eucar.be/wp-content/uploads/2015/01/DRIVE-C2X.pdf.

Car, Car 2. n.d.-a. '2020 roadmap'. https://www.car-2-car.org/about-c-its/.
———. n.d.-b. 'About C-ITS'. https://www.car-2-car.org/about-c-its/.
Cave, Martin, Christos Genakos, and Tommaso Valletti. 2019. 'The European Framework for Regulating Telecommunications: A 25-year Appraisal', *Review of Industrial Organization*, 55: 47-62.
Chan, Ching-Yao. 2017. 'Advancements, prospects, and impacts of automated driving systems', *International Journal of Transportation Science and Technology*, 6: 208-16.
Cini, Michelle, and Nieves Pérez-Solórzano Borragán. 2016. *European Union Politics* (Oxford University Press: Oxford).
Commission, European. 1992. *The future development of the common transport policy : A global approach to the construction of a Community framework for sustainable mobility* (Publications Office).
———. 2001. "White Paper European transport policy for 2010: time to decide " In. Brussels
———. 2008. "Action Plan for the Deployment of Intelligent Transport Systems in Europe and the Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL laying down the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other transport modes." In. Brussels
———. 2009. "STANDARDISATION MANDATE ADDRESSED TO CEN, CENELEC AND ETSI IN THE FIELD OF INFORMATION AND COMMUNICATION TECHNOLOGIES TO SUPPORT THE INTEROPERABILITY OF CO-OPERATIVE SYSTEMS FOR INTELLIGENT TRANSPORT IN THE EUROPEAN COMMUNITY." In.
———. 2010. "DIRECTIVE 2010/40/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport." In.
———. 2011. "Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system " In.
———. 2015. "A Digital Single Market Strategy for Europe." In.
———. 2016a. "A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility." In. Brussels
———. 2016b. "Space Strategy for Europe." In.
———. 2017. "Gear 2023." In.
———. 2018. "COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS: On the road to automated mobility: An EU strategy for mobility of the future." In.
———. 2019. 'Implementation of Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport '. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52019DC0464&from=EN
———. 2020. 'Sustainable and Smart Mobility Strategy – putting European transport on track for the future'. https://eur-lex.europa.eu/resource.html?uri=cellar:5e601657-3b06-11eb-b27b-01aa75ed71a1.0001.02/DOC_1&format=PDF
———. 2021a. "FINAL REPORT OF THE SINGLE PLATFORM FOR OPEN ROAD TESTING AND PRE-DEPLOYMENT OF COOPERATIVE, CONNECTED AND AUTOMATED AND AUTONOMOUS MOBILITY PLATFORM (CCAM Platform)." In.
———. 2021b. "A workshop on a Common European Mobility Data Space." In.
———. 2022a. "NEW RULES ON VEHICLE SAFETY AND AUTOMATED MOBILITY." In.
———. 2022b. 'New rules to improve road safety and enable fully driverless vehicles in the EU'. https://ec.europa.eu/commission/presscorner/detail/en/IP_22_4312.
———. n.d.-a. 'Connectivity'. https://digital-strategy.ec.europa.eu/en/policies/connectivity.
———. n.d.-b. 'Cooperative Vehicle-Infrastructure Systems', Accessed 11-11. https://trimis.ec.europa.eu/project/cooperative-vehicle-infrastructure-systems.

