Image: author's own, taken at the Siemens test track in Groß-Dölln, Germany.

POWER FROM ABOVE?

Barriers to the implementation of catenary hybrid trucks

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Name: Aline Scherrer, a.scherrer@students.uu.nl
Student no.: 5886694

Supervisor UU: Dr. Frank van Laerhoven, f.s.j.vanlaerhoven@uu.nl

In cooperation with: Fraunhofer ISI, Karlsruhe
Supervisor Fraunhofer ISI: Dr. Patrick Plötz, patrick.ploetz@isi.fraunhofer.de

Utrecht University

Fraunhofer ISI

Image: author's own, taken at the Siemens test track in Groß-Dölln, Germany.

Abstract

In the Paris Agreement of 2015, the international community agreed to work on keeping the rise of global temperatures well under 2°C compared to pre-industrial times. To achieve this goal, greenhouse gas (GHG) emissions need to be drastically reduced within the next 30 years. The transport sector alone makes up almost a quarter of current annual GHG emissions and emissions in this sector could not be reduced over the last decades. Comparatively little research has been done on lower-emission technologies in the freight transport sector although this sector amounts for 20% of all transport emissions and is projected to continue to grow. One technology which is currently developed to combat the emission problem of the sector are catenary hybrid trucks (CHT). CHT describe systems where heavy freight trucks on highways are operated with electricity from overhead lines. The technology is now developed to where it can be used in real-world applications, but projects are still demonstrative in nature and it is not clear whether a widespread implementation will be successful under the current circumstances. This thesis project, therefore, investigated possible barriers to the implementation of CHT. Since prior research on CHT has been largely focusing on technological and economic factors, this was done with a focus on actors. Six actor-centric barriers for implementation were collected from the literature on multi-level perspective and technological innovation systems. The current situation around the technology was then assessed in a social network analysis and content analysis based on data from publications, a survey, and interviews. The analysis showed that two of the six barriers were present. Expectations of niche actors which were supportive of the technology were not sufficiently overlapping and regime actors were found to resist change through different forms of power. This means that the found situation would have to be changed, if the goal were a successful implementation of the technology of CHT. To reduce or eliminate the two identified barriers, preliminary recommendations could be given. For an increase in the expectation overlap between niche actors, foresighting approaches and joint model building were presented as options. To reduce the strength of the current fossil-fuel based regime, technology bans or caps on CO_2 emissions in truck fleets, carbon taxes, the reduction of subsidies for fossil-fuels, and the inclusion of more diverse actors into advisory councils were suggested as possibilities.

Preface

This document puts forward the results of my master thesis project for the MSc Sustainable Development at Utrecht University. The research for this thesis was conducted in cooperation with the Fraunhofer Institute for Systems and Innovation Research ISI in Karlsruhe, Germany. It adds to the knowledge gathered around a feasibility study on catenary hybrid trucks (CHT) and their implementation. Prior to this project, the focus of the research around the feasibility study lay primarily on techno-economic aspects. To complement this approach, this research project specifically focuses on socio-political aspects and their relation to the feasibility of an implementation of CHT.

Acknowledgements

The process of writing this thesis would not have been the same without the generous support that I received from many people. First, I would like to thank my supervisor at Utrecht University, Dr. Frank van Laerhoven, for the continuous feedback, critical thoughts, and valuable advice. Thanks to his guidance and experience, I managed to always stay on track with my goals and to remain critical about my own work.

I would also like to thank my supervisor at Fraunhofer ISI, Dr. Patrick Plötz, who supported my process with his practical knowledge and his experience in the technological research landscape. Our discussions continuously helped me to get to the essence of what I wanted to convey in the thesis. I also want to thank my colleagues at Fraunhofer ISI for their many helpful comments and recommendations of useful resources.

Furthermore, this thesis greatly profited from the commitment of the respondents of my survey and the interviewees who gave me their time. The insights they shared with me resulted in a rich database and made this research project what it is.

Lastly, I want to thank my friends and family for their constant support and valuable feedback. I am grateful to have had this many people around me who have helped me make this project a reality.

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List of Abbreviations

BEV	Battery electric vehicle
CHT	Catenary hybrid trucks
EV	Electric vehicle
GHG	Greenhouse gas
HDVs	Heavy-duty vehicles
ICE	Internal combustion engine
MLP	Multi-level perspective
R&D	Research and development
SNA	Social network analysis
TIS	Technological innovation systems

For project and actor abbreviations see Appendix A and B respectively.

1. Introduction

Climate change is one of the largest challenges facing the world today. If it progresses at its current rate, it is expected to greatly disrupt natural and human systems in the future. In an unprecedented commitment under the Paris Agreement, the international community has agreed to the goal of jointly keeping the rise of global temperatures well under 2°C in this century compared to pre-industrial times (Paris Agreement, 2015).To achieve this goal, research shows that greenhouse gas (GHG) emissions need to come to a halt and ultimately be drastically reduced within the next 30 years (Eurostat, 2017).

Worldwide, the three largest contributing sectors to GHG emissions from fuel combustion are electricity and heat generation, transport, and industry (International Energy Agency, 2016). At 23%, transport alone makes up almost a quarter of all contributions in the EU and globally (Eurostat, 2017; International Energy Agency, 2016). Transportation emissions have increased by 71% since 1990 which can be largely attributed to transportation on roads, making up three quarters of total transport emissions globally in 2014 (International Energy Agency, 2016). For the transport sector this presents a key challenge since emissions could not be reduced over the last decades but have to develop towards a halt or even reduction if the international climate goals are to be achieved.

Although there is a large public interest and research focus on passenger transport and its decisive role in reducing emissions, this is not the case for freight transport. This presents a critical divide because scenarios of the International Energy Agency (2017) show a decline in oil usage by passenger cars between 2016-2040 with the respective reduction effects on GHG emissions, while oil demand for road freight is expected to continuously grow or only slightly decline. Projections for Europe also expect an increase of freight transport and related emissions which is not assumed for passenger transport (Piecyk & McKinnon, 2010). In Germany, emissions from truck transport alone have been shown to lie above 20% of all transport emissions with most emissions caused by heavy utility vehicles above 12 tons (Wietschel et al., 2017). To achieve the set climate goals, it is, hence, critical to also achieve a reduction of GHG emissions in road freight transport.

While alternative solutions such as a retreat from globalization are theoretically possible, most current solutions to making freight transport more sustainable take a technological approach (European Parliament Directorate-General for Internal Policies, 2010). One of these more conventional options as laid out by the EU - improving the efficiency and environmental performance of existing modes – has received considerable attention of research (Léonardi & Baumgartner, 2004; Liimatainen & Pöllänen, 2010; Ruzzenenti & Basosi, 2009). Some studies attest that efficiency in freight transport has increased. Nevertheless, as stated above, the transport sector has been the only sector in which emissions could not be decreased over the last years but continue to grow in volume.

Since efficiency improvements do not seem to be enough to combat the growing emissions, improving the environmental performance of existing modes has become a stronger focus in research. One currently proposed solution are catenary hybrid trucks (CHT). CHT describe systems where heavy freight trucks on highly frequented highways or federal streets are operated with electricity from overhead lines (Wietschel et al., 2017). The trucks generally function as hybrids with a combination of conventional engines and electrical counterparts and additional small batteries for the intermediate storage of energy. The purpose of both the conventional engine and the smaller batteries is the bridging of distances without overhead lines as well as to allow overtaking of other vehicles on the high-

way. Similar concepts are already used for mining vehicles and for public transit buses in cities around the world (Wietschel et al., 2017).

While the technology is not as prominent in the public discourse as, for example, electric vehicles for passenger transport, considerable amounts of research have been conducted and financed over the last years[1]. The companies Siemens and Scania carry out joint research into the electrification of road freight traffic with Siemens highlighting the doubling of energy efficiency through such new technologies in contrast to conventional internal combustion engines (Siemens, 2017b). In 2016, the first demonstration of a so-called eHighway was opened in Sweden (Scania, 2016; Siemens, 2017b). A two-kilometer long strip of the E16 motorway north of Stockholm allows catenary trucks produced by Scania to drive in regular traffic with the conductive technology by Siemens (Scania, 2016). A second demonstration project of such an overhead contact line system with electric trucks was opened close to the ports of Los Angeles and Long Beach, USA in 2017 (Siemens, 2017a, Siemens, 2017b).

A third round of demonstrations has recently been agreed upon with the German government, with three test tracks planned to start operating on highway A5 close to Darmstadt towards Frankfurt airport south, in Lübeck between the logistics center and the port, and on the federal highway B462 between Gernsbach-Obertsrot and Kuppenheim in Baden-Württemberg in the near future (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2017; Hessen Mobil, 2018; Ministerium für Wirtschaft, Verkehr, Arbeit, Technologie und Tourismus Schleswig-Holstein, 2017). On all three test distances, six kilometers of road will be fitted with masts and overhead lines in both directions.

The technology of CHT is, hence, developed to a point where it can be used in real-life situations, that is highly frequented highways and dense traffic. It is not seen as a panacea for solving the challenge of transport emissions but considered to be one feasible option with significant emissions advantages over the status quo. As outlined above, this makes both private and public actors interested in the technology. The projects, however, are still demonstrative in nature and the technology has not been implemented widely yet.

1.1 Problem description and knowledge gap

Actions are taken towards introducing CHT in demonstration projects but it is not clear yet, whether the current circumstances would allow a widespread implementation or delay or block it. The identified problem is, therefore, that possible barriers to the implementation of the new technology are not fully understood and that under these circumstances no specific actions or policies can be chosen to support such an implementation.

Furthermore, a knowledge gap around CHT exists in the literature. To date, there are few studies on the technology (Wietschel, 2016). Some general assessments on the possibilities of the electrification of heavy-duty vehicles have been made of which some include a section on catenary trucks (den Boer, Aarnink, Kleiner, & Pagenkopf, 2013; Friedemann, 2016; Gnann, Plötz, Kühn, & Wietschel, 2017; Tartaglia, Birky, Laughlin, Price, & Lin, 2017). A Web of Science search, however, showed no results for peer-reviewed articles on the technology[2]. A quick patent search, on the other hand, yielded results

[1] For a full project overview see Appendix A.

[2] Based on the keywords *e-Highway*, *catenary truck*, *electrified truck*, and *trolley truck*.

on different parts of the technology. This indicates that the technology has been developed to a functioning extent and that research interest is given but that there remains a large academic research gap regarding the technology.

1.2 Research objective and research framework

The research objective in this master's thesis was to highlight where barriers to an implementation of the technology of CHT lie. This was analyzed by making a diagnostic gap analysis in which the characteristics of the current situation were compared to the characteristics required for the successful implementation of a new technological innovation. This research objective translated into the following research framework:

An analysis of (a) literature on socio-technical systems, in terms of critical success factors for the implementation of new technological innovations, provides a number of subjects for analysis, (b) by means of which the current situation within the introduction of CHT in Germany will be analyzed with regard to the conducive situation for implementing innovative technologies. This will provide insights into the conditions that must be met for a successful implementation of the innovative technology of CHT which can (c) serve as first recommendations for policy development.

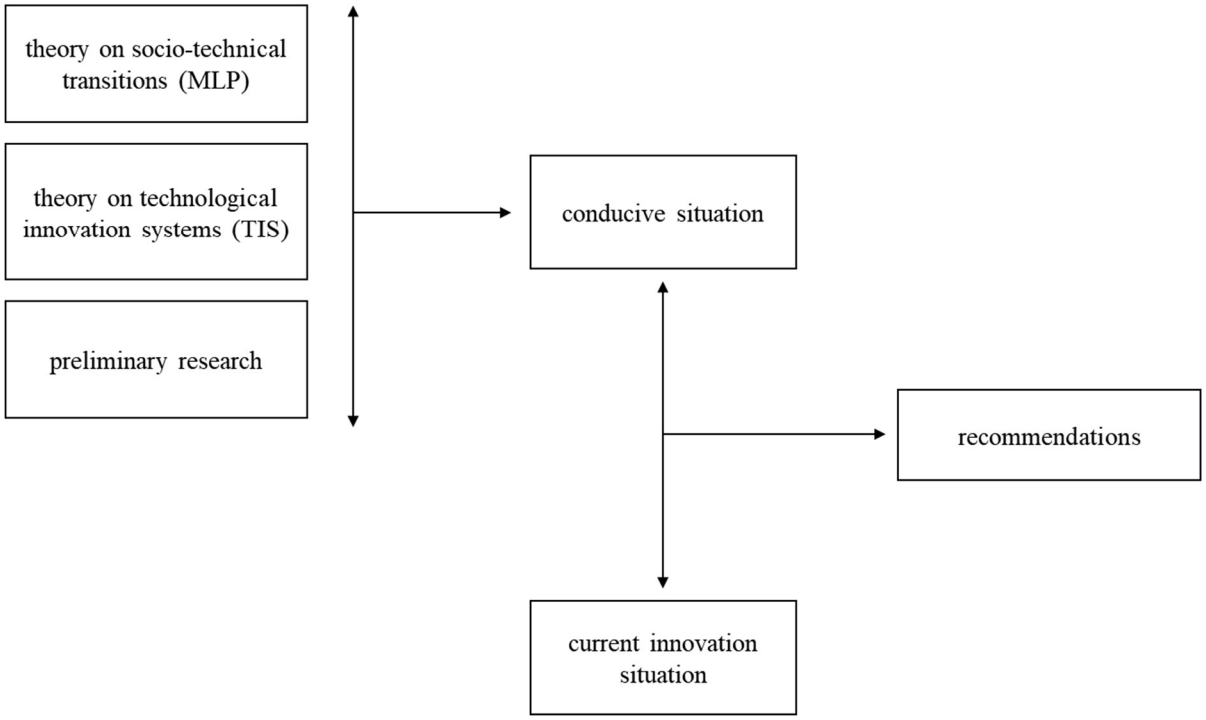

Figure 1. Research framework.

1.3 Research questions

To address the research objective, a subdivision of the research framework into its identifiable components was undertaken (Verschuren, Doorewaard, & Mellion, 2010). This division from left to right led to the following three research questions which were to be addressed in this thesis:

1. What are critical success factors, i.e. the conducive situation, for implementing the technological innovation of CHT?
2. How will the actual situation with regard to these critical success factors be assessed in the current innovation situation?
3. What is the difference between the conducive and the actual situation in terms of the critical success factors and how can this difference be reduced?

1.4 Societal and scientific relevance

The project, as a practice-oriented research project, has a high social relevance. The research has been commissioned by the Fraunhofer Institute for Systems and Innovation Research ISI in Germany which has its research focus on the developments of innovation processes and the impacts of new technologies on society. This research project contributes to shedding more light on the contextual aspects of new technologies. Based on the assumption that a certain technology can contribute to the transition to a more sustainable society, the research identifies barriers to the technology's success both in theory and in the application context. This will add to the practical understanding of transition processes and offers a basis for the development of future policies.

The project gains scientific relevance through its theoretical approach and methodology. The theoretical approach goes beyond the application of one explanatory theory and develops an assessment framework based on two prominent approaches in the innovation and transition literature. The thereby developed framework on barriers can serve as a basis for the analysis of other similar projects and serves as a critical lens on the applicability of the theories in practice. The methodology introduces social network analysis and the gathering of direct accounts from involved actors as alternative or complementary approaches to the commonly used event history analysis in TIS studies (Negro & Hekkert, 2008; Suurs, Hekkert, Kieboom, & Smits, 2010; Suurs, Hekkert, & Smits, 2009; Vasseur, Kamp, & Negro, 2013; Wieczorek, Hekkert, Coenen, & Harmsen, 2015). In this way, it can serve as a basis for further empirical research into the effects of a specific operationalization and measurement of the barriers presented in the theoretical literature.

Overall, this research project deals with the societal implementation of a technological innovation with zero-emission premises. In this project, first policy recommendations can be given based on the found barriers. It, therefore, fits in the research theme of transformative change and more specifically the governance of sustainable economies of the research programme of the Environmental Governance group at the Copernicus Institute of Sustainable Development. Of course, in a larger governance process, the diagnostic gap analysis of where implementation barriers lie and the derived policy possibilities to remove these barriers presents only the first step. A full-fledged governance strategy, including the findings of other studies on implementation challenges of related technologies, can then be developed based on this project's findings through further research.

1.5 Readers guide

Next to the introduction, this thesis consists of six sections. After a brief section on the technological background of catenary hybrid trucks, section 3 introduces the theories and concepts and arrives at a conceptual framework. Section 4 lays out the methodology of the research project and is followed by the results in section 5. Section 6 then discusses the limitations of the research project and the practical and theoretical implications of the found results, followed by a final conclusion in section 7.

2. Background: catenary hybrid trucks

The electrification of heavy vehicles with outside infrastructure has been around for decades. Many cities around the world, such as Moscow, San Francisco, Peking, Mexico City, and Geneva employ electrified inner-city buses. Furthermore, so-called *trolleytrucks* have been used in mining operations and large-scale construction sites all over the world (see Hutnyak (2004) for an informal but illustrative overview). The electrification of freight trucks on highways, however, presents a new technological and application frontier.

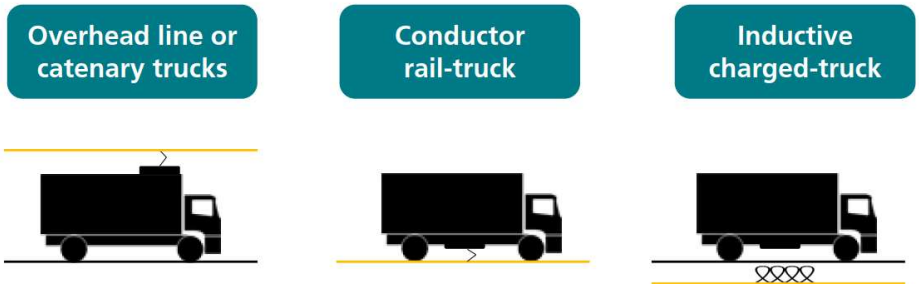

Figure 2. Different variants and energy connections for electric trucks (Wietschel et al., 2017).

There are three main possibilities for the electrification of trucks which are currently discussed: (1) overhead line or catenary trucks, (2) conductor rail-trucks, and (3) inductive charged trucks (see Figure 2).

For the catenary trucks, there are two possible execution variants. The first possibility is the combination of an electric engine with a 200-kWh battery. The second possibility is a serial diesel hybrid with a small traction battery of around 10 kWh as a puffer (Wietschel et al., 2017). The intended purpose of the smaller battery is the bridging of distances without overhead lines and the possibility to overtake other vehicles on the highway.

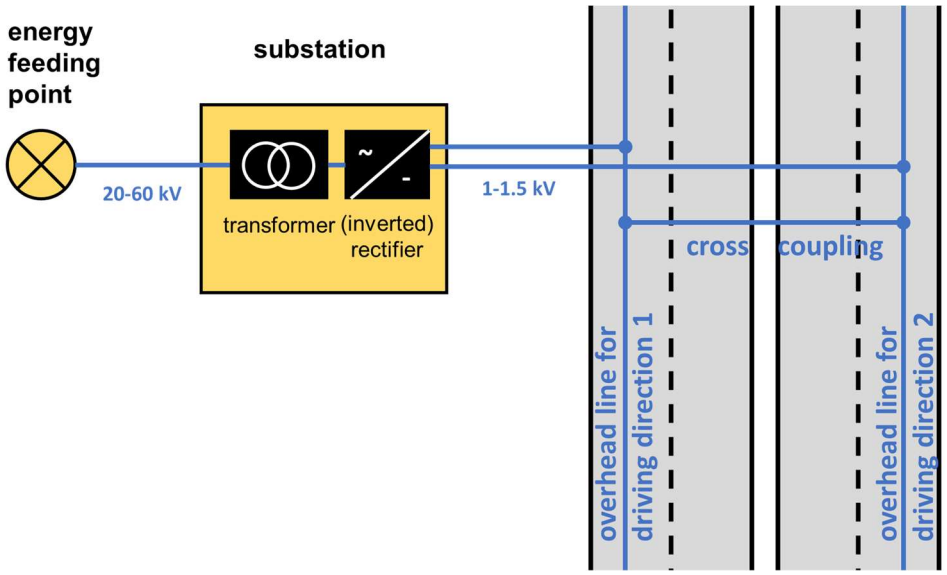

Figure 3. Sketch of the energy provision system based on Wietschel et al., 2017.

The infrastructure for catenary trucks includes five main components: (1) an energy feeding point, (2) a supply line from the energy feeding point to the electric power substation by the track, (3) a substation, (4) masts, and (5) the overhead line (catenary wire) (Wietschel et al., 2017), see Figure 3). The energy feeding point represents a branch out of the existing medium-voltage power grid of the local electric supply company. The supply lines can be 20-60 kV lines of estimated lengths between 500m and 3.000m depending on the density of the area. Substations are containers with a transformer and an (inverted) rectifier on the side of the road at a distance of around 3km from each other. Masts of concrete or steel with arms of around 6m length are installed on the right side of the road at approximately 50m distance from each other. Finally, the overhead line consists of 2-terminal grooved contact wires with 150mm² cross-sectional area, support cables (120mm² cross-sectional area), and cross-couplings between the overhead lines of both driving directions.

The truck itself is equipped with an intelligent pantograph which can be extended and lowered, and which automatically detects and connects to the overhead line while driving once the driver has given the initial order to do so via a user interface. Other vehicles can use the right lane as usual.

3. Theories and concepts for socio-technical change

To answer the posed research questions, a theory or a set of theories was needed which accounted for all relevant key concepts and could contribute to developing the set of crucial success factors. Central to the research objective is the technology of CHT and, broadly spoken, its position in the complex system of wider society. This relation and respective approach to interpret reality can be called a socio-technical system. Geels, Sovacool, Schwanen, and Sorrell (2017) define socio-technical systems as "[t]he interlinked mix of technologies, infrastructures, organizations, markets, regulations, and user practices that together deliver societal functions such as personal mobility" (p.1242).

The concept originates from field projects undertaken by the Tavistock Institute in the British coal mining industry after World War II with a focus on organizational design (Trist, 1981). The key observation which sparked the research efforts was that in organizations, the technical and social systems are inherently inter-related and that attention to this relation could make for more successful organizations. Later, Thomas Hughes (1983) developed a similar line of reasoning in his work, de-

scribing large-scale technological change through the example of the development of Western electricity networks. Hughes emphasized that an attempt to change technology or a dominant large socio-technical system could not be successful if the context, that is overlapping categories such as economic, political, and social matters, were not taken into account (Hughes, 1983).

3.1 The multi-level perspective and technological innovation systems

Socio-technical systems, hence, offer a way to describe the larger systems around technology. The change from one such system to another is what Geels (2004) then considers a system innovation. To explain the occurrence of such changes, he integrated approaches from literature in diverse fields into a new theory of socio-technical change called multi-level perspective (MLP) (Geels, 2002). This MLP or nested hierarchy is made up of three related levels: the landscape level, the regime level, and the niche level (Geels, 2002). The meso-level of regimes represents "stability of existing technological development and the occurrence of trajectories" (Geels, 2002, p. 1261). Landscape, as the macro-level describes external factors which have an influence on the other levels. Finally, niches as the micro-level account for "the generation and development of radical innovations" (Geels, 2002, p. 1261). Technological transitions are, hence, expected to develop in emerging niches under the influence of the current regime and landscape. Whether a new technology is successful or not then depends not only on processes in the niche but also in the regime and landscape.

As outlined by Markard and Truffer (2008), MLP is part of a larger *transition perspective* which looks at large transition processes at an aggregated level, "involving a variety of innovations, which possibly lead to a substitution of established technologies and a transformation of sectoral structures" (pp.596-597) under the guiding question of what drives such processes. In innovation research, a second prominent approach exists with the purpose to analyze such change processes which can be put under an *emerging technology perspective* (Markard & Truffer, 2008). Here, "the focus is on the prospects and dynamics of a particular innovation (e.g. fuel cell technology) that has the potential to contribute to far reaching changes" (Markard & Truffer, 2008, p. 596) and on "the most important drivers and barriers for a successful diffusion of a particular technology or product" (Markard & Truffer, 2008, p. 596). This perspective is the grounding for the concept of technological innovation systems (TIS).

In current research literature, a TIS is defined as "a set of elements, including technologies, actors, networks and institutions, which actively contribute to the development of a particular technology field (e.g. a specific technical knowledge field or a product and its applications)" (Bergek et al., 2015, p. 52). This definition already hints at structural elements which are considered crucial for a TIS and form the analytical basis for practical applications: actors, networks, and institutions (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008). Actors can include firms along the value chain of the technology in focus, universities and research institutes, organizations etc. For networks, different types can also be observed within the TIS under the two broad classifications of formal and informal networks (Bergek et al., 2008). A formal network with a specific task could, for example, be a standardization network, while another could be an informal network of university-industry links or professional networks. The final element to map when gathering the structure of a TIS are institutions such as laws, norms, or routines. Given the early development phases of some innovations and the prevailing uncertainties, Bergek et al. (2008) consider the mapping of these structural elements an iterative process.

The former approach of primarily describing the structural elements of this definition has been further developed to also pay attention to "the functional performance of the innovation system's components" (Wieczorek et al., 2015, p. 130). So-called *functions* were added to the structural elements to account for insights from political science, sociology, and organization theory regarding the "political nature of the innovation process and the importance of legitimation" (Bergek et al., 2008, p. 410). Seven functions are commonly identified in the literature with small differences in the respective descriptions (see Table 1).

Table 1. Functions of TIS.

No.	Functions	Authors
1	**Entrepreneurial activities /**	Hekkert, Suurs, Negro, Kuhlmann, and Smits (2007); Suurs et al. (2009)
	Entrepreneurial experimentation	Bergek et al. (2008)
2	**Knowledge development**	Bergek et al. (2008); Hekkert et al. (2007); Suurs et al. (2009)
3	**Knowledge diffusion**	Bergek et al. (2008); Hekkert et al. (2007); Suurs et al. (2009)
4	**Guidance of the search** /	Hekkert et al. (2007); Suurs et al. (2009)
	Influence on the direction of search	Bergek et al. (2008)
5	**Market formation**	Bergek et al. (2008); Hekkert et al. (2007); Suurs et al. (2009)
6	**Resource(s) mobilization**	Bergek et al. (2008); Hekkert et al. (2007); Suurs et al. (2009)
7	**Creation of legitimacy/counteract resistance to change** /	Hekkert et al. (2007)
	Legitimation	Bergek et al. (2008)
	Support from advocacy coalitions	Suurs et al. (2009)

Suurs et al. (2009) shortly describe the main functions. *Entrepreneurial activities* refer to the role of the entrepreneur who creates innovations by using experiments which translate knowledge into business opportunities. *Knowledge development* is concerned with theoretical and practical learning around the new technology and its system. *Knowledge diffusion* pertains to interactive learning between actors. *Guidance of the search* "refers to the activities that shape the needs, requirements and expectations of actors with respect to their (further) support of the emerging technology" (Suurs et al., 2009, p. 9641). *Market formation* concerns the need to create new, artificial markets for the technology since competition with incumbent technologies is usually not possible from the start. *Resource mobilization* refers to the access to financial, material, and human capital which is needed for TIS developments. Finally, actors of the incumbent system often resist new technologies. This requires counteraction from *advocacy coalitions*. *Legitimation*, a function put forward by Bergek et al. (2008) fits with this function but expands it. The authors state that new technologies and their proponents "need to be considered appropriate and desirable by relevant actors" (Bergek et al., 2008, p. 417) and that "legitimacy is a prerequisite for the formation of […] new TISs" (Bergek et al., 2008, p. 417) formed in a dynamic process by various actors. This approach, including both structural and process variables, offers a comparatively high resolution for analyzing the specific structure and workings of the system around a technological innovation.

Markard and Truffer (2008) argue that a combination of both the *transition perspective* represented by MLP and the *emerging technology perspective* represented by TIS could have merits for balancing out their respective weaknesses and strengths. TIS can add more detailed analyses of niche developments to an MLP perspective while the MLP can add to the TIS by further outlining the relation between niche and regime (Markard & Truffer, 2008). The authors accordingly introduced a combined framework which includes both a focal TIS including niches and the relationships with regimes as well as the influence of landscape developments (see Figure 4).

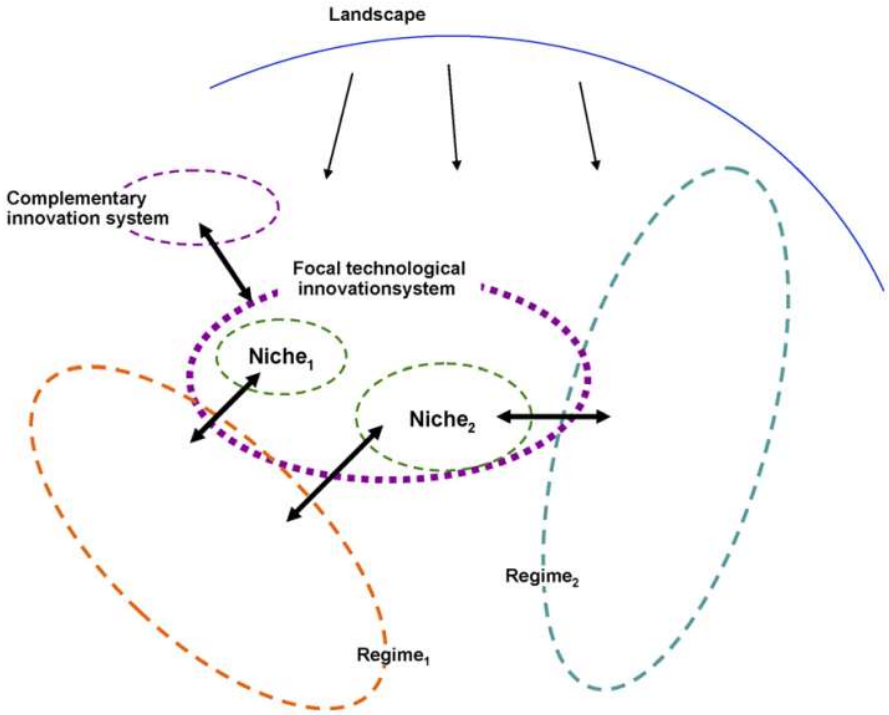

Figure 4. Interactions between TIS and the conceptual elements of the MLP (Markard & Truffer, 2008).