———. n.d.-c. 'Governance and monitoring of the single market', Accessed 14-11. https://single-market-economy.ec.europa.eu/single-market/governance-and-monitoring-single-market_en.
———. n.d.-d. 'Safety-Related Traffic Information (SRTI) & Real-Time Traffic Information (RTTI)', Accessed 07-10. https://transport.ec.europa.eu/transport-themes/intelligent-transport-systems/road/action-plan-and-directive/safety-related-traffic-information-srti-real-time-traffic-information-rtti_en.
———. n.d.-e. 'Strategic Transport Research and Innovation Agenda (STRIA)'. https://research-and-innovation.ec.europa.eu/research-area/transport/stria_en#connectedandautomatedtransport.
———. n.d.-f. 'Trans-European Transport Network (TEN-T)', Accessed 06-10. https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en.
———. n.d. . 'Cooperative, connected and automated mobility (CCAM)'. https://ec.europa.eu/transport/themes/its/c-its_en.
Commission, European, Joint Research Centre, A Ortega-Hortelano, A Tsakalidis, G Haq, F Pekár, M Balen, M Grosso, and K Gkoumas. 2019. *Research and innovation in transport infrastructure in Europe : an assessment based on the Transport Research and Innovation Monitoring and Information System (TRIMIS)* (Publications Office).
Commission, European, CONNECT E4, and MOVE B4. 2021. "Report – Workshop on the common European mobility data space." In.
Commission, European, and INEA. n.d. 'CEF Transport Projects', Accessed 06-10. https://ec.europa.eu/inea/connecting-europe-facility/cef-transport/cef-transport-projects.
Commission, European, and Directorate-General for Mobility Transport. 2020. *Next steps towards 'Vision Zero' : EU road safety policy framework 2021-2030* (Publications Office).
Council, Metropolitan. 2020. "White Paper #1: The Negative Effects of Traffic Congestion on the Twin Cities and the State of Minnesota." In.
CVISproject. n.d. 'Test sites', Accessed 20-06. http://www.cvisproject.org/en/cvis_subprojects/test_sites/index.html.
Docherty, Iain, Greg Marsden, and Jillian Anable. 2018. 'The governance of smart mobility', *Transportation Research Part A: Policy and Practice*, 115: 114-25.
Dokic, Jadranka, Beate Müller, and Gereon Meyer. 2015. *European Roadmap Smart Systems for Automated Driving*.
EATA. n.d. 'About EATA'. https://eata.be/about-us/.
Egan, Michelle 2016. 'The Single Market.' in Michelle Cini and Nieves Pérez-Solórzano Borragán (eds.), *European Union Politics* (Oxford University Press Oxford).
Elliott, David, Walter Keen, and Lei Miao. 2019. 'Recent advances in connected and automated vehicles', *Journal of Traffic and Transportation Engineering (English Edition)*, 6: 109-31.
Erhart, Jacqueline, Manfred Harrer, Stefan Ruehrup, Siegfried Seebacher, and Yannick Wimmer. 2020. *Infrastructure support for automated driving: Further enhancements on the ISAD classes in Austria*.
Ersal, Tulga, Ilya Kolmanovsky, Neda Masoud, Necmiye Ozay, Jeffrey Scruggs, Ram Vasudevan, and Gábor Orosz. 2020. 'Connected and automated road vehicles: state of the art and future challenges', *Vehicle System Dynamics*, 58: 672-704.
ERTRAC. 2019. 'Connected Automated Driving Roadmap'. https://www.ertrac.org/uploads/documentsearch/id57/ERTRAC-CAD-Roadmap-2019.pdf.
EUREKA. n.d.-a. 'About us', Accessed 20-06. https://www.eurekanetwork.org/about-us/eureka.
———. n.d.-b. 'Programme for a european traffic system with highest efficiency and unprecedented safety', Accessed 20-06. https://web.archive.org/web/20180814201633/http://www.eurekanetwork.org/project/id/45.
Eurostat. 2018. '4. WHAT IS THE DIGITAL SINGLE MARKET ABOUT?'. https://ec.europa.eu/eurostat/cache/infographs/ict/bloc-4.html.