In contrast to some other definitions, the authors follow a restricted view on TIS which is distinct from both niches and regimes. A TIS is characterized as encompassing a variety of actors with a shared vision for the innovation field, a certain division of labor between these actors, a variety of institutions and a certain degree of market formation (Markard & Truffer, 2008). The TIS interacts with one or more socio-technical regimes and with other TIS either through competition or complementation. Niches or small innovation networks are different from TIS in that they have not developed any formal internal structure. A TIS can conceptually encompass several niches or application contexts which function, for example, as testing fields. Due to the expected added value of integrating the two approaches of MLP and TIS, this combined framework was used as the basis for this research project.

3.2 Matching the framework with key characteristics of the research project

Before proceeding with this approach, it first had to be established whether the frameworks and their combination fit the study of a sustainably oriented technology and the situation around CHT specifically. This was used to determine, whether and how they could be used for the analysis. The section showed that the combination of theories presented a fit for the technology and the situation.

3.2.1 MLP, TIS, and catenary hybrid trucks

The technology of electrified trucks and highways was, amongst other factors, developed with the overall goal of GHG emission reduction and, therefore, with a critical part of the international Sustainable Development agenda in mind (Fraunhofer-Institut für System- und Innovationsforschung ISI, 2017; Scania, 2015, Scania, 2017; Siemens, 2017b). The overall aim can, therefore, be said to be a sustainability transition from the current socio-technical system to a more sustainable system in the future. Markard, Hekkert, and Jacobsson (2015) give two reasons as to why TIS is considered a key framework for studying sustainability transitions. First, "the emergence of novel technologies is a central process[es] in socio-technical transitions and several new technologies have meanwhile matured to a degree that they very much threaten established technologies, organizations, and institutional structures" (p.77). Secondly, the TIS approach has been extensively empirically confronted with technologies considered to hold sustainability promises, such as renewable energies or alternative vehicle technologies (Markard et al., 2015). The MLP, on the other hand, has been used to study a diverse range of historical transitions such as hygienic transitions or transitions in waste management (Geels & Kemp, 2007), or the transition from sailing ships to steam ships (Geels, 2002). Especially recently, however, its merits for studying sustainability transitions, such as the German energy transition, have been pointed out (Geels et al., 2017). Empirical literature, hence, indicates the usefulness of TIS and MLP when studying technologies with a sustainability promise such as CHT.

In the abovementioned definition of a TIS, the "development of a particular technology field (e.g. a specific technical knowledge field or a product and its applications)" (Bergek et al., 2015, p. 52) is central. This fits the case of CHT and the technology field can be considered mainly a product and its application. The product of CHT can be defined as the combination of an external charging infrastructure with hybrid or entirely electrified highway trucks since the combination of the two and the new automotive application rather than the individual technological parts make for the novelty.

3.2.2 Verification of conceptual levels

For meaningful analysis based on the combined framework, the situation around CHT had to fit characteristics of both the MLP and TIS approach. In order to fit a transition pathway under the MLP framework, the situation had to exhibit niche, regime, and landscape characteristics. For the situation at hand, this could be said to be the case.

Niche

Markard and Truffer (2008) differentiate between two types of niches: market niches and technological niches. Market niches come about as a by-product of a certain application context or consumer preference which "significantly deviate[s] from 'usual' contexts and practices" (Markard & Truffer, 2008, p. 605). An example given by the authors is that of the development of a market niche for photovoltaic systems due to the demand for off-grid energy supply to mountain cabins. In contrast, technological niches are created on purpose by certain actors (Markard & Truffer, 2008). A common way to refer to such niches is as "protected spaces or incubation rooms" (Markard & Truffer, 2008, p. 605) where novel technologies or practices can "develop isolated from the selection pressures of 'normal' markets or regimes" (Markard & Truffer, 2008, p. 605). Technological niches "represent the local level of the innovation process" (Markard & Truffer, 2008, p. 605) and can be described as organizational fields with small and unstable communities of interacting groups whose shared rules are still "in the making" (Geels & Schot, 2007, p. 402).

In this research project, "subsidized demonstration projects" (Geels, 2011, p. 27) planned in Germany could be made out as such a niche. This niche has not come about naturally in a certain application

context but was deliberately created by private and public actors and presents a deviation from the current regime. The three planned experiments in the federal states of Baden-Württemberg, Hessen, and Schleswig-Holstein exemplify the local level of the innovation process as well as the discrete application domain. As Markard and Truffer (2008) point out, niches are not necessarily exclusive to one TIS but can relate to other TIS. For the aforementioned niches this was the case since there can be further applications for, for example hybrid trucks, besides the combination under electrified highway systems.

Regime

Additionally, the situation around CHT had to match the level of socio-technical regimes as an interpretive analytical concept (Geels, 2012). The regime refers to the intangible rules or "'deep structure' behind activities that accounts for the stability of an existing, socio-technical system" (Geels, 2011, p. 27). Such regime rules are, for example, "shared beliefs, norms, standardized ways of doing things, heuristics, and rules of thumb" (Geels, 2012, p. 472). Existing regimes are characterized by lock-in mechanisms and incremental change in stable trajectories. Such lock-in mechanisms can be the shared beliefs, but also lifestyles, "regulations and laws that create market entry barriers, sunk investments in machines, people and infrastructure, resistance from vested interests, and low costs because of economies of scale" (Geels, 2012, p. 472). Despite these common characteristics, regimes are not homogenous and there can be internal disagreements and conflicts on certain topics.

In the transport sector, the dominant regime is the "auto-mobility regime" (Geels, 2012, p.472). However, as Geels (2012) points out, manufacturers such as the car industry are not the only pivotal actors in this regime although this is a prominent tendency in innovation studies. Politics, everyday practices by individuals, cultural associations, and the practices of professionals such as transport planners can be equally important (Geels, 2012). Geels (2012) considers the *auto-mobility regime* dominant because of its high percentage share in terms of total mobility (in terms of passenger kilometers). For freight transport in Germany, the share of truck freight transport is larger than 70% and the large majority of these trucks currently run on Diesel (Kraftfahrt-Bundesamt, 2017a; Statista, 2018). The current regime specific to this part of transportation was, therefore, in this research called *fossil-fuel based road freight transport regime*.

Landscape

The landscape refers to those external factors which have an influence on the regime and niche (and TIS in the combined framework) but cannot be changed directly or easily. For the situation around CHT, the relevant landscape factors could be considered similar to the landscape for EVs. Important landscape factors are then the availability of fossil-fuels and the status of international agreements for combating climate change (Figenbaum, 2017).

TIS

Finally, Markard and Truffer (2008) note that not every small innovation network or niche qualifies as a TIS. The characteristic of the situation around CHT, therefore, had to meet a list of minimum conditions for such a conceptualization.

First, a variety of different actors with different innovation strategies and controlling a set of different resources had to be present. In addition to the German niche around CHT, trials and applications of the technology have been initiated in both the USA and Sweden (see Appendix A for a full project overview). These additional niches within the TIS point to a number of different actors, strategies and

resources present in the TIS. Secondly, innovation tasks had to be split. For CHT, the innovation tasks are split between research institutions working on the technology and possible implementation scenarios, industry actors who develop and install infrastructure and integrate additional technology to available truck configurations (both hybrid and fully electric), and industry actors such as logistics companies who find ways to integrate the new technology into their business. At the same time, energy providers are working on the innovation task of integrating the new approach into the electricity grid.

Thirdly, a division of labor and market transactions had to be present. Here, trucks are purchased and remodeled, and remodeled trucks and catenary infrastructure are sold to logistics companies or public agencies for trials in a subsidized manner. While this presents a certain division of labor in providing parts of the technology, only one technology company currently offers the modification of trucks with the necessary pantograph technology and the road infrastructure. However, the technology presents a special case since its innovation lies in the combination of parts and the parts are largely based on tram and train technology and could, hence, theoretically be provided by another company without considerable problems[3]. In addition to the competing suppliers of sub-technologies (specifically the different available propulsion technologies and truck modifications), this can be regarded sufficient for the consumer choice of project trial organizers and a certain degree of market transactions, although immature.

Finally, a variety of internal institutions had to be given, comprising regulations, norms, use patterns and shared expectations (Markard & Truffer, 2008). Internal institutions are starting to emerge with technical norms for the catenary infrastructure, both the parts installed on the trucks as well as the parts installed by the road. Use patterns are slowly emerging with the planned trials in Germany somewhat furthering the approach taken in the USA of using the technology in highly frequented freight transport corridors between respectively a port, logistics centers, and production sites. Whether expectations of participating actors were shared and could, therefore, also be regarded as institutions was part of this research project and could not be answered preliminarily. Overall, the presence of a TIS could be confirmed, although in a still immature state. In terms of the stages of TIS development put forward by Bergek et al. (2008), Markard and Truffer (2008) locate the TIS between the formative and growth phase which fits this assessment.

3.3 Field-specific success factors

Based on the joint theoretical framework, it had to be determined what critical success factors could be made out. This required a prior determination of what could be considered a success under both TIS and MLP. Under MLP, success can be considered a successful transition from niche to regime (Hoogma, Kemp, Schot, & Truffer, 2002). Under TIS, success can be considered the successful generation, diffusion and use of the innovation (Markard & Truffer, 2008). These can be interpreted to refer to the same end situation from different perspectives. Based on these definitions of success, factors can be collected which determine such success.

[3] This point was informally brought up in a discussion during a visit to the test track of the main technology company.

As Markard and Truffer (2008) lay out, neither MLP nor TIS scholars have so far been able to arrive at a general performance assessment framework. This means, that there is no positively formulated ideal situation or innovation process that the current situation around CHT could be measured against. However, both research traditions outline a way around this challenge – they indirectly formulate a *conducive* or *close-to-ideal* situation as a situation where barriers are absent. In TIS this can be seen in the step where policy recommendations are based on the found barriers with the goal to remove those. In MLP this can be seen in the marked end point of transitions which takes place when the barriers posed by the current regime are successfully dealt with or removed and the niche becomes or replaces the regime.

It was, hence, possible to develop a list of barriers based on the TIS and MLP approach, which the present situation around CHT could then be compared against. Table 2 summarizes these barriers. Landscape barriers were not considered since they are defined as outside the reach of policies and are, therefore, not of direct interest for parties who want to support the implementation of the technology.

Table 2. Barriers for success.

Level of aggregation	**Niche**	**TIS**	**Regime**
Authors	Figenbaum (2017); Geels (2011); Nykvist & Nilsson (2015)	Bergek, Jacobsson, Carlsson et al. (2008); Suurs, Hekkert, & Smits (2009)	Figenbaum (2017); Geels, Tyfield, & Urry (2014); Markard & Truffer (2008); Nykvist & Nilsson (2015)
Barriers	Lack of niches / poorly functioning niches = **No or small (social) networks;** **No precise and broadly accepted expectations;** No 'dominant design';	Lack of entrepreneurial experimentation or activities; Lack of knowledge development and diffusion; Lack of guidance of or influence on the direction of search; Lack of market formation; Lack of resource mobilization; **Lack of legitimation or support from advocacy coalitions**	Strong ICE regime = **Resistance by regime actors through instrumental, discursive, material, and institutional forms of power;** **No or small overlap of regime actors with TIS actors;** No or small institutional overlap between regime and TIS

Notes. Bold font indicates barrier directly related to actors or actor networks (see section 3.4. dealing with the restriction of the research).

Frequently, criteria found in theoretical literature are adapted to a specific field to yield more exact representations of the empirical reality and therefore better results. Since the research field on CHT is underdeveloped, such adaptations could only be expected to be found in related areas. Under the wider umbrella of e-mobility, the research field on personal electric vehicles (EVs) is considerably further developed. It also involves the combination of an old technology, the car, with newer technologies of

batteries and electric engines. Furthermore, it requires new charging infrastructure and changed purchase behaviors on users. Despite apparent differences in scale and users, it could, therefore, be considered a sufficient parallel to the technology of CHT.

A search for TIS studies around EVs yielded a study by Köhler et al. (2013) on low-carbon cars. In his analysis, the author stuck to the structural components and functions provided by the theoretical literature on TIS. The functions were assessed with no reference to a specific underlying literature-based operationalization. This included, for example, a rather unusual operationalization of legitimation referring to consumers' opinions and behaviors (Köhler et al., 2013). Since the paper did not critically add EV-specific criteria to assess the individual functions and no other EV-specific TIS papers were found, the TIS criteria for this project remained based on the theoretical literature. This means that a lack of any of the functions of a TIS was considered a barrier.

A search for MLP studies around EVs yielded work by Bakker (2014), Budde, Alkemade, and Weber (2012), Figenbaum (2017), Geels (2012), Nykvist and Nilsson (2015), and van Bree, Verbong, and Kramer (2010). Nykvist and Nilsson (2015) used MLP to study EV implementation in Stockholm while Figenbaum (2017) assessed EV trajectories and policies in Norway. Both tested hypotheses based on MLP in a case study. Nykvist and Nilsson (2015) found that (1) a lack of niches or poorly functioning niches and (2) a strong internal combustion engine (ICE) regime formed barriers to EVs developing out of the niche. Figenbaum (2017) supported this finding from the opposite direction and found that the fast development of battery electric vehicles (BEVs) in Norway was both the result of (1) well-functioning niches for BEVs to expand in and from and (2) a weak Norwegian ICE regime. These factors were, therefore, included as barriers for success in Table 2.

Geels (2011), the author who developed MLP in its currently used form, further developed the specific factors which make for a functioning niche that can gain momentum in general. The same is true for the strength of regimes which Geels, Tyfield, and Urry (2014) further specified as different forms of enacted power. Since MLP studies have been criticized to be bottom-up centric and to not include views on possible other trajectories where, for example, regime actors also support the transition, two criteria from Markard and Truffer (2008) were also included (Geels et al., 2014). Since TIS actors are generally defined as supportive of a technology, more overlap in actors and institutions between TIS and regime is expected to lessen resistance to the technology (Markard & Truffer, 2008).

The theoretically found criteria of these two articles were supported by the barriers derived from success factors for green propulsion technologies in a translation of MLP into the field of transport studies (Geels, 2012): (1) a lack of CO_2 regulations and government subsidies for R&D, (2) a lack of new and fully committed entrants, (3) a lack of joint ventures between incumbent car companies and component (e.g. battery) suppliers, (4) a lack of support by local governments and electric utilities, (5) lock-in in currently used car fleet. (1), (4) and (5) fit the barrier *resistance by regime actors* with instrumental and institutional forms of power, (2) fits *no or small (social) networks*, and (3) supports the overlap criteria under r*egime* (see Table 2). Overall, the EV-specific MLP and TIS literature, therefore, led to the identification of 12 main barriers.

3.4 Preliminary research – restriction of scope

As a conceptual framework for the analysis in this research, the combination of both perspectives led to a large number of possible barriers to success. If all factors were taken into consideration, this could have had negative consequences for the feasibility of the project. This consideration made restrictions to certain barriers necessary. To this end, preliminary research was conducted to zoom in on one group of central or decisive barriers for the implementation of the technology of CHT. Addition-

ally, as in all empirical MLP and TIS studies, the geographical scope and time frame as well as the characteristics of the conceptual levels had to be determined.

3.4.1 A conceptual framework of actor-centric barriers

Literature on strategic niche management suggests that barriers to new technologies and transitions are either of technical, economic or social and institutional nature (Kemp, Schot, & Hoogma, 1998). A preliminary interview with an expert practically involved in the field highlighted that research around CHT was so far mainly focused on technological and economic feasibility. There was no special attention given to actors and their perspectives, strategies, or power. Geels et al. (2017) state that this is common and that "[l]ow-carbon transitions are often seen as a techno-economic implementation challenge, justified by climate science and driven by R&D and carbon pricing. But accelerated transitions also depend upon widespread social acceptance (to create legitimacy and support for strong transition policies) and business support" (p.1243). This corresponds with the view of the expert who considers an investigation into actor-related factors a necessary next step. Table 2 shows that a considerable amount of barriers can be made out in the literature which revolve explicitly around actors or actor networks. Of course, all functions in TIS are somewhat connected to actors as a structural element. However, legitimation and advocacy coalitions is the one function where subjectivity of actors directly creates or takes away the function (Markard et al., 2015). Markard and Truffer (2008) even consider the possibility for an actor-based analysis one of the key possibilities arising from the combination of transition approaches such as MLP with innovation-focused approaches like TIS. They state that the framework "provides a basis for an actor oriented analysis of innovation processes, which explicitly considers different actor strategies, resource endowments and agency" (Markard & Truffer, 2008, p. 613).

Preliminary research on both practical and theoretical views, hence, suggested that a restriction on actor- and network-centric barriers could be both practical and methodologically sounder. It had the potential to add so far unavailable knowledge to the practical situation and used the explanatory strength of two frameworks in the transition and innovation literature. This resulted in the following conceptual diagram of the remaining barriers based on the combined framework by Markard and Truffer (2008) (see Figure 4).

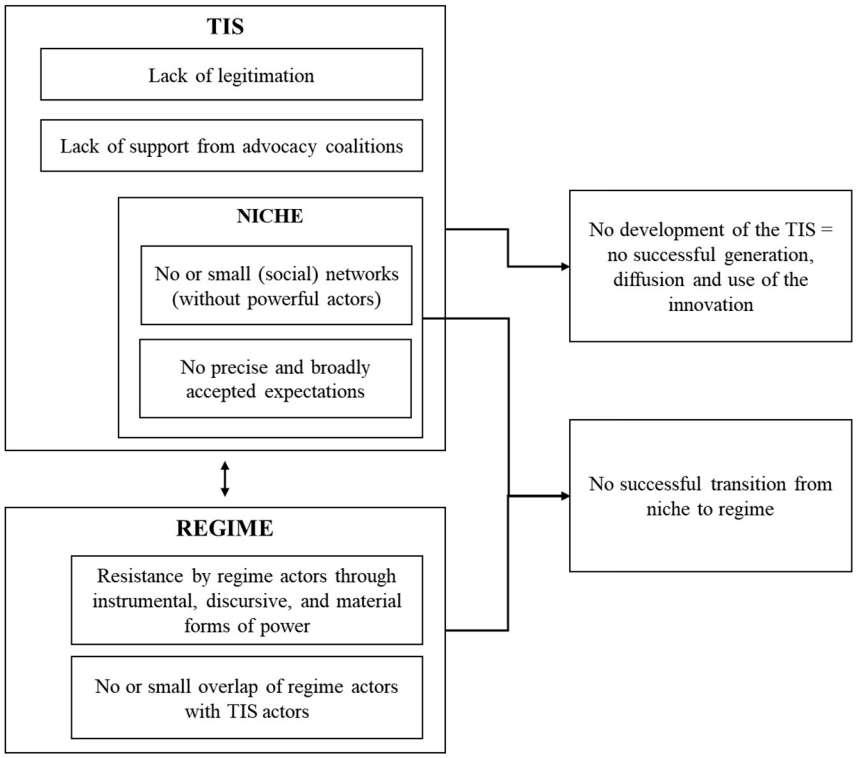

Figure 5. Conceptual framework of the actor-centric barriers situated in niche, TIS, and regime based on the combination of theoretical frameworks by Markard and Truffer (2008).

3.4.2 Geographical scope and time frame

MLP studies in the energy and transportation realm are commonly restricted to specific scales such as countries (Budde et al., 2012; Figenbaum, 2017; Tenggren, Wangel, Nilsson, & Nykvist, 2016). TIS studies also commonly use the level of countries as a focus level for studies and for comparisons in time and space (Markard, Stadelmann, & Truffer, 2009; Negro & Hekkert, 2008; Suurs et al., 2009; Suurs et al., 2010). However, authors also point out the value of broadening this scope and taking into account the interconnectedness of innovation systems and transformations (Köhler et al., 2013; Wieczorek et al., 2015). The respective theoretical literature of MLP and TIS also generally considers transformations as global and interconnected phenomena but still recommends restrictions in scope where necessary, calling on the own judgement of the researcher.

For this project, the geographical scope was dealt with in two steps. In the first step of gathering actor connections and depicting the overall network, all actors found in the online research and mentioned by the expert were added. This allowed for actors to be included on a global level in order to get a full overview of the innovation system. For the analysis, a distinction was then made in the second step. Barriers related to the regime and TIS level were assessed for all of the actors. This was based on the reasoning that internationally acting and connected regime and TIS actors can have an effect on specific niches located in one geographical location. Since one TIS generally contains many niches, both in the related-technology as well as in the geographical sense, and this presents an extensive research-field with respect to the scope of this project, the niche analysis was restricted to the conceptual niche encompassing all German CHT field trials and the respectively involved actors.

The time frame for this research was practically restricted by the topicality of discussions around CHT. With its earliest discussions coming up around 2011, the topic only started to enter the media and consciousness of more actors around five years ago. The project, therefore, takes an aggregated

view of the years 2013-2018 for the data collection and assessment. The opinions of actors collected in a snapshot manner through a survey and interviews were assumed to represent an aggregation of knowledge and opinions throughout the last years as well.

3.4.3 Conceptual levels and corresponding actors

To assess actor-specific barriers for the levels of niche, TIS, and regime, these levels needed to be defined first. Only then could actors be assigned to levels and the data be analyzed accordingly.

Niche

As laid out in section 3.2.2, the technological niche in focus for this research project was purposefully created by actors as a protected space. The three planned field trials in Baden-Württemberg, Hessen, and Schleswig-Holstein represent this niche. Niche promoting actors are then respectively those actors who have created the niche, "are prepared to work with specific functionalities" (Hoogma et al., 2002, p. 4), and are willing to invest in the new technology or practice despite uncertainties and higher costs. This actor landscape can be varied and range from regime members to outsiders, policy makers and entrepreneurs or other actors (Markard & Truffer, 2008).

TIS

Catered to the logic of their combined framework, Markard and Truffer (2008) suggest to conceptualize a technological innovation system as "a set of networks of actors and institutions that jointly interact in a specific technological field and contribute to the generation, diffusion and utilization of variants of a new technology and/or new product" (Markard & Truffer, 2008, p. 611). TIS actors were, therefore, in this research project defined as those actors who support the technology of CHT in any of these three ways.

Regime

As laid out in section 3.2.2, the analytical concept of the socio-technical regime refers to the structure and intangible rules which lead to the stability, lock-in mechanisms and only incremental changes of the existing socio-technical system. It is important to point out that actors themselves are not the regime. Actors and their behaviors rather enact the regime by acting according to the intangible regime rules and are, therefore, one visible component of the *deep structure* behind the activities (Geels, 2012). While not equal to the regime itself, actors are constrained by the regime in a certain way and those actors enacting the existing intangible rules most strongly can be called regime actors. In this research project, the regime in focus was that of the *fossil-fuel based road freight transport regime*. Of all the actors found to be involved in the technology of CHT, those were, therefore, considered regime actors whose actions predominantly draw on the intangible rules of that regime. Furthermore, preliminary research showed the involvement of actors of related regimes such as *rail freight transport*. Such actors were accordingly classified as parallel regime actors.

4. Methodology

The research objective and research questions made clear, that in-depth knowledge had to be gathered about a specific situation, or more precisely the situation around the technology of CHT. The research project therefore followed the characteristics of an in-depth empirical case study. Case studies aimed at in-depth knowledge generations lend themselves to qualitative approaches (Verschuren, Doorewaard, & Mellion, 2010). To determine the data which had to be gathered, the conceptual

framework was operationalized. The following subsection presents the operationalization of the six barriers on the basis of which the situation was assessed. Subsequently data sources, data collection and data analysis are addressed. To provide some consistency, the majority of the wording used in this section was taken from Verschuren et al. (2010).

4.1 Operationalization

Table 3 shows the operationalization of the six barriers of the conceptual framework. Where possible, the operationalization was based on literature of TIS and MLP and corresponding case studies. In addition to operationalizing questions for each barrier, the table shows the scoring system which was used to assess the barriers' degree of presence or absence.

Table 3. Operationalization of barriers.

Level	Barrier	Operationalizing question	Results	Score
TIS	*Barrier 1:* Lack of legitimation	Is the depiction of CHT more positive or negative 1) by relevant actors 2) by the media?*	1) negative; neutral; positive 2) negative; neutral; positive	barrier; barrier to slight barrier; slight barrier; slight barrier to no barrier; no barrier
	Barrier 2: Lack of support from advocacy coalitions	Do actors 1) improve and 2) lobby for the improvement of technical, institutional and financial conditions for CHT?**	1) no; partly; yes 2) no; partly; yes	"
Niche	*Barrier 3:* No or small (social) networks (without powerful actors)	1) What is the size of the networks? 2) Are powerful actors present?	1) no networks; medium; large 2) no; yes	"
	Barrier 4: No precise and broadly accepted expectations	In how far do the descriptions of expectations and visions for CHT overlap between the actors?	no overlap; some overlap; great overlap	"
Regime	*Barrier 5:* Resistance by regime actors through 1) instrumental, 2) discursive, 3) and material forms of power	1) Does the regime mobilize more resources than the niche? 2) Do regime actors dominate the discourse? 3) Do regime actors improve the technical dimension of the current regime to avoid regulation?***	1) yes; same amount; no 2) yes; equal distribution; no 3) yes; partly; no	"
	Barrier 6: No or small overlap between regime actors and TIS actors	How large is the overlap between regime actors and TIS actors?	no overlap; some overlap; great overlap	"

*operationalization based on van Alphen, Hekkert, and Turkenburg (2010).
**operationalization based on Negro and Hekkert (2008) and Suurs et al. (2009).
***operationalization based on Geels et al. (2014).

The operationalization shows that a variety of data related to actor and network attributes as well as perceptions and visions needed to be gathered. To cover the variety of necessary data for the barrier assessment, a combination of methods was chosen which is generally recommended in research design literature (Verschuren et al., 2010). Hermans and Thissen (2009) who focus on actor analysis

methods are also in favor of such an approach but recommend: "In combining methods, it will be useful to identify methods that differ in focus but that are similar in terms of information needs and sources of information" (p.814). This recommendation was followed so that multiple barriers could respectively be assessed based on the same data sources and analytical method. The combination of methods also allowed for triangulation. Triangulation does not aim to produce and check for the same results under different methods. It rather aims at gaining a well-rounded picture of a practical situation from different angles and to enable a critical comparison of the so gathered results (Verschuren et al., 2010). Lastly, the project makes use of the respective logic of social network analysis (SNA) and stakeholder analysis which will be mentioned in the methodological section where this is relevant.

4.2 Data sources and data collection

Documents and people were chosen as the sources for this research project. More specifically, the documents used were web publications and newspaper articles. People were used as experts and as informants representing their organization. On the one hand, parts of the data gathered from both sources was treated as direct information. For web publications, an example would be the extraction of information about a firm's disposable resources. For people, an example would be an expert's account on which actors are relevant to include in the research. For the central part of the research, however, documents and people were used to gather raw data to be analyzed.

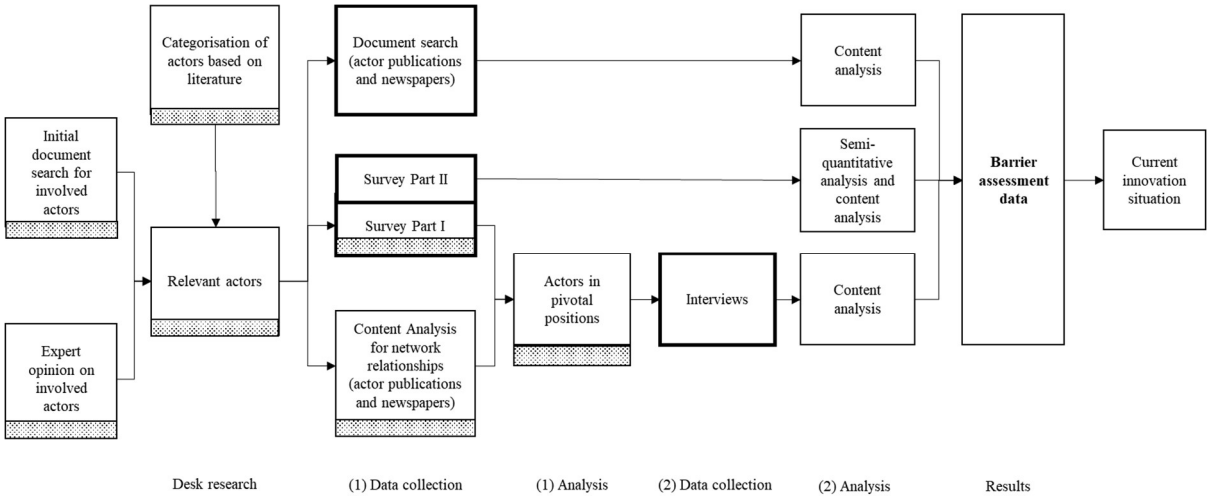

Figure 6. Overview of methodological steps for assessing the current innovation situation. Thick frames indicate empirical data collection steps. Added bars below boxes indicate parts of direct information collection and stakeholder analysis characteristics.

Figure 6 visualizes the research steps which were taken to gather the necessary data to assess the six barriers and, therefore, the current situation. The dotted boxes represent the usage of direct information while the remaining boxes represent the gathering and interpretation of raw material. The dotted parts will be referred to as the stakeholder analysis part of this research as it parallels this most widely used approach to actor analysis in the definition of Reed et al. (2009). Stakeholder analysis, here, does not refer to the much-critiqued vague approach of an expert-based description of interest and power (Reed et al., 2009) but rather to the particular way of analyzing actors in three steps: (1) identifying stakeholders, (2) categorizing stakeholders, and (3) investigating relationships between stakeholders. In this research, all three steps are necessary prerequisites for the barrier assessment, particularly because actors and networks are of central importance in TIS research. The three steps were therefore interwoven into the methods of gathering raw data for assessing the barriers. Data from documents and people was then accessed in three ways.