Festag, Andreas 2014. 'Cooperative Intelligent Transport Systems Standards in Europe', *IEEE Communications Magazine*.
Fox, W. M. 1995. 'Sociotechnical System Principles and Guidelines: Past and Present', *The Journal of Applied Behavioral Science*, 31: 91-105.
Fraedrich, Eva, Sven Beiker, and Barbara Lenz. 2015. 'Transition pathways to fully automated driving and its implications for the sociotechnical system of automobility', *European Journal of Futures Research*, 3: 3-11.
Frankenfield, Jake. 2020. 'Cloud Computing'. https://www.investopedia.com/terms/c/cloud-computing.asp.
Geels, Frank. 2005a. 'Co-evolution of technology and society: The transition in water supply and personal hygiene in the Netherlands (1850–1930)—a case study in multi-level perspective', *Technology in Society*, 27: 363-97.
———. 2005b. 'The dynamics of transitions in socio-technical systems: A multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930)', *Technology Analysis & Strategic Management*, 17: 445-76.
Geels, Frank W. 2004. 'From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory', *Research Policy*, 33: 897-920.
———. 2007. 'Transformations of Large Technical Systems: A Multilevel Analysis of the Dutch Highway System (1950-2000)', *Science, Technology, & Human Values*, 32: 123-49.
———. 2011. 'The multi-level perspective on sustainability transitions: Responses to seven criticisms', *Environmental Innovation and Societal Transitions*, 1: 24-40.
———. 2012. 'A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies', *Journal of Transport Geography*, 24: 471-82.
———. 2014. 'Reconceptualising the co-evolution of firms-in-industries and their environments: Developing an inter-disciplinary Triple Embeddedness Framework', *Research Policy*, 43: 261-77.
Geels, Frank W., Florian Kern, Gerhard Fuchs, Nele Hinderer, Gregor Kungl, Josephine Mylan, Mario Neukirch, and Sandra Wassermann. 2016. 'The enactment of socio-technical transition pathways: A reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014)', *Research Policy*, 45: 896-913.
Geels, Frank W., and Johan Schot. 2007. 'Typology of sociotechnical transition pathways', *Research Policy*, 36: 399-417.
Gil-Garcia, J. Ramon, Leonardo F. Vivanco, and Luis F. Luna-Reyes. 2014. 'Revisiting the Problem of Technological and Social Determinism: Reflections for Digital Government Scholars', *Innovation and the Public Sector*, Volume 21: Electronic Government and Electronic Participation: 254-63.
Group, Amsterdam. n.d. 'Amsterdam Group'. https://amsterdamgroup.mett.nl/default.aspx.
Hartley, Jean. 2005. 'Innovation in Governance and Public Services: Past and Present', *Public Money & Management*, 25: 27-34.
Hensher, David A., and Michiel C. J. Bliemer. 2014. 'What type of road pricing scheme might appeal to politicians? Viewpoints on the challenge in gaining the citizen and public servant vote by staging reform', *Transportation Research Part A: Policy and Practice*, 61: 227-37.
Høgselius, Per, Arne Kaijser, and Erik van der Vleuten. 2015. *Europe's Infrastructure Transition: Economy, War, Nature* (Palgrave Macmillan UK).
Hooghe, Liesbet, and Gary Marks. 2001. 'Multil-Level Governance in the European Union.' in, *Multi-level Goverance and the European Integration* (Rowman & Littlefield: Oxford).
Horizon, Jean-Francois Bonnefon, David Cerny, John Danaher, Nathalie Devillier, Veronica Johansson, Tatiana Kovacikova, Marieke Martens, Milos Mladenovic, Paula Palade, Nick Reed, Filippo Santoni de Sio, Stavroula Tsinorema, Sandra Wachter, and Karolina Zawieska. 2020. *Ethics of Connected and Automated Vehicles: Recommendations on Road Safety, Privacy, Fairness, Explainability and Responsibility*.

IEEE. 1991. 'IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries', *IEEE Std 610*: 1-217.

Inframix. 2019. 'D.5.4 Infrastructure Classification Scheme'. https://www.inframix.eu/wp-content/uploads/D5.4-Infrastructure-Classification-Scheme.pdf.

Irwin, Terry, and Gideon Kossoff. 2015. "A Concept Diagram: The Role of Design and Designers in Socio-Technical Transitions." In *6th Annual Sustainability Transitions Conference (IST)*. Sussex, UK.

Jako, Zoltan, Adam Knap, Lajos Nagy, and Andras Kovacs. 2019. "Vehicular communication–a technical overview." In *Cooperative Intelligent Transport Systems: Towards high-level automated driving*, 135-59. Institution of Engineering and Technology.

Kotsi, A. A. A., Evangelos Mitsakis, and Vasileios Psonis. 2020. 'C-ITS enabled dynamic traffic management as a service', *CEUR Workshop Proceedings*, 2803: 184-89.

Kotski, Areti, Evangelos Mitsakis, and Dimitris Tzanis. 2020. "Overview of C-ITS Deployment Projects in Europe and USA." In *2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC)*, 1-8. Rhodes.