4.2.1 Newspaper and publication search

First, newspaper articles and publications were searched through the search engine Google with the keywords *Oberleitungs-LKW*, *Elektro-LKW*, *catenary highway truck*, *eHighway*, and *trolleytruck* to cover both German and international coverage. From these articles, all mentioned actors involved on the topic of CHT were compiled into a preliminary actor list. This actor list was then verified and added to by an expert at Fraunhofer ISI who had a comprehensive overview of the stakeholder landscape around CHT (see Appendix B for the full actor list).

Secondly, newspaper articles and publications were searched for with a combination of the previously noted keywords and the names of the organizations identified as relevant actors. The combinations were entered into the search engine Google and into the search functions of the websites of all identified actors. In the found documents, network relationships between actors were searched for as a preparation for the assessment of network-related barriers. Furthermore, this network data was used for identifying the most relevant interview partners (see section 4.2.3).

Finally, newspapers and publications were searched to gather data for the barrier assessment directly. Publications were gathered in the same way as for the network relationships in the prior step. Additionally, a newspaper sample was collected. For the barrier assessment, the newspaper sample needed to be as representative as possible. To gather a large sample of German newspapers, as the focal geographical scope, articles were first searched for based on the keywords *Oberleitungs-LKW*, *E-LKW*, *Elektro-LKW*, *LKW elektrisch*, *Trolleytruck*, und *eHighway* in the database LexisNexis for the years 2013- March 2018. However, the results excluded some of the largest German newspapers. The search was, therefore, supplemented with individual searches based on the same keywords in the databases of the highest-selling national newspapers (see Appendix C for a list of the included newspapers). This search yielded 612 articles in total. After sorting out duplicates and articles not directly concerned with CHT, 74 articles remained for the analysis (see Appendix C for a full overview of all analyzed articles).

4.2.2 Survey

Data from individual people was accessed through questioning (Verschuren et al., 2010). The first questioning technique used was that of a survey[4]. The survey was designed as an online questionnaire in both German and English to be easily accessible for all respondents (see Appendix D for the questionnaires in print format). The questionnaire was built and administered with the tool EFS Questback and consisted of two parts.

The first part aimed at collecting information on the connections between the actors, that is the network between them. As recommended in SNA literature, a closed-ended roster was used on which actors could indicate multiple actors with which they had communicated or been in close contact with about CHT during the last five years. Such a roster can circumvent the problem that most people forget a significant amount of relevant connections when asked to list them in an open-ended way even if they are friends or in constant contact (Borgatti, Everett, & Johnson, 2013). The roster question pre-

[4] Verschuren et al. (2010) use the word *poll* but the word *survey* shall be used here as it is more common in the research articles reviewed for this research project.

sented a thought-intensive question for the respondents and was, therefore, placed in the beginning. The reasoning behind this was to avoid surveys stopped mid-way due to decreased concentration.

The second part of the survey aimed at gathering information directly related to the barriers. Five-point Likert scale questions were used in combination with open-ended questions where respondents could elaborate on the reasons for their choices. To avoid losing respondents, open-ended questions were not mandatory and could be skipped. The most sensitive questions about resources of the organizations were placed in the end. This is recommended in survey research to avoid deterring respondents in the beginning. After having answered all other questions, it is most likely that respondents then either also answer the sensitive questions or at least send the survey in with these questions empty, but all others filled in. Five-point Likert scales have the disadvantage of pre-determining statements and, therefore, answer options. Since the survey dealt with behavior, opinions, and expectations, however, Likert scales are a common way, especially in research in psychology, to achieve comparable results. While this research had no purely quantitative element, the commonly assumed equal distances between the answer options in Likert scales were intended to allow for a semi-quantitative comparison of frequencies in addition to the more open-ended information coded from the documents, open-ended survey questions and interviews.

To execute the online survey, contact details and email addresses of all 95 identified actors were searched online and through institute connections of Fraunhofer ISI. The goal was to find representatives of each organization which were able to give a valid account of their organization's stance on the technology of CHT. The contacted respondent sample was then a mix of subject-specific professionals such as CEOs or project leaders and organization representatives such as communication and press relations professionals. This approach proved functional and emails were often forwarded to a more knowledgeable person on the issue which resulted in the majority of answers coming from subject-specific professionals. The sent invitation email contained an actor-specific link including a code with which the survey could be accessed and sent in once. This avoided duplicate answers from the same organization.

The invitation email and first page of the survey included the information that all inserted data would be treated confidentially and would be aggregated and made anonymous for the analysis. The survey was sent out on a Wednesday afternoon, since statistically this has proven to elicit the highest response rates amongst office professionals. When possible in terms of contact details, each email was personalized to the respondent according to their name and position. One week and two weeks after the initial invitation email, reminders were sent to those actors who had not yet completed the survey. The reminders proved to greatly increase the answer rate. In total, 45 answers were received, amounting to a 47,37% return rate.

For empirical social science research which gathers information from organizations, this represents a high number (Baruch & Holtom, 2008). For the first part of the survey, however, this is slightly different. In SNA, technically only 100% answer rates are acceptable when aiming to illustrate a full network to avoid omission errors (Borgatti et al., 2013). There are, however, some ways around this dilemma which were used here. First, the collected network data for this project was undirected. This means that it did not matter in which directions actors were connected with each other since communication can generally be assumed to be a two-way activity. Therefore, the network could be symmetrized which means that connections of missing actors were filled in with the connections to this actor mentioned by other respondents. This is commonly referred to as data cleaning in SNA (Borgatti et al., 2013).

Secondly, the network data gathered in the survey was compared with network data found based on a prior document search. The results showed that save a few exceptions, the survey only added connections and that connections identified in the document search were, therefore, generally not wrongly identified. This showed that the document data could be a valid addition for actors which did not respond to the survey since it yielded only slightly incomplete but not invalid results. To make up for missing entries in the survey, the two matrices were therefore merged. The only remaining drawback of not having all respondents answer the survey was then a slightly less dense network than presumably exists in reality. The reason for the comparative validity but incompleteness of the document-based network seems rather clear: documents only show official, often project-related connections while, in reality, many actors have spoken to other organizations about CHT without any official accounts of such conversations. This further underlines the importance of having collected empirical data directly from the actors through the survey.

4.2.3 Interviews

Interviews were planned specifically to gather more nuanced information on barriers related to the perceptions, expectations, and motifs of actors. Likert scale and open-ended questions of the survey could cover most of the desired data and had the advantage of reaching a large number of actors. Nevertheless, the limited time that respondents generally spend on surveys and the restricted willingness with which survey respondents generally answer open-ended questions restricted the possibilities of getting a full and direct account of, for example, actors' expectations. While some of this information could be inferred from answers, interviews provided a way to triangulate this information with direct accounts.

However, clearly not all identified 94 actors could be interviewed due to time restrictions. A choice had to be made. The most influential actors were chosen for interviews based on their position in the established actor network. Actors were ranked according to their centrality, that is their connectedness, in the network. Betweenness centrality was chosen as the measure since "it reflects the amount of brokerage each node has between all other nodes in the network" (Borgatti et al., 2013, p. 180). Betweenness centrality measures the frequency with which a node lies on the shortest path between two other nodes, that is it "depends on the extent to which he or she is needed as a link in the chains of contact" (Nooy, Mrvar, & Batagelj, 2011, p. 150). More simply put, "nodes with high betweenness are in a position to threaten the network with disruption of operations" (Borgatti et al., 2013, p. 175). The scores of betweenness centrality for the merged network are visualized in the node sizes of Figure 9.

The six most influential actors were easily visible with a large numerical cut to the second group and a gradual fade towards all other actors. Based on these scores and the geographical delineation to Germany resulting in excluding one Swedish actor, the ten actors of the first and second group were chosen to be interviewed. Interviewees were invited based on the same contact details which were used for the survey. The interviews were then conducted as semi-structured interviews based on a list of questions which had to be included but could be slightly altered in the order they were presented (see Appendix E for the interview questions). The interviews were conducted via telephone and one in person since it was shown in methodology research that such a change in modes is not expected to significantly alter the results gathered from an interview if it does not deal with a specifically sensitive topic (Bryman, 2016). All interviews were recorded with the permission of the interviewees and subsequently transcribed. In total, six interviews were conducted.

Table 4. Overview of methods approach for each barrier.

Barrier	Sources	Data collection method	Data analysis method
Barrier 1-A	people (relevant actors); documents (newspaper articles); documents (actor publications)	document search; survey; interviews	content analysis; semi-quantitative analysis
Barrier 1-B	documents (newspaper articles)	keyword search newspaper databases	content analysis; semi-quantitative analysis
Barrier 2	people (relevant actors); documents (actor publications); documents (newspaper articles)	document search; survey; interviews	[information extraction]*; content analysis
Barrier 3	people (expert); documents (newspaper articles); documents (actor publications)	[expert interview]; document search; survey	[information extraction]; social network analysis; semi-quantitative analysis
Barrier 4	people (relevant actors); documents (actor publications); documents (newspaper articles)	document search; survey; interviews	content analysis; semi-quantitative analysis
Barrier 5-A	people (relevant actors); documents (actor publications)	document search; survey	[information extraction]*
Barrier 5-B	documents (newspaper articles)	keyword search newspaper databases	content analysis; semi-quantitative analysis
Barrier 5-C	documents (actor publications)	document search	[information extraction]; content analysis
Barrier 6	people (relevant actors); people (expert); documents (newspapers); documents (actor publications)	document search; survey	content analysis; social network analysis; semi-quantitative analysis

* square brackets indicate collection of descriptive information (in contrast to collection of raw data for the empirical analysis).

Table 4 gives an overview of the sources, data collection methods, and data analysis methods used for the assessment of the individual barriers. Divisions of barriers indicate that their subparts were respectively analyzed with different methods. As is evident from the repetition of certain combinations, the methods were chosen with the aim to be useful for as many barriers as possible despite the variety of barriers.

4.3 Data analysis

The main goal of data analysis in this research project was to allow for an assessment of the six barriers based on the gathered descriptive information and raw data. This involved to main steps. First, actors had to be identified and classified and the relations between these actors and their characteristics had to be made analyzable. This was achieved through a social network analysis. Secondly, the gathered descriptive information and raw data had to be analyzed for the barrier assessment. This was achieved through the main method of content analysis, supplemented by semi-quantitative analyses.

4.3.1 Social network analysis

SNA was chosen as a method for illustrating and analyzing the characteristics and connections between the identified relevant actors around CHT in this research project. As laid out in section 4.2.1, the relevant actors and their connections were first established through keyword searches. In the survey, as described in section 4.2.2, this connection information was then supplemented with accounts of communication provided by the actors themselves. The connection information was stored in a matrix in an undirected format, that is in dichotomous numbers [0,1]. For the creation of illustrative network graphs and the analysis of network and actor properties in relation to the network, these matrices were imported into the social network analysis program UCINET which includes the illustrative tool NetDraw. Classifications of actors according to their type, such as government or R&D, or according to their level, such as regime or niche, were imported as additional attribute datasets and could, in this way, be applied to the initial network.

SNA allows for the calculation of numerical characteristics of both individual nodes, i.e. the dots of the network which are the individual actors, or the network as a whole. To determine the most central actors for interviews, the former was used as laid out in section 4.2.3.. To describe and compare network structures in the results section, the latter was used.

4.3.2 Content analysis and semi-quantitative approaches

Content analysis allows for a systematic and replicable analysis of documents and texts according to predetermined or iteratively developed categories. As Bryman (2016) summarizes, content analysis can be used for "many different forms of unstructured information, such as transcripts and semi- and unstructured interviews or answers to open-ended questions in surveys" (p.284), all of which make up the central part of this research. Due to the extensive amount of data collected for this research project, the qualitative analysis software NVIVO was used as a database and analytical tool.

In line with Bryman's (2016) definition, content analysis in this research project was first understood as a quantitative exercise, for example when determining overall sentiment scores towards CHT in newspaper articles and when determining which actors and respective opinions were most prominent in newspaper coverage. However, scoring sentiments as a kind of disposition reflects a higher level of interpretation than merely counting words to determine how often a certain phenomenon was mentioned. This introduces greater room for researcher bias which is why this step was supported with a coding manual (see Appendix C), an approach which is more common in qualitative content analysis.

A more qualitative, or often called ethnographic approach to content analysis was pursued for the assessment of barriers where the operationalization did not suggest fixed codes for assessing the data. Here, themes were extracted in going along the raw data which were then reported with the aid of illustrative quotes (Bryman, 2016). This was the case, for example for the assessment of overlap between expectations in barrier 4. To compare coded parts of the text for actors with certain attributes, such as a specific level like niche or regime, the matrix function of NVIVO was used. An example of a such a matrix usage would be to show all coded parts of texts where niche actors voiced an expectation towards the future development of the technology.

In addition to content analysis, semi-quantitative approaches were used to analyze the descriptive information gathered in actor publications and the survey. Semi-quantitative analysis is not a fixed method in itself. It lies between qualitative and quantitative efforts and generally refers to the ranking and comparison of results without a fixed reference scale. Example are the attestation of *more* or *less* of something i.e. ranking via an ordinal scale. For this research, this provided the analytical approach for ranking information such as the amount of resources available to actors and, for example, deter-

mining tendencies such as which issues or expectations were named the most or the least by actor groups with certain attributes and how strong the thematic overlaps were. Although they are often used in a quantitative manner in other research, the Likert scales in the gathered survey results were only used in this semi-quantitative manner as this was determined to be more robust given the fixed actors and limitations of the sample size.

5. Results

This section presents the results of the research project in three steps, parallel to the depiction in Figure 6. First, the results of the actor classification are reported, followed by the illustration of the gathered network information. Finally, the majority of the section presents the results of the barrier assessment.

5.1 Actor classification

In a first research step, a list of all relevant actors around the technology of CHT was developed. A list with the full names of all actors and English translations can be found in Appendix B. Most identified actors were found to be organizations, that is actor constellations. In this research project, they are nevertheless identified as single, homogenous actors for analytical simplification. To provide a first overview of the actors, Table 4 shows a preliminary categorization according to a governance level and institutional typology (Fischer & Newig, 2016). The institutional categorization based on Späth, Rohracher, and Radecki (2016) represents the actors' respective role in society: government, R&D, industry, and civil society. This allowed for a first overview of the types of involved actors.

Table 5. Institutional and governance level typology of relevant actors around CHT.

	International	Sweden	USA	Germany (federal level)	Baden-Württemberg	Hessen	Schleswig-Holstein
Government		Energimyndigheten; Näringsdepartementet; Region of Gävleborg; Trafikverket; Vinnova	California Energy Commission; EPA; City of Los Angeles; SCAQMD	BaSt; BMU; BMVI; BMWI; UBA; SRU	E-mobil BW; City of Kuppenheim; Regierungspräsidium Karlsruhe; City of Rastatt; VM BW	Hessen mobil; VM Hessen	MELUND SH; County of Stormarn; City of Lübeck; LBV SH; VM SH
R&D	INFRAS	Chalmers; KTH; RISE Viktoria		DLR; DVGW-Forschungsstelle KIT; Fraunhofer IAO; Fraunhofer ICT; Fraunhofer IML; Fraunhofer ISI; Fraunhofer IWES; FZI; ifeu; Intraplan Consult; M-Five; Öko-Institut; PTV Transport Consult	HS Heilbronn;	TU Darmstadt	FH Kiel; TU Dresden; TU Hamburg - Harburg
Industry	CLECAT; DAF; Daimler; Ford; IVECO; Mack Trucks; MAN Truck & Bus; Renault; Scania; Siemens; Volvo		LA Metro; Port of Long Beach; TransPower	BGL; Deutsche Bahn; DSLV; VDI/VDE; VDV	Casimir Kast; Huetteman Holding; Mayr-Melnhof; Netze BW; Smurfit Kappa; Spedition Fahrner; SWEG; VSL BW	Contargo; DAW; ENTEGA; HEAG mobilo; Hegro Eichler; Meyer Logistik; RWZ; Spedition Schanz	Hans Lehmann KG; LHG; Schleswig-Holstein Netz AG; Spedition Bode; Unternehmerverband Logistik SH
Society	ICCT			ADAC; Agora Verkehrswende; Allianz pro Schiene; Greenpeace; NABU			

As a preparation for the barrier assessment, the actors were then formally classified according to the three levels of regime, TIS, and niche. The classification of actors into the three levels was done based on the definitions in section 3.4.3 and on empirical information about the actors' attributes and positions based on documents and the carried-out survey. The decision tree for this classification can be found in Appendix F. While individual classification decisions cannot be illustrated here due to anonymity reasons regarding the survey results, general decisions regarding the classification and an overview of the group sizes will be laid out in the following. First, it is important to note that actors could be classified as belonging to more than one level. The possibility for such a classification has been illustrated in MLP literature before with, for example, incumbents (representing the regime) as niche innovators of battery-electric vehicles (Späth et al., 2016). The two possible combinations were regime - TIS and regime - niche. TIS - niche was not a possible combination since, as Figure 4 shows, a niche actor is automatically a part of the TIS but not the other way around.

Actors were assigned to the combination of regime - TIS if they generally perpetuated the rules, norms, or values of the dominant regime of fossil-fuel based road freight transport but were generally open towards the new technology and showed this by, for example, conducting research on the topic. This combination of categories was, therefore, mainly assigned to research institutes and universities but also to municipalities and governmental agencies. In total, 21 actors were assigned to this combination. An additional four actors were assigned to the combination of parallel regime – TIS due to the same rationale but a perpetuation of the rules, norms, or values of a parallel transport regime. The parallel regimes found to be relevant for this research were the fossil-fuel powered car regime, the rail regime, and the public transport regime. This distinction is important as those actors were not accounted for in the barriers dealing with characteristics and actions of regime actors but only in the TIS-related barriers. Actors related to the field trials in the USA and Sweden were considered to be of parallel niches and therefore had no influence on the subsequent barrier assessment. Other possible parallel niches such as the niche of hydrogen trucks did not come up as categories since only actors directly related to CHT were included in the actor overview of this research.

Actors were assigned to the combination of regime - niche if they generally perpetuate the rules, norms, or values of the dominant regime of fossil-fuel based road freight transport but take specific actions to support the new technology such as taking part in one of the technology trials. This combination was, therefore, mostly assigned to logistics companies, companies taking part in the trials to move their goods, and coordinating or financially supportive government agencies. 33 actors were assigned to this combination. Two additional actors were assigned to belong to the parallel regime – niche combination. The 15 actors assigned to the single category regime were to a large extent industry actors such as truck manufacturers but also governmental actors. Only one actor was assigned exclusively to the niche and six actors exclusively to the TIS. A first finding was, therefore, that the regime played a significant role in the TIS and niche activities.

5.2 Actor networks

Based on a content analysis of publicly available documents, a first network of connections between the identified actors could be drawn. Figure 7 shows this network based on an optimization algorithm of the software UCINET. This algorithm is based on the three criteria of (1) point distance and path distance between nodes, (2) nodes not appearing too close so as not to obscure each other, and (3) a preference for equal-length lines (Borgatti et al., 2013). It is important to note that while this yields an optimally readable graph, it also means that the distances between the points in the diagram do not exactly reflect the path distances based on the network data (Borgatti et al., 2013).

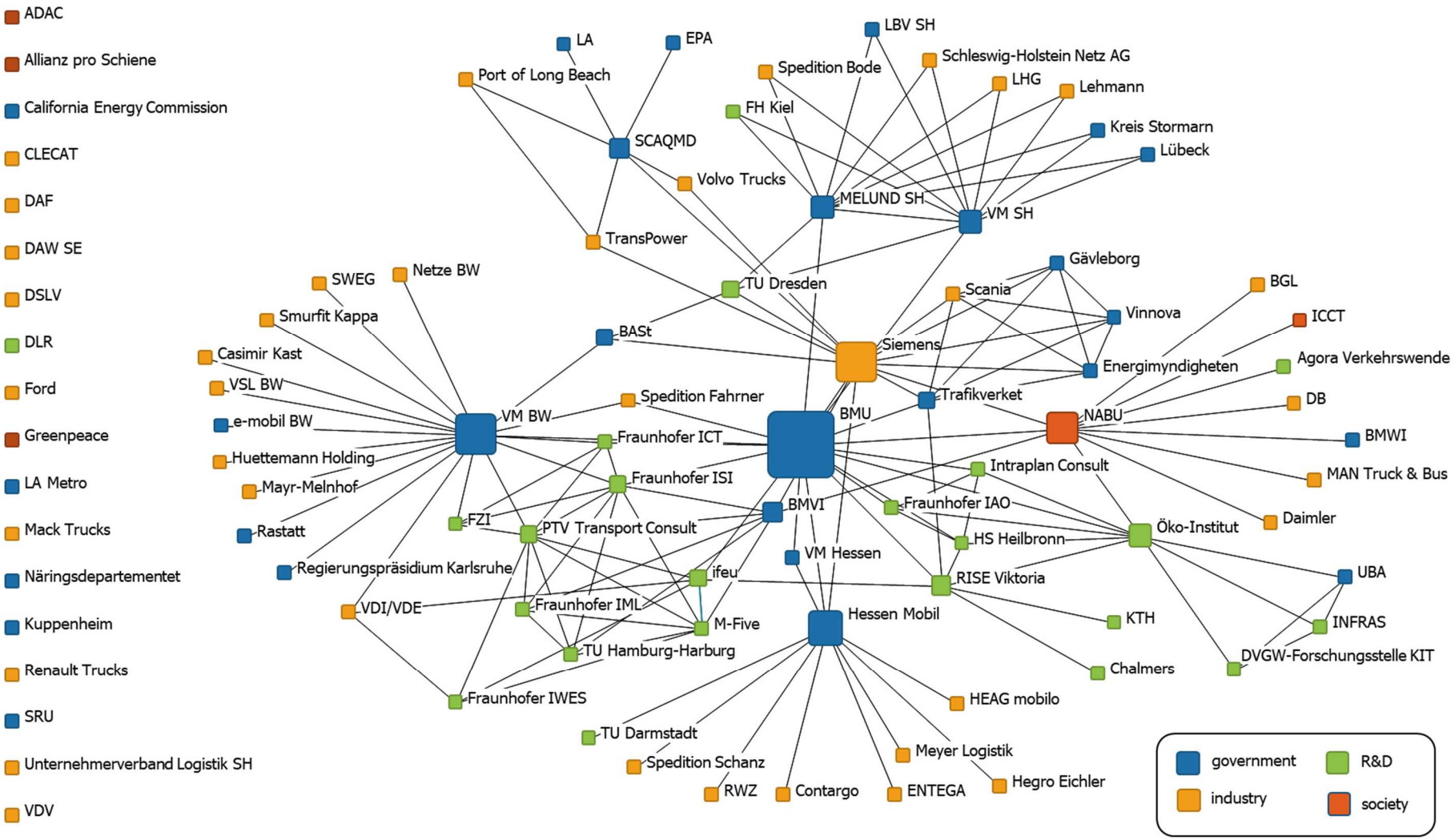

Figure 7. Network depiction based on content analysis. Node size illustrates centrality scores (Freeman betweenness). Actors listed on the left had no direct linkages to other actors based on the document analysis. For full names and English translations of actors see Appendix B.

In this first matrix based on the content analysis, the network showed 292 ties in total and had a density of 0.0334[5]. The average degree of the network, that is the average number of ties that each node (=actor) had was 3.1. The actors with the maximum number of ties were the Transportation Ministry of Baden-Württemberg (18 ties), the BMU (17 ties), and Siemens (14 ties). On the opposite end of the spectrum, 18 out of all actors identified as relevant had 0 ties and were hence not connected to any other actors. As a more complex measure for the position of individual, the size of the nodes in the network illustrates their respective centrality scores in terms of Freeman betweenness. As explained in section 4.2.3, nodes with high betweenness are brokers in the network and most needed as a link between actors. In this first network, the BMU, Siemens, the Transportation Ministry of Baden-Württemberg, Hessen Mobil as a sub-agency of the Transportation Ministry of Hessen, and NABU can be made out to have the highest betweenness scores[6].

The actors with the largest nodes can mostly be found in the middle of the network depiction and largely belong to the actor group of government actors involved in the initiation and coordination of the field trials in Germany. Around the periphery of the graph, many actors with only one connection are found. In parallel to the coordinating actors made out before, the majority of these actors can be identified as participants of the field trials in Germany. These actors on the periphery are, to a large extend, industry actors. The denser parts between the outer and inner part of the graph are occupied by different actor groups but most notably R&D actors. The two main clusters can be found on the bottom left and bottom right of the network.

The connection data gathered in the survey supplemented this preliminary network research. Figure 8 shows the network based on the data provided by respondents in this survey. The nodes representing the individual actors are anonymized based on the type of actor.

[5] As one of the simplest measures of total network cohesion, density is "the number of ties in the network expressed as a proportion of the number possible" (Borgatti et al., 2013, p. 150). It can therefore be interpreted as "the probability that a tie exists between any pair of randomly chosen nodes" (ibid). In absolute term, the meaning of this measure varies so it should be interpreted in relation to the density values of other networks.

[6] For full names and English translations of actors see Appendix B.

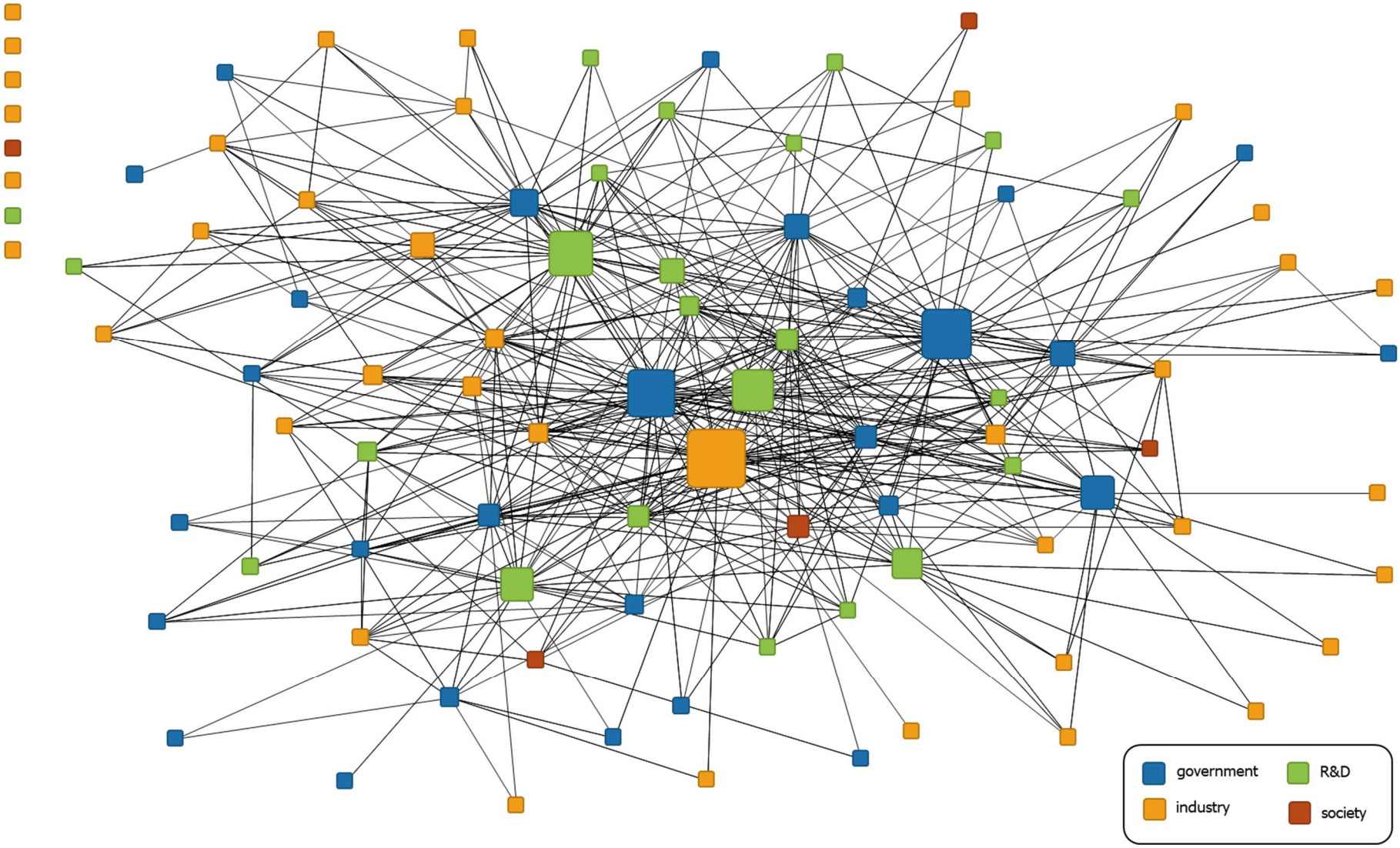

Figure 8. Network depiction based on survey results. Node size illustrates centrality scores (Freeman betweenness). Actors listed on the left had no direct linkages to other actors based on the respondents' information.

This second matrix based on the survey results had a total of 934 ties and a density of 0.1046. Overall, the network was therefore around three times denser than the network established based on the content analysis of documents. The average degree of the network, that is the average number of ties that each node (=actor) had was also around three times as high at 8.9. Only 8 actors were left with no connection to the other actors.

The maximum number of ties by individual actors were considerably higher at two times 45 and one time 41 ties for the highest-ranking actors. In this second network, the largest nodes show that the characteristics of the most central actors in terms of betweenness changed. Most notably, R&D actors filled a more central position.

Around the periphery of the graph, the actors with least connections could still be found and identified as industry actors. However, their connections largely changed from only one to predominantly two connections. Except for one very central industry actor, the actors in the brokerage roles, centrally connecting the network, can be identified as government and R&D actors. The least central actor group in this network is that of society actors.

Overall, the second network is much more connected than the first network. As touched upon in the Methods section, this could be expected since it is likely that actors communicated more about CHT with each other, possibly in informal or non-recorded settings, than official documents showed. Due to the overall increased connectedness of the graph, there are less discernible clusters.

As laid out in the Methods section, a comparison of the first and second actor network showed that the survey almost only added connections and that connections identified in the document search were, therefore, generally not wrongly identified. Document data was, therefore, used as an addition for actors who did not respond to the survey. The two matrices were, therefore, merged by determining a connection in the merged network if there was a connection in any of the two networks[7]. Figure 9 illustrates this merged network. The nodes representing the individual actors are anonymized based on the conceptual level of the actor.

[7] The possible decisions were therefore: (1,1,1), (1,0,1), (0,1,1), (0,0,0).

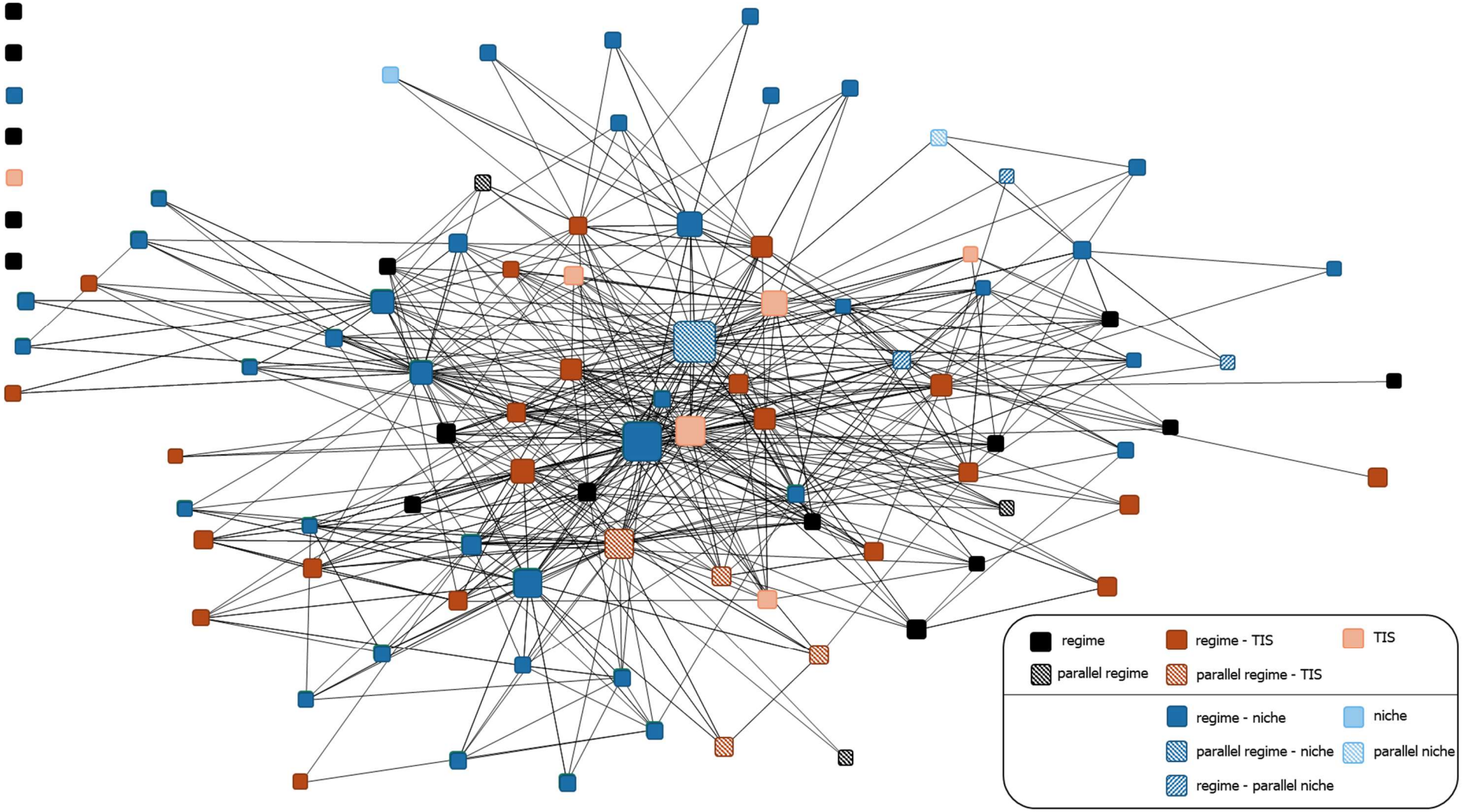

Figure 9. Network depiction based on content analysis and survey data**.** Colors indicate the respective conceptual levels. The main parallel regimes are the fossil-fuel powered car regime, rail regime, and the public transport regime. Parallel niches are field trials in the USA and Sweden.

This network no longer shows the different actor types according to an institutional typology. As a preparation for the barrier assessment and in line with the theoretical framework, it shows the actors divided into the different conceptual levels.

The network had 660 ties and a density of 0.0755. As could be expected it therefore ranks between the first and second network in these scores. The average degree of the network, that is the average number of ties that each node (=actor) had was slightly higher than the average on the second network at 10.3. The highest-ranking actors had two times 46 and one time 41 connections, almost mirroring the second network. 7 actors were found to not be connected to any other actors. The actors with the largest nodes, that is the largest betweenness scores, were actors of the conceptual level combinations of regime – niche, regime – TIS, and TIS. The two actors that were only part of a niche were amongst the least connected.

Similarly to the second network, visually no clusters could be made out anymore. Furthermore, in this network, actors of all conceptual levels could be found in central positions. One pattern could, however, be made out with respect to regime actors. Regime actors dominated the group of unconnected actors. Additionally, actors who were only regime or parallel regime actors were generally less central than actors who were both enacting the regime but also a part of the TIS or niche. Hence, many of the identified possibly relevant regime actors have not yet communicated or been in close exchange about the topic of CHT with any other relevant actors. Overall, the established actor networks allowed for a first overview and characterization of the actor landscape around CHT. However, the network structure alone does not suffice in determining whether or not the technology is likely to be implemented. The following section, therefore, uses the networks as a comprehensive basis for a barrier assessment.

5.3 Barrier assessment

This section presents the individual barrier assessments of the six identified barriers to the implementation of CHT. Table 6 gives an overview of the final scoring of each barrier.

Table 6. Barrier assessment scores.

Level	Barrier	Score
TIS	*Barrier 1:* Lack of legitimation	no barrier
	Barrier 2: Lack of support from advocacy coalitions	slight to no barrier
Niche	*Barrier 3:* No or small (social) networks (without powerful actors)	no barrier
	Barrier 4: No precise and broadly accepted expectations	slight barrier
Regime	*Barrier 5:* Resistance by regime actors through instrumental, discursive, and material forms of power	slight barrier
	Barrier 6: No or small overlap between regime actors and TIS actors	no barrier

5.3.1 TIS

The two barriers assessed on the level of TIS were the possible lack of legitimation and the possible lack of support from advocacy coalitions. With regards to legitimation, no barrier was found. With regards to the support from advocacy coalitions, a slight to no barrier was found.

Barrier 1: Lack of legitimation

Table 7. Barrier assessment results and scores for barrier 1.

Level	Barrier	Operationalizing question	Results	Score
TIS	*Barrier 1:* Lack of legitimation	Is the depiction of CPT more positive or negative		
		1) by relevant actors	positive	no barrier
		2) by the media?	positive	no barrier
			Barrier 1:	no barrier

(1) – Is the depiction of the technology more positive or negative by relevant actors?

Overall, the depiction of the technology by the identified actors around CHT was more positive. Data on the depiction of the technology of CHT was gathered through direct statements of actors in their own publications, newspaper articles, and the survey and interviews administered for this research project. In this manner, it was possible to gather direct information revealing judgement of the technology from 61 of the 96 actors.

Six of the identified relevant actors put forward clearly negative accounts of the technology. Among these actors were four actors of the classification combination industry – regime, one actor of the classification combination civil society – parallel regime, and one actor of the classification combination R&D – regime. Negative depictions revolved around the perceived wrong application context of the technology, its competitive relation for funds vis-à-vis the transport mode of rail, the perceived lacking feasibility of implementing this technology internationally in a reasonable time frame, and the high costs. As one actor put it:

> "Will it really be possible to build such a massive and new infrastructure like electric lines next to highways across borders in a conceivable time frame?"[89]

Positive depictions prevail in the analyzed data and were openly presented by 48 actors. The largest groups among these actors were 12 industry actors classified as regime – niche, 9 government actors

[8] Translations from German into English are author's own.

[9] Direct quotes gathered through the survey and interviews were anonymized in the analysis. Direct quotes of publicly available documents such as newspaper articles and publications were not anonymized (see e.g. quotes under Barrier 2).

classified as regime – niche, and 9 R&D actors classified as regime – TIS. Sorted by conceptual levels rather than types, most actors that positively depicted the technology were either regime – niche (21 actors) or regime – TIS (16 actors).

The positive depictions revolved around four main categories: (1) impacts on the environment and climate, (2) other impacts, (3) advantages over alternative technologies, and (4) the business case. The impacts on the environment and climate were mentioned by more than half of the actors (28 out of 48), with 15 actors directly pointing out the possible reductions in GHG emissions and the related contribution to the international climate goals. Furthermore, 10 actors pointed out the possibility of emissions-free driving in the ideal case where the energy used for the CHT was exclusively renewable energy. The reduction of local emissions was separately mentioned as a positive point by 6 authors. Other categories included environmental benefits and a reduction of impacts in general, cleaner transport, and the possibility to use available renewable energy. 9 actors pointed out other impacts as a reason for their positive inclination towards CHT – the largest category being a reduction of traffic noises which was deemed positive by 6 actors. Furthermore, the benefits of no noticeable effects on other car traffic, no inhibition on operational processes, and the benefits to public health were mentioned. Advantages over alternative technologies were considered a crucial positive aspect by 15 actors. The top categories were the higher energy efficiency, mentioned by 12 actors and the higher cost-effectiveness, mentioned by 8 actors. One actor also considered the technology to be safer. Finally, four actors pointed out possible positive business cases to be created by the technology. One actor each mentioned securing the existence of firms through securing a sustainable transportation connection, standing out in the intense competition of logistics, and the potential creation of projects and high-skilled jobs.

Two things have to be noted here. First, many actors, especially in the R&D – TIS classification, adhered to a neutral stance. They mentioned the possible advantages of the technology but remained scientifically critical. Only those who clearly stressed the advantages of the technology and only considered critical factors as a barrier to the necessary implementation, were coded as giving a positive depiction. Many actors presenting a more balanced view were put in the neutral category, not influencing the balance towards one side.

Secondly, the representation of the regime influences the balance of depictions. While, for example, the logistics companies who are part of the field trials in Germany are each represented individually, all other logistics companies are included in an aggregated way through their industry associations. Furthermore, negative descriptions were mostly put forward by regime actors. Many of the identified regime actors with similar characteristics as the abovementioned actors with negative accounts, have not provided any statements on the technology yet. It is, therefore, important to restrict the informative value of the currently positive balance to the available statements of the past and the current moment.

(2) - Is the depiction of the technology more positive or negative by the media?

The depiction of the technology of CHT in the media as a whole was measured through the proxy of its depiction in newspaper articles. The representative sample of articles taken from German newspapers showed that, overall, the technology of CHT was depicted more positively than negatively with one exception.

The tone of each article was judged as positive, neutral, or negative based on a list of criteria (see Appendix C for the list and the used decision tree diagram). Overall, 10 articles were accordingly

categorized as negative, 38 as having a neutral tone, and 26 as being positive towards the technology (see Appendix C for the classification overview of the individual articles). Within the negative and positive categories, 19 articles in total were coded as only "slightly positive/negative" since their tone was not neutral but not strongly leaning towards either side. This was especially true for the category of positive depiction with 17 out of 26 articles. Negative articles were generally more upfront about criticizing the technology while positive accounts were subtler by using positive language and less counter-arguments rather than openly voicing their support for the technology.

The exception to the overall positive depiction of CHT in the media was found amongst the 10 articles coded as having a negative tone. Three of these articles were not written by newspaper authors but were reader contributions to the publication. These were not cut from the sample based on the reasoning that they were added to the publication by an editor with a certain purpose in mind. The reader contributions were read and processed by the same general audience as the other articles of the publication and can, therefore, be assumed to have had a similar influence on the general opinion of the public. With one article containing independent opinions of three readers, overall 7 negative accounts of the technology of CHT were found. This stands in contrast to only 2 positive and zero neutral reader opinions in the entire sample.

Overall, however, the depiction of the technology of CHT in the media can be said to have been positive between 2013 and 2018 with 26 positive articles outweighing 10 negative articles. Barrier 1 was therefore scored as presenting no barrier.

Barrier 2: Lack of support from advocacy coalitions

Table 8. Barrier assessment results and scores for barrier 2.

Level	Barrier	Operationalizing question	Results	Score
TIS	*Barrier 2:* Lack of support from advocacy coalitions	Do actors		
		1) improve technical, institutional, and financial conditions for CHT?	yes	no barrier
			no - partly	slight barrier
			yes	no barrier
		2) lobby for the improvement of technical, institutional, and financial conditions for CHT?	no - partly	barrier to slight barrier*
			partly	slight barrier*
			no	barrier*
			Barrier 2:	slight to no barrier

* not counted towards the barrier score.

For this barrier, the available data was analyzed towards the question of whether actors improve and lobby for the improvement of technical, institutional, and financial conditions for CHT with their actions. As laid out below, a formal assessment of lobbying activities was not possible for this young technological field. Nevertheless, first inquiries into lobbying activities were made with the help of proxies. Due to this exploratory approach, however, part (2) of this barrier was not counted towards the overall score.

(1) Do actors improve the technical, institutional, and financial conditions for CHT?

For this assessment, improving technical conditions was understood as contributing to the technical development of a relevant part of or the whole technology and its installation with the purpose of improving CHT and their implementation. This excluded, for example, new technological developments around overhead lines from other contexts such as R&D in rail companies. Such developments have the potential to benefit the technology but cannot be considered direct actions of advocacy coalitions for CHT. Improving institutional conditions was understood as contributing to the change of regulations, norms, and routine behavior in favor of implementing the technology of CHT[10]. This excluded, for example, actions supporting measures regulating diesel trucks in general without a direct connection to CHT since this could also strengthen other alternative technologies. Thirdly, improvement of financial conditions was understood as directly supporting the development of CHT with financial means including both funding research and technology development as well as financing field trials and comparable activities.

Activities improving the technical conditions

The applications on highways in the USA and Sweden have shown, that the technology is ready to be applied in a real-world context. Three field trials in Germany over the next few years will add to the real-world application of the technology, both on highways and under more structurally diverse public road conditions. In order to be developed to this point, the technology has received large technological support. The activities of this improvement of technical conditions can be divided into three main categories: (1) the development of the pantograph technology and infrastructure, (2) the remodeling of trucks, and (3) the adjustment of the energy grid to accommodate the new technology.

The development of the necessary pantograph technology and infrastructure was so far mainly covered by R&D activities of the company Siemens. Partners to this development were research institutes of technical universities, both in Sweden and in Germany, for example in the project ENUBA 2 (for a full project overview see Appendix A). In addition to the newly developed parts of pantograph and infrastructure, the technology requires adjusted hybrid propulsion vehicles. The vehicles used in the applications so far were adjusted by two actor groups. In Sweden, Siemens cooperated directly with the truck manufacturer Scania to add the pantograph technology to trucks and integrate the external power supply into the propulsion of the vehicles. In other cases, such as in the USA and on the test track in Germany, existing trucks from large truck manufacturers were retrofitted with the technology in a cooperation of Siemens and third-party actors. Finally, the real-world application cases required technical support for extending the energy grid to accommodate the technology. Activities around this technological aspect were carried out by network operators in cooperation with Siemens. For the planned research trials in Germany, network operators are already a part of the actor landscape and

[10] Institutions were defined and operationalized in this way based on the definitions used in the TIS literature from which the barrier was drawn. Bergek et al. (2008) build on a definition of Douglas North and consider institutions as mainly “culture, norms, laws, regulations and routines” (p.413). However, the examples they give following this definition fall predominantly under laws and regulations. The article by Suurs et al. (2009) also mainly shows a definition of institutions as policy-related measures such as regulations and subsidy programmes. Both the formal and more informal definition of institutions shall, therefore, be included but with a specific regard for the former.

will also support the technical conditions. In total, there has hence been large technical support which allowed the technology to develop enough for real-world applications and therefore no barrier.

Activities improving the institutional conditions

So far, no regulations or laws have been adjusted or introduced to specifically address CHT. For the future, the Federal Environmental Ministry of Germany (BMU) considers the introduction of incentives for users of the technology. In the press, former environmental minister Dr. Barbara Hendricks stated that there could be start-up financing and conventional incentive programmes for environmentally-friendly trucks as well as possible toll-reductions or exemptions for CHT (Dapp, 2017; Tartler, 2017). Such incentives have, however, not been introduced yet. Two developments can be seen as first steps towards improving institutional conditions in terms of policies or regulations. In Germany, government programmes have been introduced which included research parts for CHT. The Action Programme Climate Protection 2020[11], for example, was passed by the federal cabinet in December 2014 which also included the decision to do field trials (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2018). These programmes, issued from an institutional authority, present a formal way of first introducing the new technology into the political context.

Surrounding the field trials in Germany, exemptions from two existing regulations have been discussed and implemented. First, one of the main challenges so far was to acquire the respective planning permission within the current institutional context. Full planning approval procedures[12] for highway infrastructure in Germany can currently take years. While no active changes were made to existing regulations, actors in all three field trials were able to work with the current institutional conditions to find short-cuts for the trials. A second challenge was presented by the added weight that the new technology adds to trucks which would reduce their actual load. In Hessen, industry and government have worked together to allow an additional amount of 1.000 kg of actual load for the used trucks. These two activities can be seen as a first step to questioning routine behavior and conventional regulations.

Finally, newspapers and some involved actors contributed to changing norms and routine behavior in a discursive way. In more than ten of the newspaper articles analyzed for this research, the respective author, or quoted actors such as Siemens, the BMU or VM Hessen[13] directly refer to the absurdity, unusualness or seeming outdatedness of the technology of CHT. In the same sentence, article or paragraph, the same actors then lay out why this initial appearance does, according to their opinion, not hold or why they have overcome it. It can be argued that, in this way, the actors contribute to changing the more informal norms and routine behaviors around how a highway or a truck function and what they should look like. Based on these first steps but no larger changes in the institutional landscape so far, this sub-barrier was scored as a slight barrier.

[11] German = Aktionsprogramm Klimaschutz 2020

[12] German = Plangenehmigungsverfahren

[13] For full names and English translations see Appendix B.

Activities improving the financial conditions

So far, the financial support for CHT has mainly come from actors categorized as both regime and niche. On the one side, these are the industry actors who have developed the prototypes of the technology for the application contexts of Sweden, USA, and Germany. On the other side are the government actors who provided and are going to provide the main share of the funding for the trial projects. The main projects around CHT which have been executed and planned so far and the related financial investments are summarized in Appendix A. This overview shows that there has been considerable financial support for the development of CHT. In addition to the large regime and niche actors providing funds, smaller actors have recently entered the project environments around the field trials. However, while the survey and interview data suggest that there is additional financial support coming directly from these actors in terms of preparatory time and money spent, it is not yet possible to come to a general sum of these amounts. This would in any case only add to the already significant financial support and the sub-score was set at no barrier.

(2) Do actors lobby for the improvement of technical, institutional, and financial conditions for CHT?

Lobbying can be defined as "the interaction of an individual, group, interest, or organization with government to influence current policy or create a situation conducive to shaping future policy" (Berg-Schlosser & Badie, 2011). The activities for achieving such a situation are getting access to and building a relationship with the actors who can make the decisions and influencing these actors (Berg-Schlosser & Badie, 2011). In a more formal sense, lobbying can be operationalized through the amount of information that official interest representatives, such as industry associations, exchange with government officials on a certain topic (Klüver, 2013).

For the actor environment around CHT, a large number of communication ties on the specific topic could be made out between governments and actors of industry, R&D, as well as society (see Figure 7 and Figure 8). Currently, governments are the main providers of funding and initiative to push the still young technology. The direct accounts collected by relevant actors around the technology, therefore, currently indicate no concern with generally putting the technology on the government agenda as it is perceived to already be on the agenda. However, strong opinions and ideas for change with regard to the actions of the government could be made out in the survey and interviews when discussing the technology and future developments in more detail. Given the assumption that such opinions are also voiced towards other actors and directly or indirectly (for example through statements given to newspapers) to actors of the government, these actions can be seen as a first step towards lobbying. In the following, these actions will be assessed under the three categories of lobbying for the improvement of technical conditions, institutional conditions, and financial conditions.

Lobbying for the improvement of technical conditions

As described above, the technical conditions of CHT have been developed far enough to enable the usage of the technology in real-world applications. The planned field trials are seen, by many actors, as a way to further develop and improve the technology:

> "[In the trial], important traffic- and energy-technical aspects are investigated to enable a later comprehensive extension of the system."

> „ […] positive insights for example from the testing in Sweden or the field trials in Germany can contribute [to the success]. That means, that within the planned times, the construction can be built and are built, that the experiments take place, that it is possible to really implement the a priori rather theoretically estimated and expected insights in daily operations also with multiple vehicles."

Lobbying for the establishment of field trials could, therefore, be seen as lobbying for the improvement of technical conditions. However, the official initiator for the field trials has again been the BMU as a part of the government. Possible prior lobbying activities for the general establishment of such trials by industry actors could not be found. One public statement by an industry actor suggests active lobbying but does not hold as much weight since it regards the place for the establishment of a field trial rather than their general establishment. There, Dieter Fahrner, director of Spedition Fahrner recounts:

> "I heard about the planned catenary tests in Schleswig-Holstein and Hessen through the press. So I asked our representative in the state parliament why the state of the automobile is actually not involved in such tests. I made a route suggestion and everything finally really got rolling when the Transportation Ministry stepped in."
>
> "Through a representative in the state parliament, I tried to transport the advantages of this project for us and for Baden-Württemberg to the decision makers. First, a few weeks later, the message came that Baden-Württemberg would not be available for this project. I was all the more delighted, when head of ministerial division Zembrot contacted me in the beginning of July and expressed great interest in this trial."

Furthermore, a few actors believe that the technology can only reach its full potential and application, if it becomes the only one supported by the government:

> "One has to actually rather think big and say: no, we need a clear decision on the direction. And then it has to be clear that the technology must come nation-wide as soon as possible. And I could also imagine, and this direction is thought about currently, if future projects should not be secured more strongly through appropriate laws. So, I could for example imagine that one simply enacts a project law where the German Bundestag says, we as the Federal Republic of Germany now go with the catenary technology[14]."
>
> "And what has to happen. Well, at some point the Federal Government or the ministries have to let go of being completely open in terms of propulsion options and of continuing to research in a results-open way about the different propulsion technologies. At some point they have to decide for one technology and pursue that one."

This can be seen as a first step towards lobbying for the more general improvement of technical conditions of CHT. On the other hand, most actors currently still favor "technology-openness" and hesitate to focus on only one technology like CHT. Overall, even with the necessary loose definition, not much lobbying for the improvement of technical conditions could therefore be found. This sub-part was accordingly scored with showing a barrier to a slight barrier.

[14] German = „wir setzen als Bundesrepublik Deutschland jetzt auf Oberleitungstechnologie"

Lobbying for the improvement of institutional conditions

The main institutional conditions that supporting actors in Germany are currently worrying about regarding the implementation of CHT are the legal approval procedures, more precisely the planning approval procedures[15] for such an infrastructure. With the start of the field trials, project-coordinating actors point out the need to adjust such procedures. As outlined above, in preparation for the field trials, actors in at least two of the participating states have lobbied for an exemption from the full procedures on the grounds of the experimental nature of the planned trials.

> "[…] we have discussed now that we do not need to conduct a formal approval procedure. (…) And there [in the planning approval procedure], there are exceptional facts of the case[16], if those are fulfilled you can abstain from a planning approval procedure. (…) […] and we see there actually, that all these points are fulfilled and will, therefore, not conduct a formal procedure."

> "We were faced with the challenge to get through the entire procedure within three quarters of a year to even be allowed to build. And that went in a way that is actually unparalleled in a new… so if one would now for example build something like that on another highway […], you would not be able to do it in this way. That, we are talking about pilot projects here, that means other prerequisites apply here, or respectively one can say that it is a field trial. That means one can simplify certain steps in the procedure."

According to one involved actor this followed the initial discussion with the federal level about the legal status of the technology which is now considered a road component much like a large road sign. One actor nicely summarizes what is now expected of the field trials in terms of institutional conditions, indirectly starting lobbying activities towards the legislator:

> "Nevertheless, if such a construction will or is supposed to cross over to a continuous operation later, a full planning approval procedure would have to be done, which could take several years. We could circumvent it this time by obtaining an exemption but centrally precisely through the reasoning that it is a temporary field trial. And that is of course something that cannot be transferred to future permanent constructions. But this is one of the questions we work on during the operation of the field trial: how can such a construction be implemented later? How do such procedures have to go? How could one speed up the procedure time to not wait for three years?"

Lobbying for better institutional conditions has, therefore, started and this sub-part was accordingly scored with a slight barrier.

Lobbying for the improvement of financial conditions

The current development phase of the technology in the form of the field trials is already sufficiently financed. This suggests that there has been adequate lobbying to make this possible or that lobbying

[15] German = Planfeststellungsverfahren

[16] German = Ausnahmetatbestände

was not necessary to achieve this status. Further assessments of lobbying for the financial conditions of CHT were therefore based on ensuring the financial viability of the technology on the free market in the future.

In newspaper quotations, the BMU has suggested financing possibilities such as an integration into the toll system or support measures for logistics companies. While this sends a public signal to the legislative, it is, however, a suggestion from the government itself and can therefore not be counted as lobbying activities. Only one actor openly called for further financial support and incentives which the government could and should provide to make the technology a success:

> "Well and then, with this system, one has to of course not only invest money for the infrastructure and create all prerequisites for it, but also make sure that there are sufficient incentives for the vehicle owners to use the system. That means that lastly, we would have to see with regards to price politics, energy prices, that that becomes respectively attractive for companies and that one doesn't get the idea to immediately fetch what is lost in petroleum tax on the electricity side. That would not be incentive politics that one could do in the end."

While favorable financial conditions were reached for the project phase, the picture of lobbying for future market viability of the technology therefore remains rather weak. This subscore was, therefore, scored with a barrier.

5.3.2 Niche

The two barriers assessed on the level of niche were the size of the networks and the extent of precision and acceptance in expectations. With regards to network size, no barrier was found. With regards to the extent of the precision and acceptance of expectations, a slight barrier was found.

Barrier 3: No or small social networks (without powerful actors)

Table 9. Barrier assessment results and scores for barrier 3.

Level	Barrier	Operationalizing question	Results	Score
Niche	*Barrier 3:* No or small (social) networks without powerful actors	1) What is the size of the networks?	large	no barrier
		2) Are powerful actors present?	yes	no barrier
			Barrier 3:	no barrier

How large are the actor networks within the niche?

With respect to the size of the niche networks, no barrier was found. After assigning actors to their respective levels, the network of niche actors could be separated from the total network of all actors. This network is depicted in Figure 10.

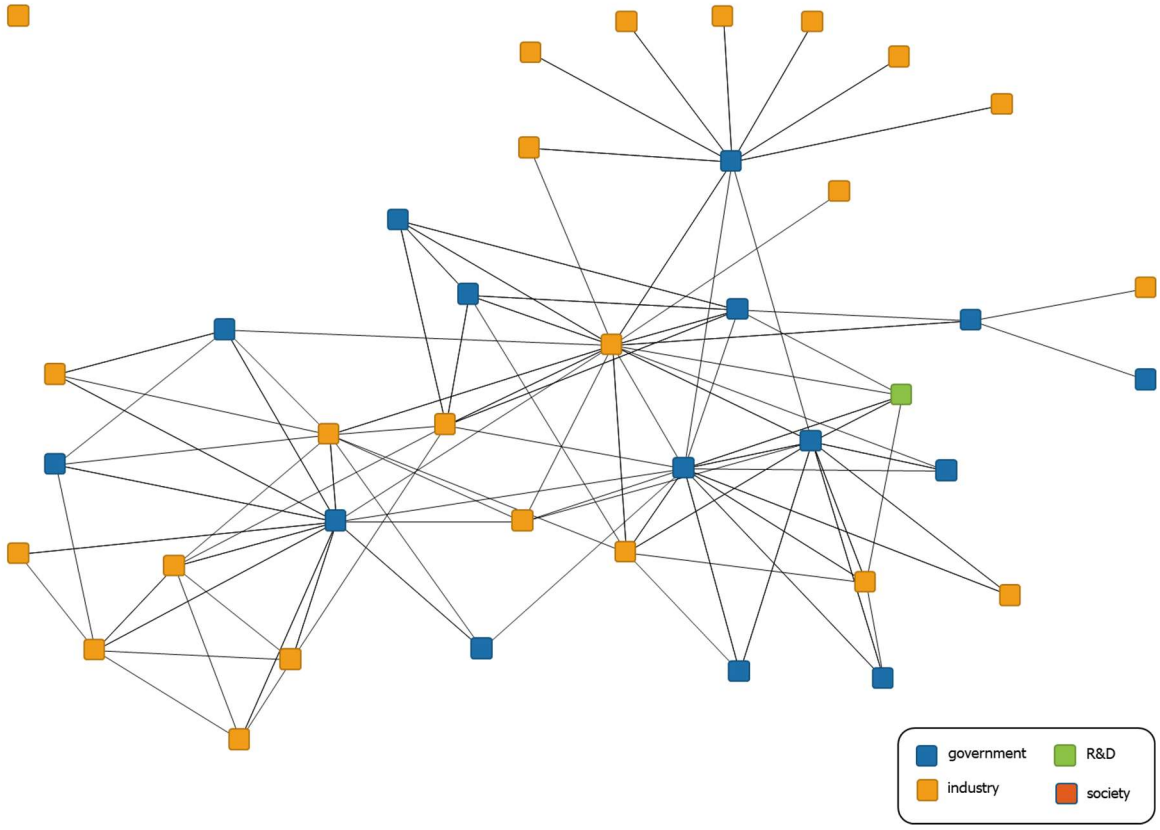

Figure 10. Visualization of the niche actor network.