Kröger, Fabian. 2016. 'Automated Driving in Its Social, Historical and Cultural Contexts.' in Markus Maurer, J. Christian Gerdes, Barbara Lenz and Hermann Winner (eds.), *Autonomous Driving: Technical, Legal and Social Aspects* (Springer Berlin Heidelberg: Berlin, Heidelberg).

Kuhlmann, Stefan, Peter Stegmaier, and Kornelia Konrad. 2019. 'The tentative governance of emerging science and technology—A conceptual introduction', *Research Policy*, 48: 1091-97.

Kungl, Gregor, and Frank W. Geels. 2018. 'Sequence and alignment of external pressures in industry destabilisation: Understanding the downfall of incumbent utilities in the German energy transition (1998–2015)', *Environmental Innovation and Societal Transitions*, 26: 78-100.

Leinmuller, Tim, and Prachi Mittal. 2019. "Connectivity for automated driving: an overview of corresponding R∧ D activities in Europe." In *Cooperative Intelligent Transport Systems: Towards high-level automated driving*, 161-77. Institution of Engineering and Technology.

Lelieveldt, Herman, and Sebastiaan Princen. 2015. *The Politics of The European Union* (Cambridge University Press Cambridge).

Li, L., K. Ota, and M. Dong. 2018. 'Humanlike Driving: Empirical Decision-Making System for Autonomous Vehicles', *IEEE Transactions on Vehicular Technology*, 67: 6814-23.

Llatser, I., T. Michalke, M. Dolgov, F. Wildschütte, and H. Fuchs. 2019. "Cooperative Automated Driving Use Cases for 5G V2X Communication." In *2019 IEEE 2nd 5G World Forum (5GWF)*, 120-25.

Lytrivis, Panagiotis, and Angelos Amditis. 2012. 'Intelligent Transport Systems: Co-Operative Systems (Vehicular Communications).' in, *Wireless Communications and Networks - Recent Advances*.

Lytrivis, Panagiotis, Evdokia Papanikolaou, Angelos J. Amditis, Martin Dirnwöber, Alexander Froetscher, Robert Protzmann, Werner Rom, and Andreas Kerschbaumer. 2018. "Advances in Road Infrastructure, both Physical and Digital, for Mixed Vehicle Traffic Flows." In *7th Transport Research Arena 2019 (TRA 2018)*. Vienna, Austria.

Maggetti, Martino. 2015. 'Hard and Soft Governance.' in Kennet Lynggaard, Ian Manners and Karl Löfgren (eds.), *Research Methods in European Union Studies* (Palgrave Macmillan UK: London).

Marletto, Gerardo. 2019. 'Who will drive the transition to self-driving? A socio-technical analysis of the future impact of automated vehicles', *Technological Forecasting and Social Change*, 139: 221-34.

Maurer, Markus. 2016. 'Introduction.' in Markus Maurer, J. Christian Gerdes, Barbara Lenz and Hermann Winner (eds.), *Autonomous Driving: Technical, Legal and Social Aspects* (Springer Berlin Heidelberg: Berlin, Heidelberg).

McCauley. 2017. 'Why Autonomous and Electric Vehicles Are Inextricably Linked', Accessed 2022. https://www.govtech.com/fs/why-autonomous-and-electric-vehicles-are-inextricably-linked.html.

McDonald, Mike. 2008. "COOPERS Co-operative Networks for Intelligent Road Safety." In.

Meng, Lu, Oktay Turetken, Onat Adalı, Jacint Castells, Robbin Blokpoel, and Paul Grefen. 2018. *C-ITS (Cooperative Intelligent Transport Systems) deployment in Europe-challenges and key findings*.

Metz, David. 2018. 'Tackling urban traffic congestion: The experience of London, Stockholm and Singapore', *Case Studies on Transport Policy*, 6: 494-98.

ministers, European transport. 2016. "Declaration of Amsterdam: Cooperation in the field of connected and automated driving." In.

Mondschein, Andrew, and Brian Taylor. 2017. 'Is traffic congestion overrated? Examining the highly variable effects of congestion on travel and accessibility', *Journal of Transport Geography*, 64: 65-76.