38 out of a total of 95 identified relevant actors form the niche around field trials in Germany. At 40%, this presents a large share of the actors found to be involved in the topic of CHT up to this point in time. Additionally, Figure 10 shows that, except for one actor, all of these niche actors form a network based on communication and close exchange about CHT. The smallest size of the network would be given if there were no connections or only one connection between two actors. Within the niche, the depicted network can, therefore, with the exception of one disconnected node, be said to be of the largest possible size.

Additionally, powerful actors were found to be a part of the niche based on two measurements. First, a quick statistic test showed that the mean of the centrality values found for niche actors was considerably higher than for actors who were not a part of the niche[17]. Central actors can be considered powerful because they connect other actors and can serve as brokers of ideas and opinions in the network. The more central positions found for niche actors can, therefore, be interpreted as those actors having more power within the network of all actors.

Secondly, actors with considerable instrumental power, that is actors who can mobilize considerable resources, are a part of the niche. The survey gathered data on the number of employees and the annu-

[17] Niche: mean=157,368; n=40; std. dev.=376,014;
non-niche: mean=65,187; n=55; std.dev.=156,796.

al revenue or budget of the actor organizations based on five-point Likert scales. Figure 11 and Figure 12 show the number of actors within the niche fitting the five ranges provided respectively.

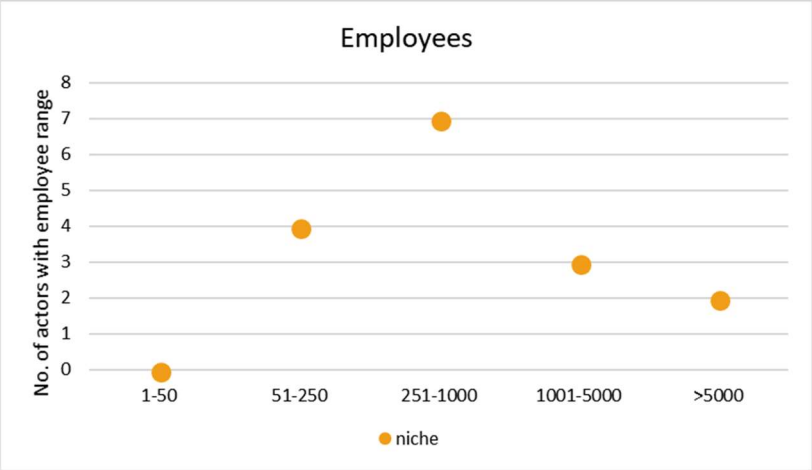

Figure 11. Frequency of employee ranges found within the niche measured through the number of actors matching these ranges at the time of the survey (March-April 2018).

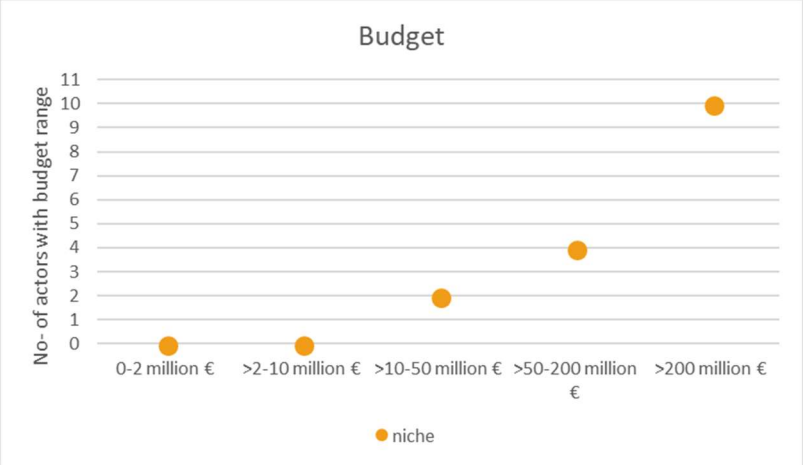

Figure 12. Frequency of annual revenue/budget ranges found within the niche measured through number of actors matching these ranges. Based on 2016 data provided in the survey (March-April 2018).

The lack of complete information for all actors does not allow for a comparison within and outside of the niche. Therefore, the provided data was not interpreted in a relational manner. Figure 11 shows that, within the limited sample of the survey, five niche actors were part of the two highest ranges of employee numbers. Furthermore, a majority of seven niche actors fell in the middle category of 251-1,000 employees.

Additionally, Figure 12 illustrates that a majority of 10 actors in the niche occupied the highest revenue/budget category of above 200 million € per year, with the second largest group of four actors falling in the category just below (>50-200 million €). While this limited information did not give an account of the distribution of all niche actors, it showed that, in terms of instrumental power, powerful actors are a part of the niche.

Barrier 4: No precise and broadly accepted expectations

Table 10. Barrier assessment results and scores for barrier 4.

Level	Barrier	Operationalizing question	Results	Score
Niche	*Barrier 4:* No precise and broadly accepted expectations	1) In how far do the descriptions of expectations for CHT overlap between the actors?		slight barrier
		2) How precise are the communicated expectations?		slight to no barrier
			Barrier 4:	slight barrier

An expectation can be defined as "the belief that something will happen or be the case" (Oxford English Dictionary, 2018). For the assessment of this barrier, broad acceptance of an expectation was measured through the amount of congruence of expectations around certain themes between actors. Precision of expectations was operationalized as the level of aggregation of any given expectation. For example, a statement asserting that *the technology will be successful* would have been rated less precise than a statement asserting that *the technology will function specifically in combination with a certain type of hybrid vehicle under the assumption that private funding of the technology can be sustainably secured at some point in the future*.

The expectations of niche actors were collected directly through closed-ended Likert-style questions in the survey and indirectly through open-ended questions in survey and interviews and actor statements about expectations in newspaper articles and publications. The precision of expectations could only be assessed based on the latter data.

The three closed-ended questions were designed from broad to narrow based on common themes emerging from the preliminary research: they addressed expectations regarding the potential for sustainability improvements through the technology, expectations regarding the chances for the establishment of the technology, and expectations about the financial profitability of the technology on the market (see Appendix D, sections 5 and 6 of the questionnaire). For each of the three relevant Likert-style questions, the answers showed one category which was predominantly chosen by the niche actors. Respectively 11 out of 17 (65%), 7 out of 17 (41%), and 7 out of 17 (41%) chose the same answer in terms of agreement with the pre-determined statement. These majorities agreed that the technology of CHT has the potential to improve the sustainability of freight transport, that there is a high chance for the technology to establish itself, and that the technology will be profitable on the free market in the future. However, it needs to be noted that 7 actors considered the chances for establishment low or medium and that 6 actors somewhat disagreed or were undecided about whether or not the technology would be profitable on the free market in the future. While majorities could be made out, the expectations can, hence, not be said to be entirely uniform based on the results from the closed-ended questions, leading to a score of medium and hence a slight barrier for this sub-assessment.

For the gathered open-ended statements, the situation was more complex since the answers did not converge around pre-determined themes as in the closed-ended questions. Therefore, the main themes mentioned by the actors in relation to expectations were gathered in a first step and ranked by the number of actors providing statements towards that theme.

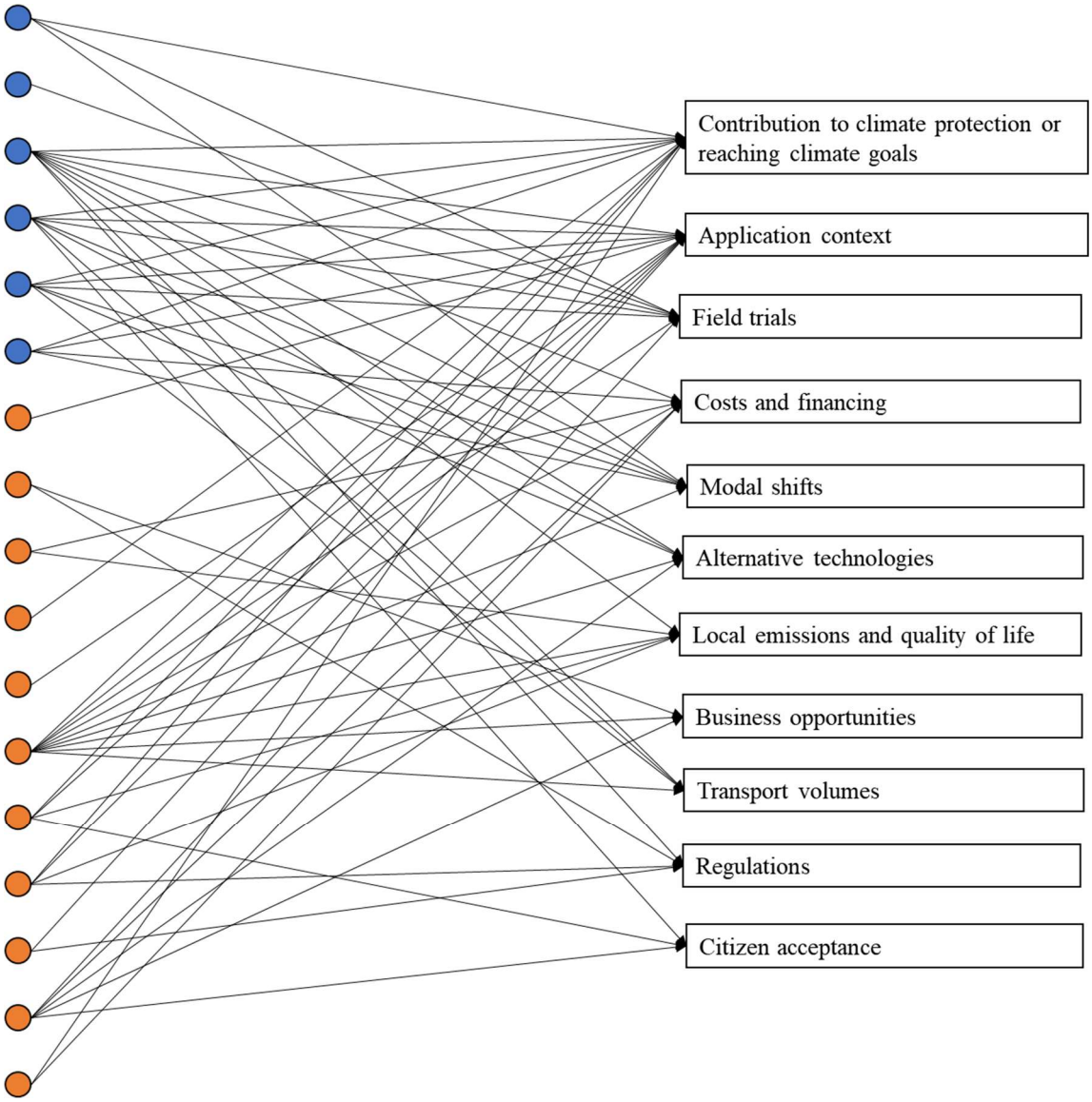

Figure 13. Dominant themes of expectations. Ranked from top to bottom by number of different actors providing statement to the theme. Blue dots represent government actors, orange dots represent industry actors.

Figure 13 illustrates the dominant themes on the right, with connections shown between each actor and the themes of expectations the actor mentions. Overlap in expectations was then only assessed for the available statements within the themes. Absent statements by an actor for a certain theme were not considered as *no expectation* but rather as *unknown* and no conclusions were therefore drawn from such absences.

Table 11. Overlap of expectation statements within found themes.

Theme	Strength of overlap
Contribution to climate protection or reaching climate goals	high
Application context	medium
Field trials	medium
Costs and financing	low
Modal shifts	high
Alternative technologies	low
Local emissions and quality of life	high
Business opportunities	high
Transport volumes	high
Regulations	high
Citizen acceptance	low
Overall	medium-high

Overall, as shown in Table 11, there was a large variance in the amount of overlap in the individual themes. For costs and financing, alternative technologies, and citizen acceptance, actors provided diverse and often contradicting expectation statements. Strong overlap could be found in the categories of climate protection, modal shifts, local emissions, business opportunities, transport volumes, and regulations. A medium overlap was found for the themes of application context and field trials. The medium to high overlap in the open-ended statements and the medium overlap in the closed-ended statements overall led to a slight barrier assigned to this sub-score.

Table 12. Precision of expectation statements within found themes.

Theme	Precision of statements
Contribution to climate protection or reaching climate goals	low - medium
Application context	medium
Field trials	medium
Costs and financing	medium
Modal shifts	high
Alternative technologies	medium - high
Local emissions and quality of life	medium - high
Business opportunities	medium - high
Transport volumes	low - medium
Regulations	medium - high
Citizen acceptance	high
Overall	medium-high

As shown in Table 12, the overall precision of statements was found to be medium to high, leading to the score of a slight to no barrier. In Appendix G, the findings displayed in Table 11 and Table 12 are laid out in more detail sorted by expectation themes and ranked by the frequency in which the individual themes were mentioned. Each theme was individually discussed there in terms of overlap and precision and supplemented with illustrative expectation statements given by the actors.

5.3.3 Regime

The two barriers assessed on the level of regime were the possible resistance by regime actors and the overlap between regime actors and TIS actors. With regards to the resistance of regime actors, a slight barrier was found. With regards to the overlap between regime actors and TIS actors, no barrier was found.

Barrier 5: Resistance by regime actors through instrumental, discursive, and material forms of power

Table 13. Barrier assessment results and scores for barrier 5.

Level	Barrier	Operationalizing question	Results	Score
TIS	*Barrier 5:* Resistance by regime actors through			
	1) instrumental,	1) Does the regime mobilize more resources than the niche?	yes	barrier to slight barrier
	2) discursive,	2) Do regime actors dominate the discourse?	no	slight to no barrier
	3) and material forms of power	3) Do regime actors improve the technical dimension of the current regime to avoid regulation?	yes	barrier to slight barrier*
			Barrier 5:	slight barrier

* not counted towards the barrier score.

Does the regime mobilize more resources than the niche?

Data on the resources of regime and niche actors was gathered through the survey. 45% of niche actors and 46% of regime actors provided answers regarding their resources in terms of employees and annual revenue or budget. This data was, therefore, not sufficient to compare the resources of niche and regime in absolute terms even under the assumption that all relevant regime actors were included in the research project.

Furthermore, this case is not clear-cut when it comes to this division between niche and regime because most niche actors are also regime actors. So, while overall the regime mobilizes more resources when counting all producers, logistics firms, and regime-enacting research bodies, the niche actors around CHT mobilize a considerable amount of resources. Therefore, this barrier was scored between a full and a slight barrier.

Do regime actors dominate the discourse?

The domination of discourse was approximated through a count of the direct and indirect quotation of certain actors in the representative newspaper sample of German newspapers. Dominance of the public discourse was, therefore, measured in a direct way.

The actor identified as clearly dominating the public discourse in German newspapers was the German Federal Ministry for the Environment (BMU) with a total of 17 quotes. Further actors with a certain dominance in the discourse were Siemens (9 quotes), the transportation Ministry of Hessen (6 quotes), the research institute Öko-Institut (4 quotes), the Swedish Transport Administration Traf-

ikverket (3 quotes), the German Environment Agency (UBA) (3 quotes), the German Automobile Club (ADAC) (2 quotes), and association Allianz pro Schiene (2 quotes). The three most dominant actors were identified as either both enacting regime and niche or regime and TIS respectively.

It can, hence, be stated that the discourse is not dominated by actors who exclusively classify as regime actors. For the analyzed newspaper sample, the discourse rests firmly in the hands of regime actors who are also directly or indirectly supportive of the technology of CHT. Nevertheless, although these regime actors are supportive of the technology, this leaves the control over the discourse in the hands of regime actors. This leads to the slight risk of this turning from a positive situation where they are also supportive and part of the niche or TIS to a situation where they no longer support the technology and return to being regime actors entirely. Due to this risk, the category was only scored with a slight to no barrier.

Do regime actors improve the technical dimension of the current regime to avoid regulation?

In this research project, regime actors could be actors in the government, industry, R&D, and society. Improvements of technical dimensions mostly related to the regime actors in the industry category, which were hence used as a focus category for this assessment. Since the response rate for such actors was low in the administered survey, publications of the main identified actors were used as a supplement.

Avoiding regulations is the activity of warding off "possible regulation by promising that solutions are 'just around the corner'" (Geels et al., 2014, p. 33) and pursuing innovation efforts within the boundaries of the regime. For the regime at hand, this would mean that actors continue to work or support work on the efficiency of fossil-fuel powered trucks in order to avoid future regulations which completely rule out fossil-fuel powered trucks as a transport choice. Currently negotiated policies on the EU level, for example, stipulate CO_2 caps for vehicle fleets. While this places a significant restriction on the emissions of fossil-fuel powered trucks, it still allows them to be used. Through continuous technical improvements, regime actors can be argued to work on keeping the focus on such caps. This way, they ward of other, potentially stricter, regulations which would force them to change from producing or supporting fossil-fuel powered trucks to only producing hybrid or entirely alternatively powered trucks. Improving regime technology is, therefore, a counter-force to the development of CHT because it leaves less room and little pressure for the production of hybrid or alternatively powered trucks needed for the CHT system.

All seven truck producers with the highest share on the German market[18] structure their online presence on trucks and sustainability around two topics: efficiency and alternative drive technologies. In all cases, the reduction of emissions of conventional trucks takes up most space in the companies' strategies for a more sustainable future. The publications refer to two types of regulations: the EU emissions norms[19] and drive-in restrictions of cities. To meet the emissions norms, industry actors

[18] DAF, Iveco, MAN, Mercedes-Benz, Renault, Scania, Volvo.

[19] Referring to norms regulating the maximum emissions of CO, THC, NMHC, Methane, NO_X, NH_3, PM and PN. Norms about maximum CO_2 emissions for heavy-duty vehicles, in the form of maximum fleet consumption, are currently still in discussion and not referred to by any industry actor.

present a wide array of efficiency measures from more efficient engines and light-weight construction to changes in driver behavior which are made possible with training efforts. To address the drive-in restrictions, the focus lies less of efficiency and more on alternative fuels like gas as well as electro-mobility. While regulations, such as inner-city restrictions, become stronger, truck producers continue to invest in efficiency measures. Governmental regime actors also put forward a mix of supporting alternative propulsion technologies, especially on the side of environmental ministries, and supporting efficiency programs, especially on the side of transportation ministries.

The indirect message from these documents is, therefore, that regime actors expect to be able to meet the demands of the future with a mix of efficiency in old technology and developments of alternative technologies. They are trying to prove to be efficient and innovative enough to not warrant additional regulations. Nevertheless, the truck manufacturers also pursue R&D for alternative technologies. The sub-barrier was, therefore, scored to be a slight barrier to a barrier. However, this bears some speculation and the direct connection between improving efficiency and avoiding stricter future regulations is not voiced by any of the actors. Therefore, this part of the assessment was not counted towards the final score of barrier 5.

Barrier 6: No or small overlap of regime actors with TIS actors

Table 14. Barrier assessment results and scores for barrier 6.

Level	Barrier	Operationalizing question	Results	Score
Regime	*Barrier 6:* No or small overlap between regime actors and TIS actors	How large is the overlap between regime actors and TIS actors?	great overlap	no barrier
			Barrier 6	no barrier

How many of the TIS actors can also be identified as regime actors?

28 out of all 95 identified relevant actors were classified as actors enacting the conceptual level of TIS. An additional 43 actors were identified as enacting the niche. As outlined in the conceptual section of this thesis, the niche-enacting actors automatically form a part of the TIS since all actors supporting the technology directly were assigned to this level fitting the indirect or direct support necessary to count as a TIS actor. Of these 71 actors, 62 actors were also identified as regime actors. 37 of these actors were both found to be a part of the German trial niches and the regime of *fossil-fuel based road freight transport*, 3 as a part of a parallel niche and the regime, and 22 as part of the TIS and the regime. Actors which were part of the relevant niche or TIS but were identified as actor of a parallel regime, such as the regime of rail freight transport, were not counted towards this score. Overall, the large majority of niche and TIS actors found in this research were also identified as regime actors. Therefore, this barrier was scored as presenting no barrier.

6. Discussion

In this section, the limitations of the research as well as the practical and scientific implications are discussed. Based on the scientific implications, suggestions for further research are given.

6.1 Limitations of the research

Limitations of a research project are commonly assessed based on fixed quality criteria. As Bryman (2016) discusses at length, there is an ongoing discussion amongst qualitative researchers of whether to apply the criteria of reliability and validity, which have been developed in the context of quantitative research, to qualitative research as well. In summary, most qualitative researchers currently operate somewhere in the middle of a spectrum between realist positions supporting the two criteria, and non-realist positions rejecting them for judging qualitative research. They combine adjusted reliability and validity measures with some additional strategies by critical qualitative researchers "such as thick descriptions, respondent validation exercise, and triangulation" (Bryman, 2016, p. 391). This stance will, therefore, be used to assess this research project through the slightly assimilated four criteria of external and internal reliability and internal and external validity (Bryman, 2016).

External reliability refers to the degree to which a study can be replicated. It is a difficult criterion to meet in qualitative research as social settings and circumstances are ever-changing. For a replicating researcher, it is therefore recommended to adopt a similar role as the original researcher (Bryman, 2016). Important aspects of my role to consider for such a replication are the facts that I am a beginning researcher who acted as both a representative of the university and the research institute for which I conducted my research. All methodological steps of the research are laid out in detail which further increases replicability. Internal reliability refers to the agreeance of different observers about what they see and hear during the research. As noted before when addressing bias in the assessment, I was the only primary researcher of the project. To combat this aspect, the more qualitative assessment strand recommends checking whether sufficient auditing by peers on proper procedures has been done based on complete records of all phases of the project like "problem formulation, selection of research participants, fieldwork notes, interview transcripts, data analysis decisions" (Bryman, 2016, p. 384). During my thesis work, I worked closely with my supervisors and could, therefore, conduct a basic auditing approach for the mentioned aspects. Additionally, decisions such as the selection of research participants and data analysis decisions are included in the body of this thesis which was possible due to the larger space provided than in a published research article.

Internal validity refers to the correspondence between the direct observations and the thereof developed theoretical ideas. In the project at hand, no theory was developed based on the observations. However, concepts were identified and extrapolated from the gathered data. The validity of these inferences was ensured in two ways. The first part of the research was reviewed through respondent validation. That is, an actor in the field was asked to judge and elaborate upon the identified facts. Secondly, great transparency and, when possible, triangulation between different sources were employed in the barrier assessment to justify the inferences from data to scores. Finally, external validity determines "the degree to which findings can be generalized across social settings" (Bryman, 2016, p. 384). As Bryman (2016) notes, this is difficult in qualitative research which operates based on case studies as was done here. The goal of this research project was to come to a conclusion about barriers to the implementation of one specific technology based on the current situation. The finding can therefore not simply be assumed to be true for a different technology even in the same stage of development. The results are therefore first and foremost to be interpreted within the time and place constraints laid out in the research design. The approach of thick description, referring to rich accounts of

the details of the studied milieu, is recommended in qualitative research to allow better judgements of transferability (Bryman, 2016). The background chapter and the extensive description of relevant actors and actor networks serves this purpose.

6.2 Practical implications - recommendations and policy directions

Based on the barrier assessment in this research, recommendations and policy directions could be discerned within the given context and limitations of the research. Recommendations were given for those barriers, which were considered to be fully or slightly present. Therefore, barriers 4 and 5 are discussed in the following.

Removing barrier 4: Achieving more precise and broadly accepted expectations

The assessment of barrier 4 has shown, that overall, the expectations of niche actors around CHT are only precise and widely accepted to a medium extent. To come to a state of no barrier, individual expectations would therefore have to be more precisely formulated and shared by more actors. The presence of multiple interests, opinions, and expectations is a common challenge in the scientific and practical work towards more sustainable development. Expectations are considered important because "by expressing expectations […] actors influence the technological innovation system and current and future technological trajectories" (Alkemade & Suurs, 2012, p. 449). Truffer, Voß, and Konrad (2008) synthesize and point out that:

> "… the specific expectations relating to future context conditions, technologies and actor roles will differ considerably between actor groups or even between individuals. In order to identify the potential room for coordinated strategy formulation, these expectations have to be mutually accommodated." (p.1361)

A certain amount of consensus is not only needed for envisioning what the future could look like given this uncertainty but also for immediate decision-making and the success of an innovation (Alkemade & Suurs, 2012).

Two relatively recent types of approaches which allow for the discussion and possibly convergence of expectations are foresighting approaches and joint model building. As Truffer et al. (2008) summarize, foresighting approaches which aim at sustainable development, can take many forms. Approaches which have been taken so far include visioning processes under transition management, "are adaptive foresight, the German Futur process, Visions assessment, Leitbild assessment, several sorts of participatory and constructive technology assessment or strategic conversations" (p.1364). Their own approach of Sustainability Foresight was originally developed for the German utility sector to develop multiple possible development paths and develop strategies based on the found scenarios (Truffer et al., 2008). Most importantly, the authors found that the Sustainability Foresight method reduced potential conflict and misunderstanding:

> "[…] the distribution of expectations over the field […] changed quite considerably and led to a better identification of potential cooperative strategies and by this to better support for sustainable transformation processes" (p.1371)

This approach can, therefore, be recommended as one possible option for a greater overlap of expectations.

The approach of joint model building follows a similar rationale but uses a different methodological basis. Especially in recent literature on sustainable transport planning but also in literature on decision-making in complex ecological and economic systems, the benefits of participatory modeling approaches for consensus-building and strategy-making have been pointed out (Costanza & Ruth, 1998; Macmillan et al., 2014; Te Brömmelstroet & Bertolini, 2011). As Costanza and Ruth (1998) summarize:

> "The process of modeling can (and must) serve this consensus building function. It can help to build mutual understanding, solicit input from a broad range of stakeholder groups, and maintain a substantive dialog between members of these groups." (p.185)

Joint modeling can be said to start one level below the activities around foresighting. Actors get together and, in a first step, set system boundaries and put their assumptions and mental models about the specific workings of the current system in a (computer-based) model (Costanza & Ruth, 1998). In a second step, the model is fed with detailed data for calibration and testing and uncertainties are analyzed. They model can then be run to get insight into the dynamic consequences of different assumptions. The third stage finally includes the production of scenarios and management options based on the models.

Due to the data intensiveness and required detail for the second step, this approach can be considered more resource-intensive than foresighting approaches. However, it would specifically tackle the issue of expectations which are currently not precise enough. If the focus lies primarily on achieving a greater transparency and overlap of expectations between the actors, the first step of model building where assumptions are made clear and basic connections are modeled could suffice.

In the research efforts around CHT, modeling and different pathway approaches have already been taken or planned, especially with regard to technology development and market introduction scenarios (Öko-Institut, 2016; Wietschel et al., 2017). Both projects point to the importance of the inclusion and discussion with a variety of actors. For one study, scientific workshops, specifically on the technical dimensions of CHT were held (Bundesministerium für Verkehr und digitale Infrastruktur, 2016). For the other project, expert participation and a project advisory council are meant to achieve that project results are available to actors in politics and industry for discussion early on (Öko-Institut, 2016). Results shall also inform other political decision-making processes and be presented to the interested public (Öko-Institut, 2016).

While the willingness for cooperation and scenario-building can, therefore, be attested in parts, there is room for the introduction of foresighting approaches and joint model building. The currently taken efforts give no explicit space to the discussion of scenarios for the technology within the entire freight transportation sector. The recommended joint approaches would require additional resources and organization but based on the barrier assessment analysis, the potential benefits for the implementation of the technology could outweigh these efforts in the future.

Removing barrier 5: Reducing the resistance of regime actors

A slight barrier was found in the assessment of possible resistance by regime actors with the strongest sub-scores in instrumental and material power. This means that regime actors of the *fossil-fuel based road freight transport regime* can use their resources as well as their regular activities and processes to withstand changes to the regime which would be brought about by CHT. On the basis of this assessment, this resistance would therefore have to be reduced if the goal is to ensure an implementation of the technology.

In recent innovation literature, such destabilizing efforts have attracted more attention (Kivimaa & Kern, 2016; Wesseling & van der Vooren, 2017). Kivimaa and Kern (2016) especially argue for an innovation policy mix which does not only include *creative* policies, for a technology push and demand pull, but also *destructive* policies aiming at the destabilization of regimes. Based on their review of literature in the field, Kivimaa and Kern (2016) put forward four ways in which destructive policy instruments can influence the innovation system: (1) control policies, (2) significant changes in regime rules, (3) reduced support for dominant regime technologies, and (4) changes in social networks through the replacement of key actors.

In their strongest form, control policies stand for the banning of certain technologies, such as the phasing out of fluorescent light bulbs. For the case at hand, this would equal the phasing out of fossil-fuel powered trucks. As statistics of vehicle stocks of trucks in Germany show, only 1.2% of all registered trucks currently run on alternative fuels (Kraftfahrt-Bundesamt, 2017a). No discernible growth could be made out in these shares between 2012 and 2016 (Kraftfahrt-Bundesamt, 2013, Kraftfahrt-Bundesamt, 2014, Kraftfahrt-Bundesamt, 2015a, Kraftfahrt-Bundesamt, 2016, Kraftfahrt-Bundesamt, 2017b). Additionally, this number is skewed by the comparatively high share of alternative fuels in smaller trucks with actual loads up to 1 ton at an average of 1.88% and much smaller shares for trucks above 6 tons (0.08%) and 12 tons (0.03%) (Kraftfahrt-Bundesamt, 2017a). This is important to note since large German trucks above 15 tons actual load, transport around 80% of the total annual volume of goods (Kraftfahrt-Bundesamt, 2015d, Kraftfahrt-Bundesamt, 2015c, Kraftfahrt-Bundesamt, 2015b, Kraftfahrt-Bundesamt, 2015e)[20]. Based on this simple measure, it seems that phasing out fossil-fuel powered trucks at this point in time would tear immense holes into road haulage. Nevertheless, a specific type of indirect and local banning policies has been growing: urban access regulations. In their most extreme form, they completely prohibit access of diesel vehicles to cities which comes close to a technology ban considering that goods still have to reach these areas (European Commission, 2018b). As an indirect banning policy, they present one option to weaken the regime. However, they do not restrict the large amounts of freight traffic outside of cities.

Less stringent control policies named by the authors are taxes, import restrictions, and regulations. They provide the examples of "carbon trading, pollution taxes or road pricing to put economic pressure on current regimes" (Kivimaa & Kern, 2016, p. 208). The recent proposal of the European Commission for fleet-wide CO_2 emission targets for heavy-duty vehicles (COM/2018/284) can be considered such a control policy[21]. However, the European Commission explicitly states, that the first target, a mandatory reduction of emissions by 15% from 2019 to 2025 "can be achieved using technologies that are already available on the market" (European Commission, 2018a). In the proposal itself, the Commission then speaks of "fuel-efficient HDVs" and asserts that "[c]ontrary to cars and vans, zero- and low-emission heavy-duty vehicles are not yet available on the market, except for buses" (COM/2018/284 final, 2018). This means that, despite the intention of offering super credits for manufacturers introducing zero- and low-emission vehicles, the proposed regulation would not necessitate actions by manufacturers going beyond efficiency improvements and other related measures until 2025. Furthermore, the more aspirational target of a CO_2 decrease of 30% until 2030 will be

[20] Based on 2015 numbers.

[21] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2018:284:FIN

reviewed and adjusted in 2022 "to incorporate additional information on the new technologies needed to meet this target" (European Commission, 2018a) and it is not yet clear whether this would result in more stringent or more lenient goals. Based on this simple consideration, it can hence be said that more efforts besides this proposed regulation would be needed to destabilize the regime enough to make CHT more attractive. Such additional efforts are not likely to evolve on the EU level and could correspondingly be introduced at the national level.

A second possibility, according to the authors' synopsis, are significant changes in regime rules. In contrast to individual regulations, this pertains the whole reconfiguration of institutional rules and especially economic frame conditions. Policy instruments of this approach would be "structural reforms in legislation or significant new overarching laws" (Kivimaa & Kern, 2016, p. 209) such as when in the 1990s electricity markets were privatized and liberalized.

A much-discussed possibility for such overarching legislations in the realm of sustainability are carbon taxes (Lin & Li, 2011). Such taxes have already been introduced more than 20 years ago, primarily by Scandinavian countries. They have a wider application scope than the freight transport sector alone but often include exemptions for specific energy-intensive industries (Lin & Li, 2011). Due to these exemptions, the real mitigation effects of carbon taxes have been less positive than what initial models had predicted but positive effects could still be made out for specific configurations. Based on these more successful cases, Lin and Li (2011) suggest either flat-rate taxation or raised tax rates in cases where differential tax rates are used to maintain competitiveness. Since German truck producers want to retain their competitiveness on the European and global market, differential carbon tax rates could be the more realistic option. This would, however, need to be analyzed overarchingly considering all other affected sectors, especially sectors such as energy production which as of 2016 still included a share of coal as a primary energy source for 40,3% of all produced energy in Germany (Statistisches Bundesamt, 2017).

Thirdly, support can be reduced for dominant regime technologies. In many areas, institutionalized support for incumbent technologies, such as fossil-fuel powered technologies, exist. Policies of the third type would be counteracting these already existing support policies such as R&D funding, subsidies or tax deductions for actors involved in the production and diffusion of dominant regime technologies. In Germany, the most relevant indirect subsidy in this regard are the lower taxes on diesel fuel. The subsidy is considered indirect because the annual motor vehicle tax in Germany is higher for diesel vehicles than for gasoline vehicles but the taxes on the fuel itself are lower. This leads to a financial benefit for the owners of diesel vehicles above a certain mileage. For 2012 alone, the loss in tax revenue from this subsidy amounted to around 7.4 billion € (Umweltbundesamt, 2016). The reduction of these subsidies could increase the incentive to develop, buy and use other, more efficient and lower emission technologies.

Finally, the regime can be destabilized through changes in its social networks. Especially "close relationships between government and key regime actors is often seen as a major source of lock-in" (Kivimaa & Kern, 2016). One way to work against this specific lock-in is the replacement of incumbent actors and existing skills and knowledge and the creation of new venues to bypass existing ones (Kivimaa & Kern, 2016). In terms of practical policy instruments, this can mean the introduction to more niche actors to policy advisory councils to balance out the number of incumbents or the creation of new platforms and networks targeting change (Kivimaa & Kern, 2016).

For the transportation sector in Germany, the close relationship between the government and key regime actors is especially evident. The automobile industry and the government do not only have close

communicative ties through frequent meetings but have also had a significant exchange of personnel over the last years (Greenpeace, 2016; Lamprecht, 2017). A replacement of incumbent actors in the government and automobile industry would therefore, if possible, at least take several years if offices are passed on in a regular manner. However, the introduction of other actors to advisory councils could be increased. In the drafting process of the current German mobility and fuel strategy[22], R&D actors, societal actors, and smaller industry actors were able to participate (Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2013). Of course, the specific effect of this inclusion would have to be analyzed in more detail. As a new platform, a roundtable or official forum for actors focusing on alternative truck technologies could be created. Currently, there is no central discussion platform for producers and users as well as the supply chain actors of such alternatives. An exchange of faced challenges and assessments could lead to a stronger political position and lobby against incumbent technologies and actors. This research showed that the communication between different CHT trial projects has also been limited so far and has gone mainly through one large industry actor. This could be improved through such a forum as well.

As is obvious from the way in which this research was set up and based on the aforementioned literature consensus on the necessity of policy mixes, destabilizing the regime alone does not automatically mean that CHT will be widely implemented and that it will succeed. In their case studies, Kivimaa and Kern (2016) also find that destabilizing functions are generally addressed by fewer policies despite their demonstrated necessity. However, if the political will is given, the suggested policy instruments can help remove this particular barrier presented by incumbent regime actors and their institutional surroundings.

6.3 Scientific implications and further research

This research project resulted in several insights that are relevant for the scientific debate on CHT and innovation development.

Firstly, the research project fills a gap in the literature around the technology of catenary hybrid trucks. Due to its relatively recent development, so far, the considerations of whether and how CHT could be successfully implemented were based on technological and economical assessments. In terms of actors, research so far has only included limited descriptive sections on stakeholder characteristics and possible standpoints (Jöhrens, Rücker, Bergk, Schade, & Hartwig, 2017; Wietschel et al., 2017). This research project went beyond assumptions about stances of actor groups in the transportation sector. It complements previous approaches by making actors central and approaching the technological development of CHT from a socio-technical perspective. For the first time, primary data from individual respondents was gathered to assess possible barriers posed by actually involved actors. The advantage of such an approach is that it was able to yield clear aspects where the current situation regarding actors around CHT would have to be improved if an implementation of the technology was desired.

Secondly, next to its primarily practical focus, the research project adds insights to the literature body of MLP and TIS in terms of concepts and methods. Conventionally, MLP and TIS studies are done separately from each other and with an exclusive focus on secondary data sources, either through a

[22] German = Mobilitäts- und Kraftstoffstrategie (MKS)

documents study of events or accounts provided by experts (Geels, 2011; Suurs & Hekkert, 2009; Vasseur et al., 2013). Both aspects have been considered to leave room for improvement (Geels, 2011; Markard & Truffer, 2008). Based on the consideration of a possible added value from theory integration, this research project presents one of the first attempts to operationalize the combined framework of MLP and TIS developed by Markard and Truffer (2008) for a practical application. When combining barriers found in each theory, it became apparent, that the barriers surrounding actors complemented each other well and no duplications of important factors for the development of a technology were found. On a very basic level, this points to the value of combining both theories for a richer picture of the situation at hand.

Methodologically, two additional approaches were added to the field which were made possible by decreasing the focus of the study exclusively to actors. On the one hand, a network analysis approach was added which had been a suggested method with possible added value by Geels (2011). This way, a direct depiction of ties between actors around the technology of CHT was possible. In this research project, the networks were then used for the barrier assessment. Furthermore, they can serve as the basis for further research including a time dimension which could map the dynamics of possible network changes and develop further hypotheses and insights from there. On the other hand, the focus made it possible to gather primary data from actors through a survey and interviews, yielding information on their personal expectations. This added a more nuanced view of actors' positions and expectations than what is possible with secondary data such as documents and expert accounts.

This point, however, leads directly to an aspect where further research is required. So far, even the combination of the two frameworks provided no way of tracking the relation between the support or non-support of actors and their underlying expectations and interests. The assumption regarding the development is, simply put, that those actors who are supportive of and positive about the technology now in the formative phase, will also be supportive and positive in the next development phase and that the decisive point is whether opposing actors will change their mind or will not be strong enough to withstand the development. In voicing their expectations however, supporting actors gave clear qualifiers of aspects or developments that their support is contingent upon. More than half of the interview and survey respondents, from which expectation statements were gathered, considered the continuous promotion of the technology by national governments decisive for their support. A number of industry actors base their support on the expectation of future profitability. Government actors themselves, to a large extent, base their support on international political developments around climate agreements. For these supporting actors that would mean that their support would no longer hold if the government withdrew their support for CHT, it would prove to not be profitable, or international agreements to reduce CO_2 would cease to exist or the problem would be solved otherwise. The framework used for the assessment, currently provides no room for such considerations related to expectations which have been deemed important by other MLP researchers (Bakker, 2014; Budde et al., 2012). Further research could look into this aspect and possibly draw insights from the literature on technology diffusion and hype cycles as well as their underlying psychological mechanisms.

Finally, this research project showed that the combined theories and the respective assessment might not be nuanced enough to account for different actor configurations and the related political dimension of the development of an innovation. With regard to expectations, for example, an overlap of expectations amongst niche actors is considered desirable. On the other hand, the domination of the discourse by regime actors is considered part of a barrier. For the project at hand, these barriers were assessed apart from each other. However, they were related by the fact that most niche actors identified in this research were also regime actors, that is incumbents. This possibility has been pointed to in other recent research, especially regarding the relationship of automobile companies to innovations

in the transportation sector (Späth et al., 2016). In the research for this thesis, hints have been found that the control of the niche by incumbents leads to certain ways of framing the discourse which might not be the most effective if the only goal would be the development of the technology but are deemed more politically acceptable in Germany, where the government has an interest in the flourishing of the strong automobile industry. One actor especially pointed out that strong regime actors involved in the niche demand the issue to be framed as a climate change issue and consciously steer away from calling it a public health issue since this could harm the whole industry. In the USA, in contrast, public documents on CHT directly point to the benefits of the new technology for public health in the smog-ridden area around LA. Further research could analyze how such differences in framing related to the development of an innovation in different political contexts. This parallels, for example, calls for the integration of context factors in TIS by Bergek et al. (2015). Furthermore, one of the most central niche actors in this research project was part of a parallel regime which can be considered as a competition to the centrally analyzed regime of *fossil-fuel based road freight transport*. If such a parallel regime controls the discourse, a different effect could be expected than if the mainly relevant regime or the niche alone do so. If the combination of MLP and TIS is to be applied to other cases in the future, such more complex actor configurations which occur in practice should be further taken into account in theory development.

7. Conclusion

This research examined the difference between an ideal situation for innovation development and the current situation around the technology of catenary hybrid trucks. The insights can now be used to answer the research questions:

1. *What are critical success factors, i.e. the conducive situation, for implementing the technological innovation of CHT?*
2. *How will the actual situation with regard to these critical success factors be assessed in the current innovation situation?*
3. *What is the difference between the conducive and the actual situation in terms of the critical success factors and how can this difference be reduced?*

First, the ideal conducive situation was established utilizing a combination of the theories of MLP and TIS. This ideal situation, narrowed down to an ideal situation around actors in the preliminary research, constituted an absence of the six barriers of (1) a lack of legitimation, (2) a lack of support from advocacy coalitions, (3) no or small (social) networks without powerful actors in the niche, (4) no precise and broadly accepted expectations in the niche, (5) resistance by regime actors through instrumental, discursive, and material forms of power, and (6) no or small overlap of regime actors with TIS actors. Based on the assumptions of the theories, the absence of these barriers was considered a necessary but not sufficient criterion for the successful development of the TIS and transition of the technology from the niche to the regime.

For the actual situation, two out of the six barriers were found to be present. Firstly, this was the medium score resulting from the assessment of the precision and acceptance of expectations in the niche (barrier 4). Expectations of the individual niche actors were found to only overlap to a medium extent in the identified eleven themes of expectations respectively. Furthermore, the precision of the expectations could only be rated as medium to high. Secondly, a medium score resulted from the assessment of the resistance by regime actors through instrumental, discursive, and material forms of power (barrier 5). Regime actors were found to resist in a medium to strong way through instrumental and mate-

rial forms of power and to slightly resist through discursive forms of power. This means that they were found to mobilize more resources and foster technical developments of the incumbent technologies, as well as to influence the public discourse to some degree.

Based on these findings in the barrier assessment, preliminary recommendations could be given for the reduction or elimination of these two barriers. For the reduction or elimination of barrier 4, foresighting approaches and joint model building were suggested as possible approaches. Foresighting approaches are commonly used in the field of sustainable development and planning for more sustainable infrastructure and transportation, to arrive at scenarios for the future with which a number of different actors can agree. They have also been considered to allow for the convergence of expectations into shared visions. Joint model building, as a more technical but still discursive approach, has been shown to be able to elicit the underlying assumptions of different types of actors and to arrive at a shared representation of how a specific sector or (socio-ecological) system works. Based on such a jointly built model, different expectations for the future could, therefore, be made visible and discussable between actors and possibly lead to joint visions.

For the reduction or elimination of barrier 5, different policy recommendations could be given which are commonly considered to have the potential to reduce the strength of a certain regime. Different possibilities for weakening the current regime of *fossil-fuel based road freight transport* were discussed under four *destructive* types of approaches: (1) control policies, (2) significant changes in regime rules, (3) reduced support for dominant regime technologies, and (4) changes in social networks. Specific possibilities which could be considered are technology bans or caps on CO_2 emissions in truck fleets, carbon taxes, the reduction of subsidies for current fuels, specifically diesel in Germany, and the inclusion of more diverse actors into the advisory councils and decision fora around transportation in general and the technology of CHT specifically.

In summary, it is important to point out again that this research does not contribute to the decision-making of which transport technology should be used in freight transport in the future. The technology of CHT holds many sustainability promises but whether or not it will be employed remains, to a large extent, a political decision. However, this research project was able to show which aspects have to be improved when it comes to the actor constellation and actor behavior around CHT, to ensure that the technology will be more successfully implemented if this is set as a common goal. Under the premise that expectations will become more shared between niche actors and the current regime will be put under more pressure, the analysis has shown that the current actor landscape provides a good situation of the technology of CHT to establish itself.

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Appendix A

Project overview CHT

Table A1. Overview of projects related to CHT.

Project name	Initiating actors	Location	Time frame	Description	Financing	Link to official information
ENUBA	Siemens	Groß-Dölln, Germany	01.05.2010 - 30.09.2011	A study and demonstration on a private road that examined the electrification of heavy-duty commercial vehicles with a catenary system to find solutions for less environmentally intensive transportation in conurbations.	total: €5.4 million - €2.16 million BMU - Siemens	https://www.erneuerbar-mobil.de/projekte/enuba
ENUBA 2	DLR, Siemens, TU Dresden	Groß-Dölln, Germany	01.04.2012 - 31.12.2015	Developing a complete system of catenary electric heavy-duty vehicles and an extension for bus applications. Research on technical, ecologic, economic, and legal aspects. Building of a 2km test track.	total: around €15 million -BMU -Siemens	https://www.erneuerbar-mobil.de/sites/default/files/2016-09/Flyer_ENUBA%202.pdf
(eHighway LA)	Siemens, SCAQMD	Los Angeles & Long Beach, California	2017	eHighway demonstration: 1 mile of highway equipped with a catenary system in both directions for freight transport near ports.	total: $13.5 million: $2.5 million SCAQMD; $4 million settlement China Shipping; $3 million California Energy Commission; $2 million Port of Long Beach; $2 million LA Metro; $1.3 million Siemens	http://siemensusa.synapticdigital.com/Featured-Multimedia-Stories/siemensehighway-roll-out/s/e9ff6e36-9c89-43b3-98e4-3a773420e98f

StratON	Öko-Institut, Fraunhofer IAO, Hochschule Heilbronn, Intraplan Consult GmbH		01.07.2016 - 31.12.2018	Research on catenary heavy-duty vehicles and alternative propulsion technologies. Focus on technology, GHG emissions, resource demand, interdependencies with the energy sector and development strategies.	-BMU	https://www.oeko.de/fileadmin/oekodoc/Flyer-zum-Verbundprojekt-StratON.pdf
(eHighway Sweden)	Siemens, Scania	Sweden	June 2016 - 2018	World's first eHighway system on public roads. Operating two adapted diesel hybrid vehicles under a catenary system spanning around 2km on the highway.	total: SEK 77 million (public money)- SEK 48 million (business community and Gävleborg regional authority)	https://www.scania.com/group/en/worlds-first-electric-road-opens-in-sweden/
Roadmap OH-LKW	ifeu, Fraunhofer IWES		01.09.2016 - 28.02.2019	Research on implementation pathways of heavy-duty vehicles with electric propulsion systems and their energy supply through overhead lines.	-BMU	https://www.erneuerbar-mobil.de/sites/default/files/2017-03/Flyer_Roadmap%20OH-Lkw%20%28final%29.pdf
ELANO	Siemens	Groß-Dölln, Germany	01.01.2016 - 30.09.2019	Further development, optimization, and testing of electrified heavy-duty hybrid trucks and the overhead infrastructure.	-Siemens	https://www.erneuerbar-mobil.de/sites/default/files/2016-08/ELANO_BMU-Flyer_RZ_Final_2016_08_11%20%282%29.pdf
eWayBW	Ministerium für Verkehr Baden-Württemberg	Gernsbach-Obertsrot - Kuppenheim, Baden-Württemberg, Germany	01.10.2017 - 31.12.2019	Field trial to test electric propulsion systems for heavy-duty vehicles on federal roads in Baden-Württemberg. Planning and construction of about 6km of overhead catenary infrastructure.	total: €17.6 million -€16.8 million BMU -€0.8 million state of Baden-Württemberg	https://www.erneuerbar-mobil.de/sites/default/files/2018-04/Flyer_eWayBW.pdf

ELISA I	Hessen Mobil, TU Darmstadt	Frankfurt - Darmstadt, Hessen, Germany	01.01.2017 - 31.12.2018	ELISA I - Planning and construction of about 6km of overhead catenary lines in both directions to allow for trucks to travel over 15km electrically powered.	total: €14.6 million -€14.6 million BMU	https://www.erneuerbar-mobil.de/sites/default/files/2017-12/Flyer_EliSA_DIN_lang_07.pdf
ELISA II	Hessen Mobil, TU Darmstadt	Frankfurt - Darmstadt, Hessen, Germany	2019 - 2022	ELISA II - Field testing of the system.		https://www.erneuerbar-mobil.de/sites/default/files/2017-12/Flyer_EliSA_DIN_lang_07.pdf
FESH I	Ministerium für Wirtschaft, Verkehr, Arbeit, Technologie und Tourismus des Landes Schleswig-Holstein	Hamburg - Lübeck, Schleswig-Holstein, Germany	01.01.2017 - 31.12.2018	Field trial eHighway to test heavy-duty vehicles with pantographs in Schleswig-Holstein. Planning and construction of around 6km of overhead catenary infrastructure in both directions.	total: €14 million -€14 million BMU	https://www.erneuerbar-mobil.de/sites/default/files/2017-07/eHighway_Flyer.pdf
FESH II	Ministerium für Wirtschaft, Verkehr, Arbeit, Technologie und Tourismus des Landes Schleswig-Holstein	Hamburg - Lübeck, Schleswig-Holstein, Germany	mid 2018-2021	FESH ii - Field testing of the system.		https://www.erneuerbar-mobil.de/sites/default/files/2017-07/eHighway_Flyer.pdf

Appendix B

Actors

Table A1. List of relevant actors based on literature search and expert opinion including full names and translations.

Abbreviated name	Full name	Full name English translation
ADAC	Allgemeiner Deutscher Automobil-Club	German automobile club
Agora Verkehrswende	Agora Verkehrswende	Agora Verkehrswende
Allianz pro Schiene	Allianz pro Schiene e.V.	Alliance pro Rail
BASt	Bundesanstalt für Straßenwesen	Federal Road Research Institute
BGL	Bundesverband Güterkraftverkehr Logistik und Entsorgung (BGL) e.V.	Federal association for road haulage logistics and disposal
BMU	Bundesministerium für Umwelt, Naturschutz und Nukleare Sicherheit	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BMVI	Bundesministerium für Verkehr und digitale Infrastruktur	Federal Ministry of Transport and Digital Infrastructure
BMWI	Bundesministerium für Wirtschaft und Energie	Federal Ministry for Economic Affairs and Energy
California Energy Commission	California Energy Commission	California Energy Commission
Casimir Kast	Casimir Kast Verpackung und Display GmbH	Casimir Kast Packaging and Display
Chalmers	Chalmers tekniska högskola	Chalmers University of Technology
CLECAT	European Association for Forwarding, Transport, Logistics and Customs Services	European Association for Forwarding, Transport, Logistics and Customs Services
Contargo	Contargo GmbH & Co. KG	Contargo GmbH & Co. KG
DAF	DAF Trucks N.V.	DAF Trucks N.V.
Daimler	Daimler AG	Daimler AG
DAW SE	DAW SE	DAW SE
DB	DB Schenker	DB Schenker (logistics division of German rail operator Deutsche Bahn AG)
DLR	Deutsches Zentrum für Luft-und Raumfahrt	German Aerospace Center
DSLV	Deutscher Speditions-und Logistikverband	German forwarding and logistics association
DVGW-Forschungsstelle KIT	DVGW-Forschungsstelle am Engler-Bunte-Institut des Karlsruher Instituts für Technologie (KIT)	DVGW research center at the Engler-Bunte-Institute of the Karlsruhe Institute of Technology (KIT)
e-mobil BW	e-mobil BW GmbH	e-mobil BW GmbH
Energimyndigheten	Energimyndigheten	Swedish Energy Agency
ENTEGA	ENTEGA Energie GmbH	ENTEGA Energie GmbH

EPA	United States Environmental Protection Agency	United States Environmental Protection Agency
FH Kiel	Fachhochschule Kiel	University of Applied Sciences Kiel
Ford	Ford	Ford
Fraunhofer IAO	Fraunhofer-Institut für Arbeitswirtschaft und Organisation IAO	Fraunhofer Institute for Industrial Engineering IAO
Fraunhofer ICT	Fraunhofer-Institut für Chemische Technologie ICT	Fraunhofer Institute for Chemical Technology
Fraunhofer IML	Fraunhofer-Institut für Materialfluss und Logistik IML	Fraunhofer Institute for Material Flow and Logistics
Fraunhofer ISI	Fraunhofer-Institut für System- und Innovationsforschung ISI	Fraunhofer Institute for Systems and Innovation Research ISI
Fraunhofer IWES	Fraunhofer-Institut für Windenergie und Energiesystemtechnik IWES	Fraunhofer Institute for Wind Energy Systems
FZI	FZI Forschungszentrum Informatik	FZI Research Center for Information Technology
Gävleborg	Region Gävleborg	Administrative district Gävleborg (Sweden)
Greenpeace	Greenpeace e.V.	Greenpeace e.V.
HEAG mobilo	HEAG mobilo GmbH	HEAG mobilo GmbH
Hegro Eichler	Hegro Eichler GmbH	Hegro Eichler GmbH
Hessen Mobil	Landesbehörde für Straßen- und Verkehrsmanagement	state authority for street and transport management
HS Heilbronn	Hochschule Heilbronn	Heilbronn University of Applied Sciences
Huettemann Holding	GmbH & Co. KG	GmbH & Co. KG
ICCT	International Council on Clean Transportation (deutsch ~ Internationaler Rat für sauberen Verkehr)	International Council on Clean Transportation
ifeu	Institut für Energie- und Umweltforschung Heidelberg GmbH	Institute for energy and environmental research Heidelberg
INFRAS	INFRAS AG Bern	INFRAS AG Bern
Intraplan Consult	Intraplan Consult GmbH	Intraplan Consult GmbH
IVECO	IVECO	IVECO
Kreis Stormarn	Kreis Stormarn	District Stormarn
KTH	Kungliga Tekniska högskolan	KTH Royal Institute of Technology in Stockholm (Sweden)
Kuppenheim	Stadt Kuppenheim	City of Kuppenheim
LA	City of Los Angeles (CA, USA)	City of Los Angeles (CA, USA)
LA Metro	LA Metro (CA, USA)	LA Metro (CA, USA)
LBV SH	Landesbetrieb Straßenbau und Verkehr Schleswig-Holstein	Road construction and transportation agency Schleswig-Holstein
Lehmann	Hans Lehmann KG	Hans Lehmann KG
LHG	Lübecker Hafen-Gesellschaft mbH	Lübecker Hafen-Gesellschaft mbH (Lübeck port corporation)
Lübeck	Hansestadt Lübeck	Hanseatic City Lübeck
Mack Trucks	Mack Trucks	Mack Trucks
MAN Truck & Bus	MAN Truck & Bus AG	MAN Truck & Bus AG
Mayr-Melnhof	Mayr-Melnhof Gernsbach GmbH	Mayr-Melnhof Gernsbach GmbH

MELUND SH	Ministerium für Energiewende, Landwirtschaft, Umwelt, Natur und Digitalisierung Schleswig-Holstein	Ministry for Energy Transition, Agriculture, Environment, Nature and Digitalisation Schleswig-Holstein
Meyer Logistik	Ludwig Meyer GmbH & Co KG	Ludwig Meyer GmbH & Co KG
M-Five	M-Five GmbH Mobility, Futures, Innovation, Economics	M-Five GmbH Mobility, Futures, Innovation, Economics
NABU	Naturschutzbund Deutschland e.V.	Nature And Biodiversity Conservation Union Germany
Näringsdepartementet	Ministerium für Unternehmen und Innovation (Schweden)	Ministry of Enterprise and Innovation (Sweden)
Netze BW	Netze BW GmbH	Netze BW GmbH
Öko-Institut	Öko-Institut e.V. Institut für angewandte Ökologie	Öko-Institut e.V. Institute for Applied Ecology
Port of Long Beach	Port of Long Beach	Port of Long Beach (CA, USA)
PTV Transport Consult	PTV Transport Consult GmbH	PTV Transport Consult GmbH
Rastatt	Stadt und Landkreis Rastatt	City and district of Rastatt
Regierungspräsidium Karlsruhe	Regierungspräsidium Karlsruhe	Regional Board Karlsruhe
Renault Trucks	Renault Trucks	Renault Trucks
RISE Viktoria	Research Institutes of Sweden, RISE Viktoria	Research Institutes of Sweden, RISE Viktoria
RWZ	Raiffeisen Waren-Zentrale	Raiffeisen Waren-Zentrale
Scania	Scania	Scania
SCAQMD	South Coast Air Quality Management District	South Coast Air Quality Management District (CA, USA)
Schleswig-Holstein Netz AG	Schleswig-Holstein Netz AG	Schleswig-Holstein Netz AG
Siemens	Siemens AG	Siemens AG
Smurfit Kappa	Smurfit Kappa Baden Board GmbH	Smurfit Kappa Baden Board GmbH
Spedition Bode	Spedition Bode GmbH & Co. KG	Spedition Bode GmbH & Co. KG
Spedition Fahrner	Spedition Fahrner GmbH	Spedition Fahrner GmbH
Spedition Schanz	Spedition Hans Adam Schanz GmbH & Co.KG	Spedition Hans Adam Schanz GmbH & Co.KG
SWEG	Südwestdeutsche Verkehrs-Aktiengesellschaft	Southwest German Transportation Corporation
Trafikverket	Trafikverket	Swedish Transport Administration
TransPower	Transportation Power, Inc.	Transportation Power, Inc.
TU Darmstadt	Technische Universität Darmstadt	Technical University Darmstadt
TU Dresden	Technische Universität Dresden	Technical University Dresden
TU Hamburg-Harburg	Technische Universität Hamburg-Harburg	Technical University Hamburg-Harburg
UBA	Umweltbundesamt	Federal Environment Agency
Umweltrat	Sachverständigenrat für Umweltfragen der Bundesregierung	Environment Council of the Federal Government
Unternehmerverband Logistik SH	Unternehmerverband Logistik Schleswig-Holstein	Trade association logistics Schleswig-Holstein
VDI/VDE	VDI/VDE Innovation + Technik	VDI/VDE innovation + technology
VDV	Verband Deutscher Verkehrsunternehmen	Association of German transportation companies

Vinnova	Vinnova, Sveriges innovationsmyndighet	Swedish Central Agency for Innovation Systems
VM BW	Ministerium für Verkehr Baden-Württemberg	Ministry of Transport, State of Baden-Württemberg
VM Hessen	Hessisches Ministerium für Wirtschaft, Energie, Verkehr und Landesentwicklung	Ministry of Economics, Energy, Transport and Regional Development, State of Hessen
VM SH	Ministerium für Wirtschaft, Verkehr, Arbeit, Technologie und Tourismus Schleswig-Holstein	Ministry of Economic Affairs, Transport, Employment, Technology and Tourism, State of Schleswig-Holstein
Volvo Trucks	Volvo Trucks	Volvo Trucks
VSL BW	Verband Spedition und Logistik Baden-Württemberg	Forwarding and logistics association Baden-Württemberg

*if there is not country qualifier, the organisation is German.