Nitsche, P., I. Mocanu, and M. Reinthaler. 2014. "Requirements on tomorrow's road infrastructure for highly automated driving." In *2014 International Conference on Connected Vehicles and Expo (ICCVE)*, 939-40.

NordicWay. n.d. 'Home '. https://www.nordicway.net/.

Parliament, European. 2022. "European Parliament resolution of 6 October 2021 on the EU Road Safety Policy Framework 2021-2030 — Recommendations on next steps towards 'Vision Zero' (2021/2014(INI))." In, 45-55.

Parliament, European, and Council of the European Union. 2022. "REGULATION (EU) 2019/2144 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL." In.

Partnership, CCAM. n.d.-a. 'Clusters'. https://www.ccam.eu/our-actions/clusters/.

———. n.d.-b. 'SRIA'. https://www.ccam.eu/our-actions/sria/.

———. n.d.-c. 'WHAT IS CCAM ? CCAM Partnership', Accessed 27-06. https://www.ccam.eu/what-is-ccam/ccam-partnership/.

Phinnemore, David. 2016. 'The European Union: Establishment and Development.' in Michelle Cini and Nieves Pérez-Solórzano Borragán (eds.), *European Union Politics* (Oxford University Press Oxford).

Platform, C-ITS. 2017. "C-ITS Platform: Final report Phase II." In.

Provan, Keith G., and Patrick Kenis. 2007. 'Modes of Network Governance: Structure, Management, and Effectiveness', *Journal of Public Administration Research and Theory*, 18: 229-52.

Ryghaug, Marianne, and Marit Toftaker. 2014. 'A Transformative Practice? Meaning, Competence, and Material Aspects of Driving Electric Cars in Norway', *Nature and Culture*, 9: 146-63.

Sabel, Charles, and Jonathan Zeitlin. 2010. *Experimentalist Governance in the European Union: Towards A New Architecture*.

SAE. 2021a. "(R) Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles." In.: SAE.

———. 2021b. 'SAE Levels of Driving Automation™ Refined for Clarity and International Audience'. https://www.sae.org/blog/sae-j3016-update.

Safespot. n.d. 'Consortium', Accessed 20-06. http://www.safespot-eu.org/consortium.html.

Sager, Tore. 2006. 'Freedom as Mobility: Implications of the Distinction between Actual and Potential Travelling', *Mobilities*, 1: 465-88.

Santoni de Sio, Filippo. 2021. 'The European Commission report on ethics of connected and automated vehicles and the future of ethics of transportation', *Ethics and Information Technology*, 23: 713-26.

Schroten, A., Van Grinsven., E. Tol, L. Leestemaker, P.P. Schackmann, D. Vonk-Noordegraaf, J. Van Meijeren, and S. Kalisvaart. 2020. "Research for TRAN Committee – The impact of emerging technologies on the transport system." In. Brussels European Parliament, Policy Department for Structural and Cohesion Policies.

Sharma, Anshuman, and Zuduo Zheng. 2021. 'Connected and Automated Vehicles: Opportunities and Challenges for Transportation Systems, Smart Cities, and Societies.' in.

Shove, Elizabeth, Matt Watson, and Nicola Spurling. 2015. 'Conceptualizing connections: Energy demand, infrastructures and social practices', *European Journal of Social Theory*, 18: 274-87.