**in the case of name changes over the last years, the most recent actor names are provided.

Appendix C

Overview searched newspapers

Table C1. List of searched newspapers.

	LexisNexis	Additional
National	Bild am Sonntag	Frankfurter Allgemeine Zeitung
	Bild Bund	Frankfurter Allgemeine Sonntagszeitung
	Börsen-Zeitung	Süddeutsche Zeitung
	Deutsche Welle	
	Energie & Management	
	Jüdische Allgemeine	
	Lebensmittel Zeitung	
	Der Tagesspiegel	
	taz, die Tageszeitung	
	VDI nachrichten	
	Die Welt	
	Welt Aktuell	
	Die Welt am Sonntag	
	Welt kompakt	
	Die Zeit (inklusive Zeit Magazin)	
Regional	Aachener Nachrichten	
	Aachener Zeitung	
	Aar Bote	
	Allgemeine Zeitung (Mainz)	
	Alt-Neuöttinger Anzeiger	
	B.Z.	
	Bayerische Gemeindezeitung	
	Der Bayerwald-Bote	
	Bergische Morgenpost	
	Berliner Kurier	
	Berliner Zeitung	
	Bild Regionalausgaben	
	Bürstädter Zeitung	
	Darmstädter Echo	
	Deggendorfer Zeitung	
	Der Neue Kämmerer	
	Frankfurter Neue Presse	
	Frankfurter Rundschau	
	General-Anzeiger (Bonn)	
	Giessener Anzeiger	
	Groß-Gerauer Echo	
	Hamburger Morgenpost	
	Hocheimer Zeitung	
	Hofheimer Zeitung	
	Idsteiner Zeitung	
	Kölner Express	
	Kölner Stadt-Anzeiger	

Kölnische Rundschau
Kreis Anzeiger
Lampertheimer Zeitung
Landauer Neue Presse
Lauterbacher Anzeiger
Main-Spitze
Main-Taunus-Kurier
Mitteldeutsche Zeitung
Neuss Grevenbroicher Zeitung
Nordwest-Zeitung
Nürnberger Nachrichten
Nürnberger Zeitung
Oberhessische Zeitung
Odenwälder Echo
Passauer Neue Presse
Rhein Main Digital GmbH
Rheinische Post Düsseldorf
Ried Echo
Rottaler Anzeiger
Sächsische Zeitung
Schwarzwälder Bote
Solinger Morgenpost
Starkenburger Echo
Stuttgarter Nachrichten
Stuttgarter Zeitung
Südwest Presse
Usinger Anzeiger
Vilshofener Anzeiger
Die Welt Berlin
Die Welt Hamburg
Wiesbadener Kurier
Wiesbadener Tageblatt
Wormser Zeitung

Criteria for categorizing newspaper articles as depicting CHT positively, neutrally, or negatively

- Is there a strong presence of positive/negative wording (especially adjectives) in direct relation to the technology?
- Does the article end on a positive/negative note in a balancing contrast to the overall tone of the article?
- Does the article only include positive/negative accounts of directly quoted actors?
- Does the article present alternative technologies or approaches and highlight their advantages over CHT?

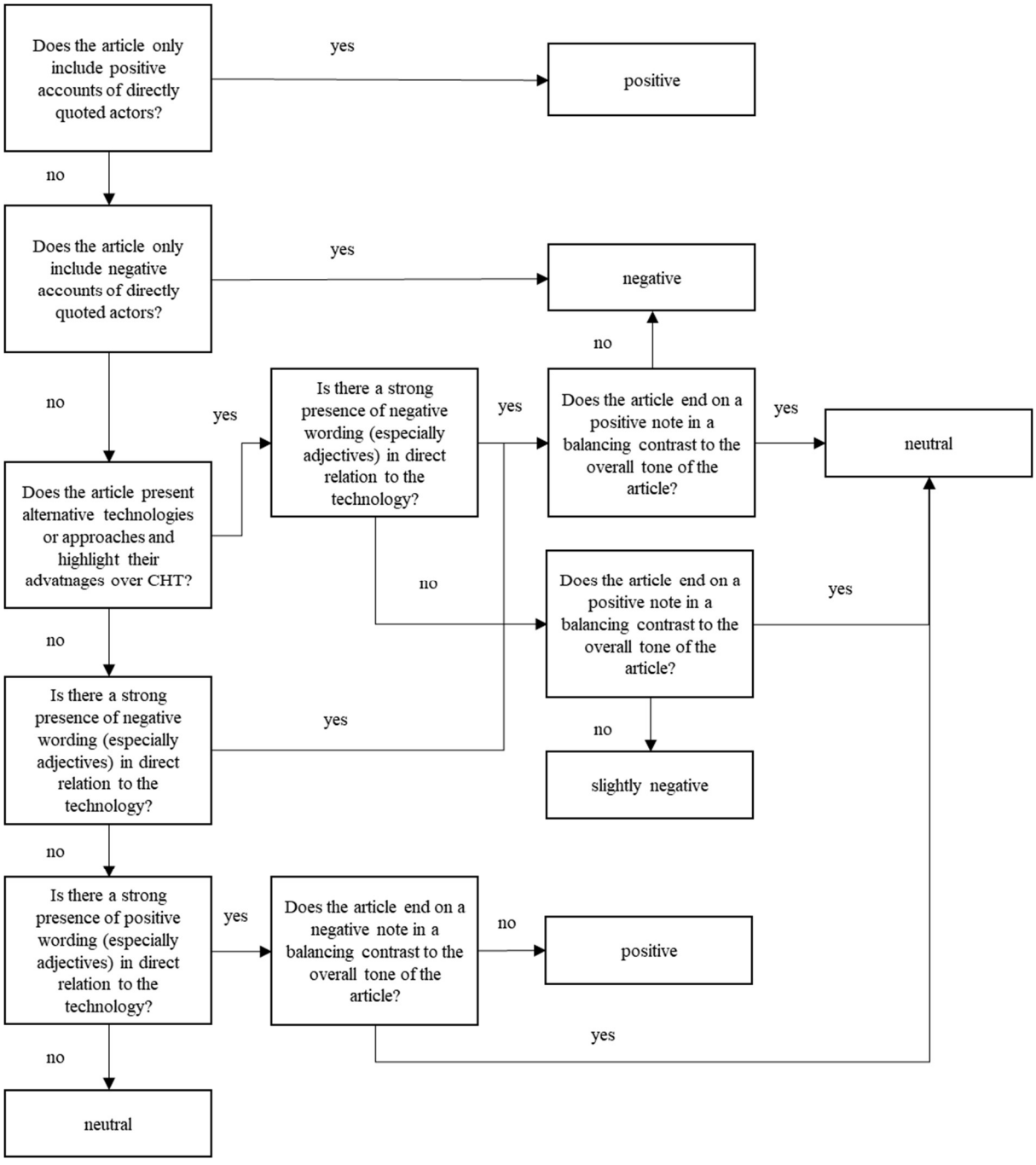


Figure C1. Decision tree for coding the tone of newspaper articles.

Overview analyzed newspaper articles

Table C2. List of analyzed newspaper articles including coding of tone sorted by date.

Title	Newspaper	Date	Coding tone
Keine neuen Straßen in diesem Jahr; Sanierungsprogramm sieht im Landkreis Darmstadt-Dieburg 22 Projekte vor	Darmstädter Echo	20.03.2018	neutral
Aufbruch in neue Mobilitätswelt; Digitalisiert, vernetzt und klimaschonend soll es auf Hessens Straßen und Schienen in Zukunft zugehen	Frankfurter Neue Presse (Regionalausgaben)	07.03.2018	neutral
Auf A5 sind bald E-Brummis unterwegs	BILD Frankfurt	06.03.2018	neutral
Baustart für eHighway an der A1 verzögert sich	BILD Hamburg	05.03.2018	neutral
Lübeck; Teststrecke für E-Lkw verzögert sich	Die Welt Hamburg	05.03.2018	neutral
Bau von Teststrecke für Laster mit Stromabnehmern beginnt	Frankfurter Allgemeine Zeitung	05.03.2018	neutral
Die elektrische Autobahn; Hessen Mobil beginnt an diesem Montag auf der A5 zwischen Darmstadt und Frankfurt mit Einrichtung der Baustelle	Allgemeine Zeitung (Germany)	05.03.2018	slightly positive
Technisch machbar - aber extrem teuer	Frankfurter Allgemeine Zeitung	19.01.2018	slightly negative
Geld wäre besser angelegt	Nordwest-Zeitung	30.12.2017	negative
Ab 2019 Test auf A5 für Lkw mit Oberleitungen	Aachener Nachrichten	19.12.2017	neutral
Auf der A5; Hessen testet Elektro-Brummis	BILD Frankfurt	19.12.2017	neutral
Erster eHighway startet 2019; Im Test; Lkw mit Stromabnehmern	General-Anzeiger (Bonn)	19.12.2017	neutral
Startschuss für ersten eHighway; Lkw mit Strom aus Oberleitung; Teststrecke auf A5	Schwarzwälder Bote	19.12.2017	neutral
Laster sollen mit Strom aus Oberleitungen fahren; Startschuss für ein Pilotprojekt in Hessen. Auf der A5 bei Darmstadt können E-Laster künftig während der Fahrt Strom tanken und mit Öko-Energie fahren. Die Technik liefer Siemens	taz, die Tageszeitung	19.12.2017	neutral
A5 wird zur Elektro-Autobahn; Teststrecke in Hessen: Oberleitungs-LKW sollen Güterverkehr umweltfreundlicher machen	Frankfurter Neue Presse	19.12.2017	slightly positive
Ökostrom aus der Oberleitung für E-Laster	Energie & Management	18.12.2017	neutral
Startschuss für ersten eHighways - Lastwagen mit Strom aus Oberleitung	Frankfurter Allgemeine Zeitung	18.12.2017	neutral
Plädoyer für E-Auto-Quote	Frankfurter Rundschau	24.11.2017	neutral

Das Rennen um den E-Truck; Tesla will einen Elektro-Lastwagen vorstellen. MAN-Chef Joachim Drees erklärt, warum er den amerikanischen Konkurrenten nicht fürchtet	Welt kompakt	13.11.2017	neutral
Klimascchutz im Verkehr ist nötig und machbar	Frankfurter Allgemeine Sonntagszeitung	05.11.2017	positive
Güterverkehr: Lastwagen hängen die Bahn ab	Stuttgarter Zeitung	02.11.2017	positive
Vorausdenken für den Wirtschaftsstandort; Strategiegespräch - Logistikunternehmer Dieter Fahrner begrüßt Norbert Beck	Schwarzwälder Bote	26.10.2017	neutral
Der E-Lkw überholt	Frankfurter Allgemeine Zeitung	14.10.2017	negative
Entega-Vorstandsvorsitzende mit Forderungen an neue Regierung	Energie & Management	27.09.2017	neutral
"Sorge um Kinder und Ehepartner"; Der Landtag in Kiel stimmt für eine Erleichterung des Familiennachzugs von Flüchtlingen*	Die Welt Hamburg	22.09.2017	positive
Fahrner bringt e-Highway ins Rollen; Umweltministerin Hendricks überreicht Förderbescheid für einzigartige Lkw-Strecke im Murgtal	Schwarzwälder Bote	13.09.2017	slightly positive
Elektro-Lkw für den Umweltschutz; Murgtal wird bundesweit dritte Teststrecke für Oberleitungs-Hybrid-Lastwagen	Stuttgarter Nachrichten	12.09.2017	neutral
Oberleitungs-Lkw rollen bald auf Bundesstraße	Schwarzwälder Bote	12.09.2017	neutral
Teststrecke für Oberleitungs-Lkw	Stuttgarter Zeitung	12.09.2017	neutral
Siemens rüstet für einen Feldversuch die Autobahn A5 mit Anlage aus; Auch Stromleitungen sollen Lkw rollen lassen	Nürnberger Zeitung	12.08.2017	neutral
Zwischen Frankfurt und Darmstadt rollen bald Oberleitungs-LKW	Frankfurter Allgemeine Zeitung	11.08.2017	neutral
Wasserstoff statt Diesel?; Der Abgas-Skandal erschüttert Deutschland. Verbrennungsmotoren werden infrage gestellt, E-Autos als Alternative gelobt. Doch eine saubere Technologie ist in Vergessenheit geraten	Die Welt	07.08.2017	negative
Oberleitung gegen Steckdose; Autokonzerne starten Testphasen für elektrische Lkws mit unterschiedlichen Systemen	taz, die Tageszeitung	23.06.2017	neutral
Das lange Leben der Uralttechnik	Frankfurter Allgemeine Zeitung	19.04.2017	negative
Hendricks fährt auf Lkw mit Oberleitung ab	Der Tagesspiegel	12.04.2017	positive

Die großen Brummis sollen an die Elektro-Leine; Schwere Lkw könnten schon bald auf der Autobahn umweltfreundlicher fahren: Elektrische Oberleitungen sollen helfen, die Abgase zu reduzieren.	Südwest Presse	12.04.2017	positive
Schluss mit Elefantenrennen; E-Laster im Test: Die ersten Feldversuche mit Hybridfahrzeugen sind ab 2019 geplant	General-Anzeiger (Bonn)	12.04.2017	slightly positive
Besser Wasserstoff	Frankfurter Allgemeine Zeitung	22.02.2017	negative
Keine Verlagerung auf die Schiene	Franfkurter Rundschau	20.02.2017	positive
Und der Güterverkehr stagniert	Süddeutsche Zeitung	13.02.2017	negative
Oberleitungs-Lkw kommen nach Deutschland; Zwei Länder wollen Teststrecken für Elektro-Laster mit Stromabnehmer - Zukunftsvision für umweltfreundliche Ferntransporte	Lebensmittel Zeitung	10.02.2017	neutral
Intermodale Verkehre sind besser	Frankfurter Rundschau	09.02.2017	negative
Zug-Maschine	Süddeutsche Zeitung	09.02.2017	slightly positive
Autobahnen unter Strom	Sächsische Zeitung Stammausgabe Dresden	06.02.2017	slightly positive
Europäisch denken	General-Anzeiger (Bonn)	04.02.2017	slightly negative
Strom tanken an der Oberleitung; Bei Frankfurt und Lübeck entstehen bis Ende 2018 zwei neue Teststrecken für Elektro-Lkw	General-Anzeiger (Bonn)	04.02.2017	Slightly positive
Die Technologie	General-Anzeiger (Bonn)	04.02.2017	slightly positive
Lastwagen sollen mit Strom fahren; Projektstart für Oberleitungs-Lkw	Der Tagesspiegel	04.02.2017	Slightly positive
2019 Test von Elektro-Lkw deutschen Autobahnen	Berliner Zeitung	03.02.2017	neutral
Feldversuch mit Elektro-Lkw auf A5	Frankfurter Neue Presse	03.02.2017	neutral
Feldversuch mit Elektro-Lkw auf A5	Frankfurter Neue Presse (Regionalausgaben)	03.02.2017	neutral
Autobahnen unter Strom	Süddeutsche Zeitung	03.02.2017	neutral
Teststrecke für Elektrolastwagen; Auf der A5 zwischen Darmstadt und dem Flughafen sollen ab 2019 Oberleitungen erprobt werden	Frankfurter Neue Presse	03.02.2017	slightly positive
Oberleitungen für Lkws im Test auf der A5	Frankfurter Neue Presse (Regionalausgaben)	03.02.2017	slightly positive
Agentur: Stromlastwagen sollen kommen; Umweltschutz	taz, die Tageszeitung	25.01.2017	neutral
E-Lkw mit Oberleitung vor der Erprobung	Nürnberger Nachrichten	25.01.2017	neutral
Praxistest für Oberleitungs-LKW soll Ende 2018 starten	Energie & Management	25.01.2017	slightly positive
Oberleitungs-Lkw bald auf zwei Autobahnen	Frankfurter Allgemeine Zeitung	24.01.2017	neutral
Siemens plant Versuch mit Oberleitungs-	Mitteldeutsche Zeitung	18.11.2016	neutral

Lkw			
Klimaneutraler Verkehr ist machbar	Energie & Management	08.11.2016	slightly positive
Oberleitung versorgt umweltfreundliche LKW; Scania und Siemens testen auf schwedischer Autobahn Elektro-Laster mit Stromabnehmer - VW-Tochter bringt auch Brennstoffzellen	Lebensmittel Zeitung	02.09.2016	slightly positive
E-Highways für den Lkw-Verkehr	Frankfurter Rundschau	26.08.2016	slightly positive
Autobahn mit Oberleitung	Frankfurter Allgemeine Woche	19.08.2016	positive
Schneller als ein Porsche	VDI Nachrichten	05.08.2016	neutral
So funktioniert die erste Elektro-Autobahn; Siemens und Scania lassen Laster nur mit Strom fahren. Die Technik ist allerdings teuer und veraltet.	Die Welt	24.06.2016	negative
Lastwagen mit langer Leitung; Was kann man fürs Klima tun, wenn das Bahnnetz zu dünn ist? Schweden hat eine Antwort: Lkws elektrifizieren	taz, die Tageszeitung	08.06.2016	slightly positive
Sauber zustellen; Deutsche Post DHL Group verteilt Briefe und Pakete mit E-Fahrzeugen	Der Tagesspiegel	06.06.2016	neutral
Nach Art der Trolleybusse	Frankfurter Rundschau	04.01.2016	positive
Siemens bringt Strom-LKW auf die Straßen; Güterverkehr wächst und die Schiene ist überlastet	Die Welt	17.11.2015	slightly positive
Schluss mit Brummi	Süddeutsche Zeitung	28.07.2015	positive
Siemens baut E-Autobahn in Kalifornien	VDI Nachrichten	15.08.2014	neutral
Siemens baut Lastwagen-Highway mit Oberleitung; Ab Sommer 2015 sollen vorerst nur 4 LKWs pro Tag auf der Teststrecke fahren, doch das Konzept ist ausbaufähig	Welt kompakt	08.08.2014	neutral
Siemens testet in den USA; Mit dem Lkw über die E-Autobahn	Nürnberger Zeitung	07.08.2014	neutral
Schweden tüfteln an Elektrotrassen; Stockholmer Verkehrsbehörde plant Pilotprojekt für Straßen mit Stromführung für den Schwerlastverkehr. Die Skandinavier streiten nur noch über die Technik: Oberleitungen oder Schienen?	taz, die Tageszeitung	14.08.2013	neutral

*second part of the article introduces other policy decisions, including decision on CHT.

Appendix D

Survey

Fragebogen

1 Sprachauswahl

Wählen Sie bitte Ihre bevorzugte Sprache.
Please select your preferred language.

- ○ Deutsch
- ○ English

2 Intro

Utrecht University

Fraunhofer ISI

Umfrage - Oberleitungs-LKW

Sehr geehrte/r Umfrageteilnehmer/in,

vielen Dank, dass Sie sich die Zeit nehmen, mit Ihrer Expertise an dieser Umfrage teilzunehmen.

Diese Umfrage trägt zu einem aktuellen Forschungsprojekt des **Fraunhofer Institut für System- und Innovationsforschung (ISI)** im Bereich des nachhaltigen Güterverkehrs bei. Die Ergebnisse werden im Rahmen meiner **Masterarbeit an der Universität Utrecht** verarbeitet. Untersucht wird, inwiefern **Oberleitungs-LKW** eine Möglichkeit zur nachhaltigeren Gestaltung des Güterverkehrs darstellen. Eine wissenschaftliche Einschätzung dieser Technologie ist aufgrund von bereits stattgefundenen und geplanten Feldversuchen derzeit besonders relevant.

Das Ausfüllen der Umfrage sollte nicht länger als **10 Minuten** dauern. Sie können nur einmal an der Umfrage teilnehmen. Alle angegebenen Daten werden vertraulich behandelt und in der Auswertung aggregiert und anonymisiert.

Mit freundlichen Grüßen,

Aline Scherrer, Studentin MSc Sustainable Development, Universität Utrecht

Sollten im Laufe der Bearbeitung Fragen oder Anmerkungen auftreten, kontaktieren Sie mich gerne unter a.scherrer@students.uu.nl

3 Persönliche Informationen

Welche Organisation repräsentieren Sie in dieser Umfrage?

Tragen Sie den vollen Namen Ihrer Organisation in das vorgegebene Feld ein.

4 Kommunikation und Kollaboration

Mit welchen der aufgeführten Akteure hat Ihre Organisation in den letzten 5 Jahren zum Thema Oberleitungs-LKW zusammengearbeitet oder in engem Austausch gestanden?

Bei dieser Frage sind mehrere Antworten möglich. Wählen Sie die Kästchen hinter allen Akteuren aus, mit denen Ihre Organisation in den letzten 5 Jahren zum Thema Oberleitungs-LKW kommuniziert oder kollaboriert hat.

Nicht enthaltene Akteure können am Ende der Liste ergänzt werden.

Sollte Ihre Organisation mit keinem anderen Akteur kollaboriert oder kommuniziert haben, so ist dies auch ein gültiges Ergebnis. Kreuzen Sie in diesem Fall das Kästchen "nicht zutreffend" am Ende der Liste an.

- [ ] ADAC
- [ ] Bundesanstalt für Straßenwesen (BASt)
- [ ] Bundesumweltministerium (BMUB)
- [ ] Bundesverkehrsministerium (BMVI)
- [ ] Bundeswirtschaftsministerium (BMWI)
- [ ] Bündnis Allianz pro Schiene
- [ ] California Energy Commission
- [ ] Casimir Kast Verpackung und Display GmbH
- [ ] Chalmers Tekniska Högskola (Technische Hochschule)
- [ ] CLECAT - European Association for Forwarding, Transport, Logistics and Customs Services
- [ ] Contargo AG
- [ ] DAF
- [ ] Daimler
- [ ] DAW SE
- [ ] Denkfabrik Agora Verkehrswende
- [ ] Deutsche Bahn
- [ ] Deutscher Speditions-und Logistikverband (DSLV)
- [ ] DVGW-Forschungsstelle am Engler-Bunte-Institut des KIT
- [ ] e-mobil BW GmbH
- [ ] ENTEGA

- [ ] Energiewendeministerium Schleswig-Holstein
- [ ] Energimyndigheten (Schwedische Energieagentur)
- [ ] FCA (Fiat)
- [ ] FH Kiel
- [ ] Ford
- [ ] Fraunhofer IAO
- [ ] Fraunhofer ICT
- [ ] Fraunhofer IML
- [ ] Fraunhofer ISI
- [ ] FZI Forschungszentrum Informatik
- [ ] Regierungsbezirk Gävleborg, Schweden
- [ ] Greenpeace
- [ ] Hans Lehmann KG
- [ ] HEAG mobilo AG
- [ ] Hegro Eichler GmbH
- [ ] Hessen Mobil (hessische Landesbehörde für Straßen- und Verkehrsmanagement)
- [ ] Hochschule Heilbronn
- [ ] Huettemann Logistics GmbH
- [ ] INFRAS AG Bern
- [ ] Intraplan Consult GmbH
- [ ] Ort Kuppenheim
- [ ] LA Metro, CA, USA
- [ ] Landesbetrieb Straßenbau und Verkehr Schleswig-Holstein (LBV SH)
- [ ] Logistikverband BGL
- [ ] Los Angeles, CA, USA
- [ ]

- [ ] Lübecker Hafen-Gesellschaft mbH
- [ ] Hansestadt Lübeck
- [ ] Mack Trucks
- [ ] MAN Truck & Bus AG
- [ ] Mayr-Melnhof Gernsbach GmbH
- [ ] Meyer Logistik (Ludwig Meyer GmbH & Co KG)
- [ ] M-Five
- [ ] NABU
- [ ] Näringsdepartementet (Verkehrsministerium Schweden)
- [ ] Netze BW GmbH
- [ ] Öko-Institut
- [ ] Port of Long Beach, Los Angeles, CA, USA
- [ ] PTV Transport Consult GmbH
- [ ] Raiffeisen Waren-Zentrale (RWZ)
- [ ] Regierungspräsidium Karlsruhe
- [ ] Renault
- [ ] Scania
- [ ] Schleswig-Holstein Netz AG
- [ ] Siemens
- [ ] Smurfit Kappa Baden Board GmbH
- [ ] South Coast Air Quality Management District (SCAQMD), CA, USA
- [ ] Spedition Bode
- [ ] Spedition Fahrner GmbH
- [ ] Spedition Schanz
- [ ] Stadt und Landkreis Rastatt
- [ ]

- [ ] Kreis Stormarn
- [ ] Südwestdeutsche Verkehrs-Aktiengesellschaft (SWEG)
- [ ] Trafikverket (Transportbehörde), Schweden
- [ ] TransPower
- [ ] TU Darmstadt
- [ ] TU Dresden
- [ ] TU Hamburg-Harburg
- [ ] Umweltbundesamt (UBA)
- [ ] Umweltrat (Sachverständigenrat für Umweltfragen der Bundesregierung)
- [ ] Unternehmerverband Logistik Schleswig-Holstein
- [ ] US-Umweltschutzbehörde EPA
- [ ] VDI/VDE Innovation + Technik
- [ ] Verband Deutscher Verkehrsunternehmen (VDV)
- [ ] Verband Spedition und Logistik Baden-Württemberg
- [ ] Verkehrsministerium Baden-Württemberg
- [ ] Verkehrsministerium Hessen
- [ ] Verkehrsministerium Schleswig-Holstein
- [ ] Vinnova (Schwedisches Zentralamt für Innovationssysteme)
- [ ] Volvo
- [ ] _____
- [ ] _____
- [ ] _____
- [ ] _____
- [ ] _____
- [ ] _____
- [ ] _____

☐

☐

☐

☐ Nicht zutreffend

5 Statements zu Oberleitungs-LKW

Meine Organisation ist der Entwicklung und Verbreitung von Oberleitungs-LKW gegenüber positiv eingestellt.

Kreuzen Sie die zutreffende Antwort auf einer Skala von "trifft nicht zu" bis "trifft zu" an.

- ○ trifft nicht zu
- ○ trifft eher nicht zu
- ○ teils-teils
- ○ trifft eher zu
- ○ trifft zu
- ○ keine Angabe

Warum ist dies der Fall?

Beschreiben Sie knapp die Gründe für Ihre Antwort zur vorherigen Frage.

Wie hoch sehen Sie die Chance, dass sich Oberleitungs-LKW durchsetzen werden?

Kreuzen Sie die zutreffende Antwort auf einer Skala von "sehr gering" bis "sehr hoch" an.

- ○ sehr gering
- ○ gering
- ○ mittel
- ○ hoch
- ○ sehr hoch
- ○ keine Angabe

Warum ist dies der Fall?

Beschreiben Sie knapp die Gründe für Ihre Antwort zur vorherigen Frage.

Meine Organisation unterstützt aktiv die Entwicklung und Verbreitung von Oberleitungs-LKW.

Kreuzen Sie die zutreffende Antwort auf einer Skala von "trifft nicht zu" bis "trifft zu" an.

- ○ trifft nicht zu
- ○ trifft eher nicht zu
- ○ teils-teils
- ○ trifft eher zu
- ○ trifft zu
- ○ keine Angabe

Warum ist dies der Fall?

Beschreiben Sie knapp die Gründe für Ihre Antwort zur vorherigen Frage.

Welche Faktoren und Rahmenbedingungen beeinflussen Ihre Unterstützung für die Entwicklung und Verbreitung von Oberleitungs-LKW?

Kreuzen Sie alle zutreffenden Antworten an.

- ☐ Internationale politische Entwicklungen
- ☐ Erschwinglichkeit
- ☐ Förderung durch nationale Politik
- ☐ Entwicklungsstand der Technologie
- ☐ Eigenmotivation bezüglich Nachhaltigkeit
- ☐ Finanzielle Anreize
- ☐ Unterstützung der Technology durch andere Akteure
- ☐

Bekanntheitsgrad der Technologie

☐ Andere:

6 Statements zu Oberleitungs-LKW 2

Wie unterstützt Ihre Organisation die Entwicklung und Verbreitung von Oberleitungs-LKW?

Beschreiben Sie knapp Ihre Aktivitäten in diesem Bereich.

Die Technologie "Oberleitungs-LKW" hat das Potenzial, die Nachhaltigkeit des Güterverkehrs zu verbessern.

Kreuzen Sie die zutreffende Einschätzung Ihrer Organisation auf einer Skala von "stimme nicht zu" bis "stimme zu" an..

- ○ stimme nicht zu
- ○ stimme eher nicht zu
- ○ unentschieden
- ○ stimme eher zu
- ○ stimme zu
- ○ keine Angabe

Die Technologie "Oberleitungs-LKW" wird in Zukunft auf dem freien Markt rentabel sein.

Kreuzen Sie die zutreffende Einschätzung Ihrer Organisation auf einer Skala von "stimme nicht zu" bis "stimme zu" an.

- ○ stimme nicht zu
- ○ stimme eher nicht zu
- ○ unentschieden
- ○ stimme eher zu
- ○ stimme zu
- ○ keine Angabe

7 Ressourcen

Wie viele Mitarbeiter sind derzeit bei Ihrer Organisation beschäftigt?

Kreuzen Sie das entsprechende Intervall an. Bei international agierenden Organisationen ist hier die globale Gesamtzahl der Mitarbeiter gemeint.

- ☐ 1-50
- ☐ 51-250
- ☐ 251-1.000
- ☐ 1.001-5.000
- ☐ mehr als 5.000

Wie hoch war der Jahresumsatz (private Organisationen) bzw. der jährliche Haushalt (öffentliche Organisationen) Ihrer Organisation im Jahr 2016?