Sjoberg, K., P. Andres, T. Buburuzan, and A. Brakemeier. 2017. 'Cooperative Intelligent Transport Systems in Europe: Current Deployment Status and Outlook', *IEEE Vehicular Technology Magazine*, 12: 89-97.
Soteropoulos, Aggelos, Mathias Mitteregger, Martin Berger, and Jakob Zwirchmayr. 2020. 'Automated drivability: Toward an assessment of the spatial deployment of level 4 automated vehicles', *Transportation Research Part A: Policy and Practice*, 136: 64-84.
Ucarer, Emek M. 2016. 'The Area of Freedom, Security, and Justice.' in Michelle Cini and Nieves Pérez-Solórzano Borragán (eds.), *European Union Politics* (Oxford University Press: Oxford).
Van Kersbergen, Kees, and Frans Van Waarden. 2004. ''Governance' as a bridge between disciplines: Cross-disciplinary inspiration regarding shifts in governance and problems of governability, accountability and legitimacy', *European Journal of Political Research*, 43: 143-71.
Van Meerkerk, Jordy, Annemiek Verrips, and Hans Hilbers. 2015. "A Social Cost Benefit Analysis of Road Pricing in the Netherlands." In.
van Woensel, T., and F. R. B. Cruz. 2009. 'A stochastic approach to traffic congestion costs', *Computers & Operations Research*, 36: 1731-39.
Williams, R. 2008. "Completing the picture — the road operator's role in vehicle its solutions." In *IET Road Transport Information and Control - RTIC 2008 and ITS United Kingdom Members' Conference*, 1-7.
Yu, Chong Ho, A. Jannasch-Pennell, and Samuel Digangi. 2011. 'Compatibility between Text Mining and Qualitative Research in the Perspectives of Grounded Theory, Content Analysis, and Reliability', *Qualitative Report*, 16: 730-44.
Zeitlin, Jonathan. 2005. 'Introduction: The Open Method of Coordination in Question'.
Zlocki, Adrian, Dominik Raudzus, Lutz Eckstein, and Lu Meng. 2019. 'ICT-based cooperative ITS: towards automated road transport.' in Lu Meng (ed.), *Cooperative Intelligent Transport Systems: Towards high-level automated driving* (Institution Of Engineering And Technology).

Appendix A: Operationalization of categories for socio-technical system of CCAM

Category	Operationalization
Automobile	The automobile and its functional digital and physical components.
Road and traffic system	All physical and digital infrastructural components related to the functioning and organization of the CCAM and traffic systems.
Regulation and policies	Rules, regulations and policies related to the functioning and the allowance to function of the automobile and the CCAM system on the road and in the traffic system.
Markets and user practices	Organization of supply and demand related to the functioning and usage of the automobile, the connective data exchange, and the practices of users related to these.
Culture and symbolic meaning	How the automobile and the CCAM system and its usage in society is culturally viewed and understood, including the values attached towards it.
Fuel and charging infrastructure	The infrastructure related to the refuelling and recharging of the automobile as part of the CCAM system.
Production system and industry structure	The value chain for the production and assembly of the automobile and physical and digital CCAM infrastructure, and how industries are organized around these practices.
Maintenance and distribution networks	Organization on the maintenance and distribution of digital and physical CCAM system components and how these practices are conducted starting with the personnel conducting these activities.

Appendix B: Socio-technical system analysis

Source	Type of document	Relevant since
Sharma and Zheng (2021)	Book chapter	Chapter from a book on automation in cities. The chapter focusses on the technology central, Connected Automated Vehicles, and the effect on transportation systems, smart cities and societies.
Marletto (2019)	Academic article	Scientific publication in which three socio-technical transition pathways are developed for automated vehicles, hence addressing the transformative potential.
Abdelkader, Elgazzar, and Khamis (2021)	Academic article	Scientific study which reviews Connected vehicles and its core enabling technologies.
ACE (n.d.)	Website	Expandatory source on fundamental requirements for digital systems based on interoperability and compatibility.
Alonso Raposo et al. (2021)	Academic article	Scientific publication in which it is focussed upon the potential economic effects of CCAM in the EU.
Amditis et al. (2019)	Book chapter based the on INFRAMIX EU project	Scientific publication in which a taxonomy is developed for road infrastructure on CCAM, therefore focussing on the technical infrastructural components.
Bohm (2019)	Book chapter	Scientific publication on the general components of C-ITS.
Botte et al. (2019)	Academic article	Scientific publication on the practices and policies on cooperative driving in the EU.
Chan (2017)	Academic article	Scientific publication on the state of the art on the ADS technology.
Commission (2016a)	Policy communication	EU strategy on the coordinated deployment of C-ITS.
Commission (2017)	Policy report	The Gear 2030 report aimed to ensure that Europe has the most innovative automobile industry globally from 2030 and beyond.
Commission (2018)	Policy communication	EU strategy for mobility of the future.
Commission (2021a)	Policy report	Report of the CCAM platform set up by the Commission.
Dokic, Müller, and Meyer (2015)	Roadmap	Roadmap on smart systems developed for automated driving by scholars meant to provide advice to the Commission.
Elliott, Keen, and Miao (2019)	Academic article	Scientific publication on CAV technology.

Erhart et al. (2020)	Conference paper	Paper on the ISAD classes in Austria.
Ersal et al. (2020)	Journal paper	Article discussing the state of the art on connected automated mobility.
ERTRAC (2019)	Roadmap	Roadmap by ERTRAC containing the joint stakeholder view on CCAM in the EU.
Festag (2014)	Academic article	Paper on the standardization of C-ITS frequencies in the EU.
Fraedrich, Beiker, and Lenz (2015)	Academic article	Publication on the socio-technical implications of automated mobility.
Horizon et al. (2020)	Ethical report	Ethical assessment of CCAM.
Inframix (2019)	Classification scheme	Classification scheme on CCAM infrastructure.
Jako et al. (2019)	Book chapter	Chapter on V2X technologies.
Kotsi, Mitsakis, and Psonis (2020)	Academic article	Publication on C-ITS implementation projects.
Kotski, Mitsakis, and Tzanis (2020)	Academic article	Publication on C-ITS traffic control and management.
Li, Ota, and Dong (2018)	Academic article	Publication on ADS decision making.
Llatser et al. (2019)	Academic article	Publication on the usage of 5G in V2X communication.
Lytrivis and Amditis (2012)	Academic article	Publication on C-ITS technology.
Lytrivis et al. (2018)	Conference paper	Publication based on the Inframix CCAM work
Meng et al. (2018)	Conference paper	Publication on C-ITS deployment in the EU.
ministers (2016)	Declaration	Declaration of Amsterdam by transport ministers of EU member states on collaboration on C-ITS and CCAM.
Nitsche, Mocanu, and Reinthaler (2014)	Conference paper	Publication on the infrastructural requirements for ADS.
Platform (2017)	Policy report	Report from the C-ITS Platform.
SAE (2021b)	Taxonomy	Publication of SAE on automated driving.
SAE (2021a)	Website	Website of SAE.
Sager (2006)	Journal paper	Publication on the connection between freedom and mobility.
Santoni de Sio (2021)	Journal paper	Ethics of transportation based on CAV.
Schroten et al. (2020)	Policy report	Report on emerging technologies in the transport system
Soteropoulos et al. (2020)	Journal paper	Publication on the deployment of ADS, AV and the connection with ODD.
Zlocki et al. (2019)	Book chapter	Chapter on the state of the art on C-ITS and automated mobility.

Appendix C: Sources used for MLP and TEF analysis

Source	Type of document	Relevant since
EUREKA (n.d.-a)	Website	Website with information on EUREKA, which is the funding for the PROMETHEUS project.
Festag (2014)	Academic article	Study discussing the standardization efforts on C-ITS.
EUREKA (n.d.-b)	Website	Website with information on the PROMETHEUS project.
Zlocki et al. (2019)	Book chapter	Introduction of a book on C-ITS.
Maurer (2016)	Book chapter	Introduction of a book on automated driving.
Kröger (2016)	Book chapter	Book chapter on the social, historical and cultural contexts of automated driving.
Leinmuller and Mittal (2019)	Book chapter	Book chapter on CAD R&D activities in the EU.
Kotski, Mitsakis, and Tzanis (2020)	Academic article	Article providing an overview of C-ITS deployment projects in the EU and USA.
Meng et al. (2018)	Conference paper	Conference paper on C-ITS deployment in the EU and its key challenges.
Commission (2008)	Commission staff working document	Proposal for Directive 2010.
Commission (2009)	Standardization mandate	Mandate from the Commission to CEN, CENELEC and ETSI for creating C-ITS communication standards.
Commission (2010)	Directive	Directive on the creation of a framework for ITS deployment.
Commission (2011)	Roadmap	Roadmap from the Commission towards a single European Transport Area for a competitive and efficient transport system.
Platform (2017)	Report	Final report of the C-ITS platform.
Commission (2015)	Commission strategy	Digital single market strategy.
ministers (2016)	Declaration	Declaration of Amsterdam by transport ministers calling for more coordination on CCAM.
Commission (2016a)	Commission strategy	Strategy on C-ITS.
Commission (2016b)	Commission strategy	Space strategy.
Commission (n.d.-e)	Website	Website on STRIA, which is the Strategic Transport Research and Innovation Agenda.
Commission (2017)	Report	GEAR 2030 to ensure that the EU has the most competitive, innovative and sustainable automotive industry in 2030 and beyond.
Commission (2018)	Strategy	EU strategy on CCAM.

ERTRAC (2019)	Roadmap	Roadmap from ERTRAC on CAD.
Commission and Transport (2020)	Policy	Policy framework on road safety for 2021-2030 with recommendations to achieve vision zero.
Commission (2019)	Report	Evaluation of Directive 2010 on ITS deployment.
Commission et al. (2019)	Science for policy report	Scientific publication on research and innovation in European transport infrastructure.
Commission (2020)	Strategy	Sustainable and smart mobility transition.
Commission (2021a)	Report	Report from the CCAM Platform.
Brown et al. (2021)	Study	Study request by the EP on the automotive landscape focussing on the green and digital trends.
Commission, E4, and B4 (2021)	Workshop power point	Workshop on a common European Mobility Data space.
Commission (2021b)	Report on workshop	Report from the workshop on European Mobility Data space.
Parliament and Union (2022)	Regulation	Regulation with which the specifications for the acceptance of CCAM is laid down.
5GAA (n.d.)	Website	Website of the 5GAA.
ACEA (2016)	Website	News article on 5GAA.
Alonso Raposo et al. (2021)	Academic article	Scientific publication in which it is focussed upon the potential economic effects of CCAM in the EU.
Benson and Jordan (2016)	Book chapter	Book chapter on EU environmental policy.
C2X (2015)	Website	Website on Drive C2X.
Car (n.d.-b)	Website	Website of Car2Car.
Car (n.d.-a)	Website	Website of Car2Car.
Cave, Genakos, and Valletti (2019)	Academic article	Scientific publication on EU telecommunication policy.
Commission (1992)	White paper	Commission white paper on The future development of the common transport policy : A global approach to the construction of a Community framework for sustainable mobility.
Commission (2001)	White paper	White Paper European transport policy for 2010: time to decide.
Commission (2022b)	Website	Website of the EC on Vehicle Safety Regulation.
Commission and INEA (n.d.)	Website	Website on the Connecting Europe Facility.

CVISproject (n.d.)	Website	Website on the CVIS project.
Egan (2016)	Book chapter	Book chapter on the Single Market.
Eurostat (2018)	Website	Website with information on the digital single market.
Høgselius, Kaijser, and van der Vleuten (2015)	Book	Book on the development of EU infrastructure.
McDonald (2008)	Report	Report on the COOPERS project.
NordicWay (n.d.)	Website	Website on the Nordic Way project.
Parliament (2022)	Policy document	European Parliament resolution on EU road safety.
Parliament and Union (2022)	Regulation	Vehicle Safety Regulation.
Partnership (n.d.-c)	Website	Website of CCAM Partnership.
Partnership (n.d.-b)	Website	Website of CCAM Partnership.
Partnership (n.d.-a)	Website	Website of CCAM Partnership.
Sabel and Zeitlin (2010)	Academic article	Scientific publication on EU governance.
Safespot (n.d.)	Website	Website on the Safespot programme.
Zeitlin (2005)	Academic article	Scientific publication on EU governance.
Botte et al. (2019)	Academic article	Scientific publication on the practices and policies on cooperative driving in the EU.
Commission (n.d.-a)	Website	EU policy on connectivity.
Commission (n.d.-f)	Website	Website on the Trans European Transport Network.
Commission (n.d.-d)	Website	Information on traffic information and road safety in the EU.
Commission (n.d.-b)	Website	Information on CVIS project.
Commission (n.d.-c)	Website	Website on the Single Market.
Kuhlmann, Stegmaier, and Konrad (2019)	Academic article	Scientific publication on governance innovation.
Sjoberg et al. (2017)	Academic article	Scientific publication on C-ITS in the EU.
Phinnemore (2016)	Book chapter	Chapter on the development of the EU.
Ucarer (2016)	Book chapter	Chapter on freedom, security and justice in the EU.
Lelieveldt and Princen (2015)	Book	Book on EU politics.
Cini and Pérez-Solórzano Borragán (2016)	Book	Book on EU politics.