Kreuzen Sie das entsprechende Intervall an.

- ☐ 0-2 Mio. €
- ☐ >2-10 Mio. €
- ☐ >10-50 Mio. €
- ☐ >50-200 Mio. €
- ☐ >200 Mio. €

Was ist Ihre Rolle in Ihrer Organisation (z.B. Projektleiter für [...], Pressesprecher, Geschäftsführer, Referent für [...], etc.)

Tragen Sie die entsprechende Rolle oder Position in das vorgegebene Feld ein. Diese Daten werden, wie alle anderen Daten des Fragebogens, vertraulich behandelt und für die Analyse aggregiert und anonymisiert.

8 Bestätigung absenden

Mit Klick auf den Button "WEITER" schließen Sie die Umfrage ab.

9 Endseite

Utrecht University

Fraunhofer ISI

Vielen Dank für Ihre Teilnahme.

Bei Fragen oder Anregungen wenden Sie sich gerne an:
a.scherrer@students.uu.nl

Figure C1. Printed questionnaire German version.

Fragebogen

1 Sprachauswahl

Wählen Sie bitte Ihre bevorzugte Sprache.
Please select your preferred language.

- ○ Deutsch
- ○ English

2 Intro

Utrecht University

Survey - Catenary Highway Trucks

Dear survey participant,

thank you very much for taking the time to contribute to this survey with your expertise.

This survey contributes to a current research project of the **Fraunhofer Institute for System and Innovation Research (ISI)** in Karlsruhe, Germany on sustainable freight transport. The results will be used in the context of my **Master's thesis at Utrecht University in the Netherlands**. The research gathers in how far **catenary highway trucks** present a possibility for a more sustainable design of freight transportation. A scientific assessment of this technology is especially relevant because of past and currently planned field tests.

Answering the survey should take no longer than **10 minutes**. You can fill in the survey only once. All inserted data will be treated confidentially and will be aggregated and made anonymous for the analysis.

Best regards,

Aline Scherrer, student MSc Sustainable Development, Utrecht University

Should questions or remarks come up during the course of answering the survey, feel free to contact me under: a.scherrer@students.uu.nl

3 Persönliche Informationen

Which organisation do you represent in this survey?

Enter the full name of your organisation in the given field.

4 Kommunikation und Kollaboration

With which of the following actors has your organisation collaborated or been in close exchange with on the topic of catenary highway trucks during the last 5 years?

Multiple answers are possible for this question. Tick the boxes behind all actors with which your organisation has communicated or collaborated on the topic of catenary highway trucks during the last 5 years.

Actors which are not in the list can be added at the end of the list.

In case your organisation has not communicated or collaborated with any actor, this also presents a valid result. In this case, tick the box "not applicable" at the bottom of the list.

- [ ] ADAC (General German Automobile Association)
- [ ] BASt (Federal Highway Research Institute, Germany)
- [ ] BMUB (Federal Environmental Ministry, Germany)
- [ ] BMVI (Federal Transportation Ministry, Germany)
- [ ] BMWI (Federal Economic Ministry, Germany)
- [ ] Bündnis Allianz pro Schiene (Alliance pro Rail, Germany)
- [ ] California Energy Commission
- [ ] Casimir Kast Verpackung und Display GmbH
- [ ] Chalmers Tekniska Högskola (University of Technology)
- [ ] CLECAT - European Association for Forwarding, Transport, Logistics and Customs Services
- [ ] Contargo AG
- [ ] DAF
- [ ] Daimler
- [ ] DAW SE
- [ ] Denkfabrik Agora Verkehrswende
- [ ] Deutsche Bahn (German Railway)
- [ ] DSLV (German Forwarding and Logistics Union)
- [ ] DVGW-Forschungsstelle am Engler-Bunte-Institut des KIT (DVGW research center)
- [ ] e-mobil BW GmbH
- [ ] ENTEGA
- [ ] Energiewendeministerium (Energy Transition Ministry), Schleswig-Holstein, Germany
- [ ] Energimyndigheten (Swedish Energy Agency)
- [ ] FCA (Fiat)
- [ ]

- [ ] FH (University of Applied Sciences), Kiel, Germany
- [ ] Ford
- [ ] Fraunhofer IAO
- [ ] Fraunhofer ICT
- [ ] Fraunhofer IML
- [ ] Fraunhofer ISI
- [ ] FZI Forschungszentrum Informatik (FZI Research Center Computer Science)
- [ ] Government district Gävleborg, Sweden
- [ ] Greenpeace
- [ ] Hans Lehmann KG
- [ ] HEAG mobilo AG
- [ ] Hegro Eichler GmbH
- [ ] Hessen Mobil (state authority for street and transport management, Hessen, Germany)
- [ ] Hochschule (college) Heilbronn, Germany
- [ ] Huettemann Logistics GmbH
- [ ] INFRAS AG Bern
- [ ] Intraplan Consult GmbH
- [ ] Town of Kuppenheim, Germany
- [ ] LA Metro, CA, USA
- [ ] LBV SH (state enterprise for road construction and transporation, Schleswig-Holstein)
- [ ] BGL (Logistics Union)
- [ ] Los Angeles, CA, USA
- [ ] Lübecker Hafen-Gesellschaft mbH
- [ ] City of Lübeck, Germany
- [ ] Mack Trucks
- [ ] MAN Truck & Bus AG
- [ ]

- Mayr-Melnhof Gernsbach GmbH
- [ ] Meyer Logistik (Ludwig Meyer GmbH & Co KG)
- [ ] M-Five
- [ ] NABU
- [ ] Näringsdepartementet (Ministry of Enterprise and Innovation, Sweden)
- [ ] Netze BW GmbH
- [ ] Öko-Institut
- [ ] Port of Long Beach, Los Angeles, CA, USA
- [ ] PTV Transport Consult GmbH
- [ ] Raiffeisen Waren-Zentrale (RWZ)
- [ ] Regierungspräsidium (Regional Board) Karlsruhe, Germany
- [ ] Renault
- [ ] Scania
- [ ] Schleswig-Holstein Netz AG
- [ ] Siemens
- [ ] Smurfit Kappa Baden Board GmbH
- [ ] South Coast Air Quality Management District (SCAQMD), CA, USA
- [ ] Spedition Bode
- [ ] Spedition Fahrner GmbH
- [ ] Spedition Schanz
- [ ] City and county of Rastatt
- [ ] County of Stormarn, Germany
- [ ] SWEG (Southwest German Transportation Corporation)
- [ ] Trafikverket (transport authority), Sweden
- [ ] TransPower
- [ ] TU (University of Technology) Darmstadt, Germany
- [ ]

- TU (University of Technology) Dresden, Germany
- [ ] TU (University of Technology), Hamburg-Harburg, Germany
- [ ] UBA (Federal Environment Agency), Germany
- [ ] Umweltrat (Environment Council), Germany
- [ ] Unternehmerverband (trade association logistics) Logistik, Schleswig-Holstein, Germany
- [ ] United States Environmental Protection Agency
- [ ] VDI/VDE Innovation + Technik
- [ ] VDV (Union of German transportation companies)
- [ ] Verband Spedition und Logistik (Forwarding and Logistics Union), Baden-Württemberg, Germany
- [ ] Verkehrsministerium (Transportation Ministry) Baden-Württemberg, Germany
- [ ] Verkehrsministerium (Transportation Ministry) Hessen, Germany
- [ ] Verkehrsministerium (Transportation Ministry) Schleswig-Holstein, Germany
- [ ] Vinnova (Swedish Innovation Agency)
- [ ] Volvo
- [ ]
- [ ]
- [ ]
- [ ]
- [ ]
- [ ]
- [ ]
- [ ]
- [ ]
- [ ]
- [ ] Not applicable.

5 Statements zu Oberleitungs-LKW

My organisation has a positive attitude towards the development and diffusion of catenary highway trucks.

Tick the applicable answer on a scale from "untrue" to "true".

- untrue
- somewhat untrue
- neither true nor untrue
- somewhat true
- true
- not applicable

Why is this the case?

Shortly describe the reasons for your answer in the previous question.

How high do you consider the chances that catenary highway trucks will establish themselves?

Tick the applicable answer on a scale from "very low" to "very high".

- very low
- low
- medium
- high
- very high
- not applicable

Why is this the case?

Shortly describe the reasons for your answer in the previous question.

My organisation actively supports the development and diffusion of catenary highway trucks.

Tick the applicable answer on a scale from "untrue" to "true".

- untrue
- somewhat untrue

- ○ neither true nor untrue
- ○ somewhat true
- ○ true
- ○ not applicable

Why is this the case?

Shortly describe the reasons for your answer in the previous question.

Which factors or surrounding conditions influence your support for the development and diffusion of catenary highway trucks?

Tick all applicable answers.

- ☐ international political developments
- ☐ affordability
- ☐ promotion by national government
- ☐ development status of the technology
- ☐ intrinsic motivation for sustainability
- ☐ financial incentives
- ☐ support of the technology by other actors
- ☐ degree of awareness of the technology
- ☐ Other:

6 Statements zu Oberleitungs-LKW 2

How does your organisation support the development and diffusion of catenary highway trucks?

Shortly describe your activities in this area.

The technology "catenary highway trucks" has the potential to improve the sustainability of freight transport.

Tick the applicable opinion of your organisation on a scale from "does not apply" to "does apply".

- ○ disagree
- ○ somewhat disagree
- ○ neither agree or disagree
- ○ somewhat agree
- ○ agree
- ○ not applicable

The technology "catenary highway trucks" will be profitable on the free market in the future.

Tick the applicable opinion of your organisation on a scale from "does not apply" to "does apply".

- ○ disagree
- ○ somewhat disagree
- ○ neither agree or disagree
- ○ somewhat agree
- ○ agree
- ○ not applicable

7 Ressourcen

How many employees currently work at your organisation?

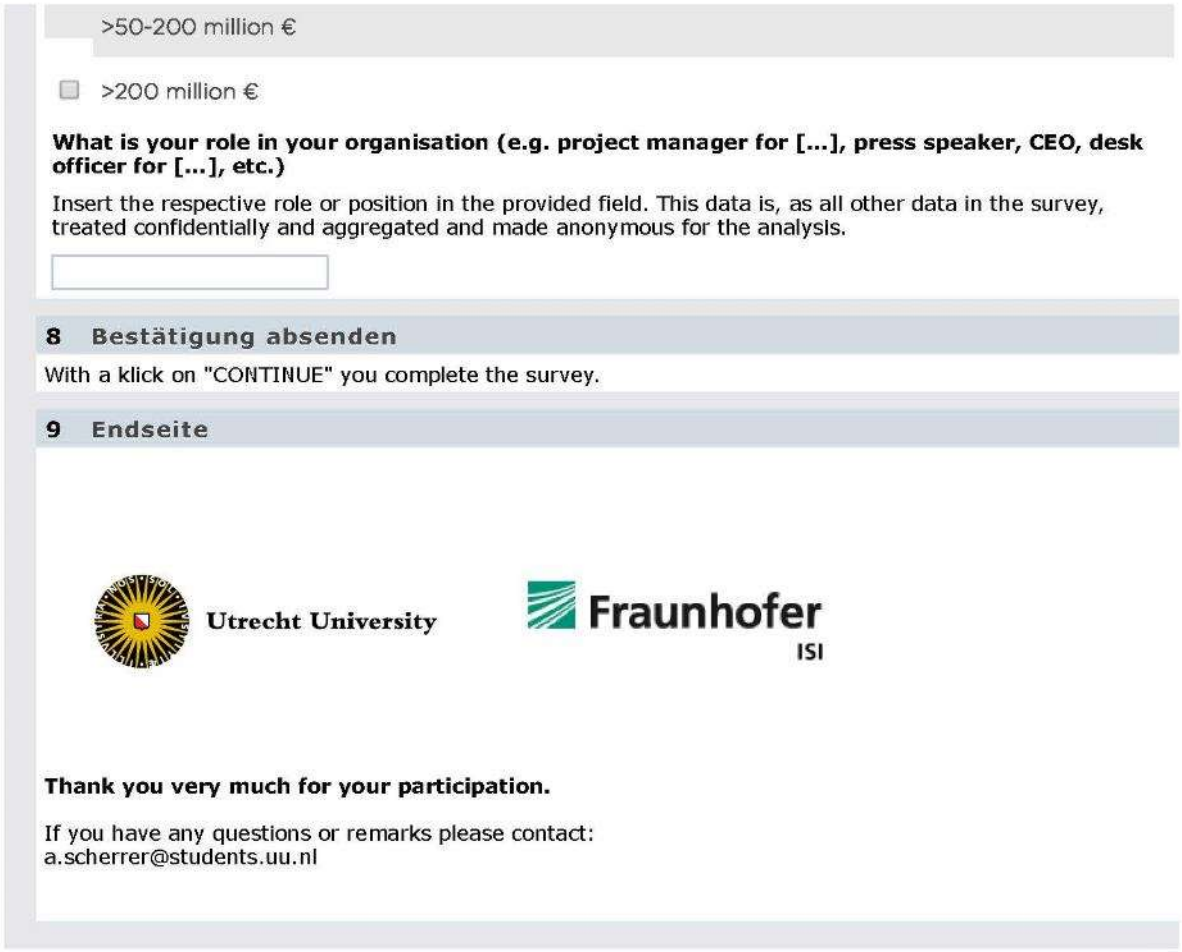
Tick the applicable interval. For internationally active organisations, this refers to the total global number of employees.

- ☐ 1-50
- ☐ 51-250
- ☐ 251-1.000
- ☐ 1.001-5.000
- ☐ more than 5.000

How high was the annual revenue (private organisations) or rather the annual government budget (public organisations) of your organisation in 2016?

Tick the applicable interval.

- ☐ 0-2 million €
- ☐ >2-10 million €
- ☐ >10-50 million €
- ☐



>50-200 million €

☐ >200 million €

What is your role in your organisation (e.g. project manager for [...], press speaker, CEO, desk officer for [...], etc.)

Insert the respective role or position in the provided field. This data is, as all other data in the survey, treated confidentially and aggregated and made anonymous for the analysis.

8 Bestätigung absenden

With a klick on "CONTINUE" you complete the survey.

9 Endseite

Utrecht University

Fraunhofer ISI

Thank you very much for your participation.

If you have any questions or remarks please contact:
a.scherrer@students.uu.nl

Figure C2. Printed questionnaire English version.

Appendix E

Interview guide

Table E1. Overview of interview questions in original German version and translated to English.

Einleitende Fragen	**Introductory questions**
- Seit wann sind Sie mit der Technologie der Oberleitungs-LKW generell in Kontakt? - Was ist Ihre Rolle in Ihrer Organisation im Hinblick auf Oberleitungs-LKW?	- Since when are you in contact with the technology of catenary trucks? - What is your role in your organization with regard to catenary trucks?
Güterverkehr allgemein	**Freight haulage in general**
- Welches sind Ihrer Meinung nach die derzeit größten Nachhaltigkeitsprobleme im Straßengüterverkehr? - Wie können diese Herausforderungen am besten gelöst werden? - Wer steht hierfür in der Verantwortung und sollte die Verbesserungen anregen (d.h. von welchem Akteur oder welcher Akteursgruppe sollten diese Verbesserungen ausgehen)?	- What are, in your opinion, the currently largest sustainability problems in road freight haulage? - How can these challenges be solved best? - Who has the responsibility for that or should initiate improvements (i.e. from which actor or actor group should such improvements stem)?
Oberleitungs-LKW	**Catenary trucks**

- Warum, denken Sie, sind Oberleitungs-LKW gerade jetzt ein Thema / viel diskutiert? Was macht den Zeitpunkt aus?
  o Warum beschäftigen Sie (als Organisation) sich damit? Und warum zu diesem Zeitpunkt? Was sind die Gründe und waren die Auslöser?
- Was ist Ihre generelle Einschätzung der Technologie?
- Welche Aktivitäten verfolgt Ihre Organisation im Hinblick auf Oberleitungs-LKW?
  o Technisch und/oder
  o institutionell und/oder
  o finanziell
- Wie schätzen Sie die zukünftige Entwicklung dieser Technologie ein?
  o Welche Faktoren können zum Gelingen oder Scheitern der Technologie beitragen?
- Generiert die Technologie einen Mehrwert
  o für Ihre Organisation?
  o Für die Gesellschaft?
	- Why do you think are catenary trucks a topic/ much discussed right now? What determines the point in time?
	  o Why do you engage with the technology (as an organization)? Why at this point in time? What are the reasons and have been the triggers?
	- What is your general evaluation of the technology?
	- Which activities does your organization pursue with regard to catenary trucks?
	  o Technically and/or
	  o Institutionally and/or
	  o Financially
	- How do you estimate the future development of this technology?
	  o Which factors can contribute to success or failure of the technology?
	- Does the technology generate added value
	  o For your organization?
	  o For society?

Alternativen	**Alternatives**

- Welche anderen Ansätze (z.B. Technologien, Transportmodi) stehen in direkter Konkurrenz mit der Technologie Oberleitungs-LKW?
- Welche(n) dieser Ansätze sehen Sie als sinnvolle Alternative zu Oberleitungs-LKW an?
  o Trägt Ihre Organisation zu solchen Alternativen bei? Wenn ja, wie?
	- Which other approaches (e.g. technologies, transport modes) present direct competition to the technology of catenary trucks?
	- Which of these approaches do you consider a sensible alternative to catenary trucks?
	  o Does your organization contribute to such alternatives? If yes, how?

Appendix F

Actor classification

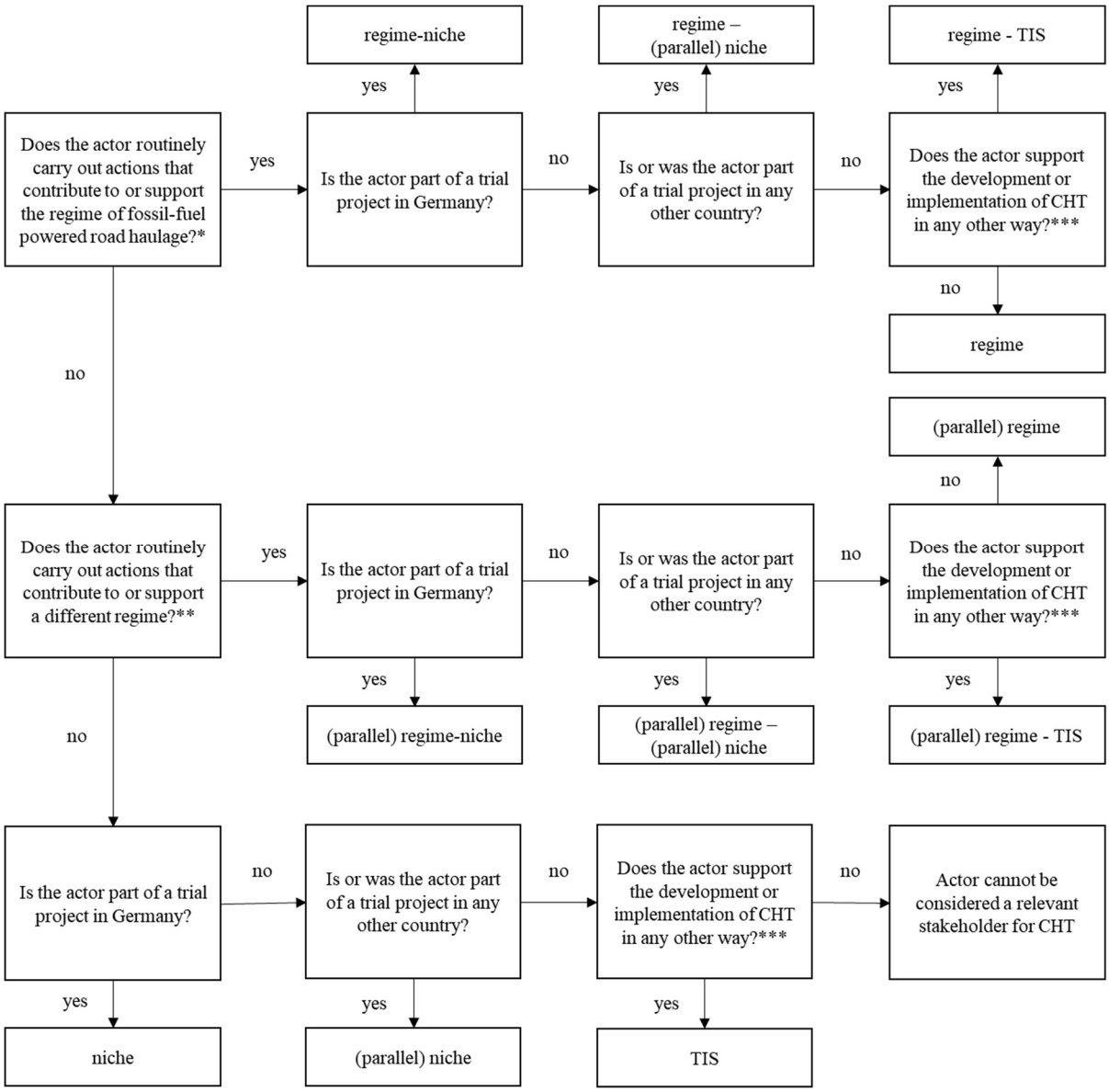


Figure E1. Decision tree for actor classifications.

*possible regime actions:

- Production of (specialized parts of) fossil-fuel powered trucks
- Construction, maintenance, and administration of road infrastructure
- Carrying out of logistics processes with fossil-fuel powered trucks

**possible different regimes:

- Rail transport regime
- Ship transport regime

- Fossil-fuel powered passenger transport regime
- Public transport regime

***other ways of supporting the development or implementation of CHT:

- CHT-related research
- Positive statements towards the technology in public

Appendix G

Barrier assessment – supplementary material

Table G1. Barrier 4 – Individual assessment of overlap and precision of statements within the identified main themes of expectations.

Theme	*Contribution to climate protection or reaching climate goals*
Assessment expectation overlap	Quotes
10 of the 17 niche actors expect the technology to contribute to a lowering of greenhouse gas emissions. 6 actors specifically make the connection to climate change and climate protection goals. An apparent difference in the presentation of expectations is that industry actors, both logistics companies and technology producers, were focused solely on the emissions reduction itself while the connection to climate change (goals) in particular was made by the government actors.	"electrically run catenary trucks as a solution on the pathway to climate neutral freight transportation, which enables many emission free kilometers with little renewable energy" "the CT exhibits great potential to contribute to reaching the climate protection goals" "CT can provide a valuable contribution to the decarbonization in road haulage" "can contribute to process transports more environmentally and climate friendly"
Assessment precision	
The precision of the expectations around the contribution of CHT to climate protection was rated as low to medium. The niche actors expect a contribution, and some mention specific ways in which an emission reduction would be possible such as through only using renewable energy for the technology, but there are no detailed expectations given about the difference to the current situation or the impact in a future transportation scenario.	
Theme	*Application context*
Assessment expectation overlap	Quotes
10 actors voiced expectations related to the specific application of the technology. Three governmental actors expect the technology to be implemented nationwide at some point. One of these actors also expects the possibility to develop the system along the transeuropean transportation network. Three industry actors consider the technology only fit for specific distances, one specifying these to be the most used distances. Since the nationwide development is also expected to only be implemented on a certain share of highways and not everywhere, this is not necessarily a contradiction in expectations but still reflects a different phrasing. Two industry actors already expect very specific scenarios for the inclusion of the technology in logistics processes.	"We will not build power poles and overhead lines on every highway in Germany but only where it makes sense." "The hope is that this will be the basis infrastructure of a German highway in the future." "Application probably only useful for certain distances." "The environmental ministry considers an overhead line network of 400km useful in a first step. Then one could go to 1000 and in the last step 5000 kilometers."
Assessment precision	
The precision of the statements on application expectations was scored as medium, shown in the large variance between low precision and high precision reflected in the quotes above (sorted from low to high precision).	

Theme	*Contribution to climate protection or reaching climate goals*
Assessment expectation overlap	Quotes
10 of the 17 niche actors expect the technology to contribute to a lowering of greenhouse gas emissions. 6 actors specifically make the connection to climate change and climate protection goals. An apparent difference in the presentation of expectations is that industry actors, both logistics companies and technology producers, were focused solely on the emissions reduction itself while the connection to climate change (goals) in particular was made by the government actors.	"electrically run catenary trucks as a solution on the pathway to climate neutral freight transportation, which enables many emission free kilometers with little renewable energy" "the CT exhibits great potential to contribute to reaching the climate protection goals" "CT can provide a valuable contribution to the decarbonization in road haulage" "can contribute to process transports more environmentally and climate friendly"
Assessment precision	
The precision of the expectations around the contribution of CHT to climate protection was rated as low to medium. The niche actors expect a contribution, and some mention specific ways in which an emission reduction would be possible such as through only using renewable energy for the technology, but there are no detailed expectations given about the difference to the current situation or the impact in a future transportation scenario.	
Theme	*Field trials*
Assessment expectation overlap	Quotes
7 actors have specific expectations about the purpose and added value of the field trials. Two actors see the field trials as a basis for a discussion of a Germany-wide construction which is expected to happen should the trials go well. Two government actors and two industry actors expect very specific knowledge to be created in the field trials. The government actors and one of the industry actors expect specific transportation and energy-technical knowledge with respect to energy savings, emissions, ecologic and economic advantages and disadvantages, scalability, procedural aspects, feasibility in real-world applications, and possible business models and processes. One industry actor expects to be able to find a viable business model together with providers or truck producers.	"In the case of an optimal test process, Germany's highways would be electrified nationwide." "Important traffic and energy technical aspects are being researched, to enable a later nationwide development of the system."
Assessment precision	
With some statements being very precise and some very general, the precision of statements on expectations around field trials was scored as medium.	
Theme	*Costs and financing*
Assessment expectation overlap	Quotes
6 of the 17 niche actors voice expectations about costs and financing of the technology. However, the expectations under this theme are very diverse. Two	"If the new technology establishes itself, trucks could, in the future, get by with combustion engines of car dimension which

industry actors point to the high expected infrastructure costs, while two governmental actors consider the investment as comparatively low and expect it to be doable, especially in light of the entire governmental transportation investments. 3 actors have the expectation that, in the long run, catenary trucks will be cheaper than current trucks and other alternatives, especially in the running and maintenance, for example through considerable fuel savings. One governmental actor expects future scenarios where users could finance such a system, for example through tolls or electricity bills and one actor expects additional costs for logistics companies, for example for the training of drivers.	would make them cheaper to purchase (…). Additionally, there would be decreasing fuel costs. Balanced with the additional costs for the pantograph system, trucks could become cheaper for logistics companies in total than today (…).” “Through electrification, the total costs for the operation of a typical freight haulage truck can be significantly lowered. The increased efficiency of the eHighway trucks, the long life span of electric engines and especially the independence from expensive fossil fuels allow for clear cost saving potential in the logistics branch.”
Assessment precision	
The precision of statements related to costs and financing was rated as medium. Two actors supported their expectations with specific amounts of expected costs, one for infrastructure and one for fuel savings, while the actors voiced less specific expectations about cost developments and general ideas.	
Theme	*Modal shifts*
Assessment expectation overlap	Quotes
6 actors consider the potential of a shift away from road transport to other transport modes limited and expect even greater limitations to such a shift in the future. Except for one industry actor, these actors are all governmental. While inland water transportation is mentioned as one option by a few actors, they consider it only a side note due to its small percentage share in the modal split. The main focus of the expectations about why road haulage will retain the largest share in the modal split lies with rail transportation. All 6 actors share the expectation that rail transportation will not be able to accommodate the growing transport volumes even with great effort.	“Even optimistic scenarios only expect the share of rail in cargo transportation to be at a maximum of 30% for 2050. Therefore, we need to also change over trucks to renewable energies.” “Transport volumes, according to prognoses, will increase. And rail cannot accommodate this, even with its best development plans.” “(…) even with an overproportional growth in the transportation share of rail, we will not be able to solve climate protection problems. That means, that is also a sham debate [Scheindebatte], that one says, dear state why do you actually invest in streets, why don’t you do much more for rail. It just doesn’t work. Because rail cannot fulfill these transportation tasks in the same way. That means, no direct competition.” “Such an increase in freight haulage cannot be coped with solely through a forced shift of transportation to rail. As such, the study “Klimaschutzbeitrag des Verkehrs bis 2050” commissioned by the Umweltbundesamt, shows that – given the right framework conditions – the traffic performance of rail could be increased more than twofold in comparison to today. Even then, however, 60% of freight traffic performance would remain on the street in 2050. Against this background,

	develops the strong demand to shift over trucks to low or even neutral greenhouse gas emitting propulsion technologies." "Even with great efforts to transport more goods over rail or inland water transportation, the highest share of around 70 percent will continue to fall upon streets."
Assessment precision	
The precision of the expectation statements around the modal split was rated as high. Except for one actor, all actors give precise expectations of what the percentage share of rail and respectively road cargo transport will look like in the future.	
Theme	*Alternative technologies*
Assessment expectation overlap	Quotes
5 actors of both government and industry voice expectations about alternative technologies. Three actors expect CT to be more feasible than the alternatives of purely electric and fuel cell propulsion. Two actors voice the expectation of battery technology or fossil fuel cells possibly developing greatly over the next few years and making the technology of CT obsolete due to being able to cover large distances as well. Regarding this possibility, one of the former, positively inclined actors still sees as synergy since even for fully electrified trucks, connecting to a catenary system would make long loading times at the start or destination obsolete.	"Pure battery vehicles will (despite foreseeable progress in the area of batteries) not be sufficient in the near future to cover heavy freight haulage (e.g. 40-ton trucks) on medium and large distances." "It could also be possible, that in three, four, five years when the field trials are over, battery technology has already developed so quickly that such intermediate charging solutions are not necessary anymore." "Large long-term competition from battery-powered trucks with large ranges." "We are not completely convinced yet that in 2022, when this project ends, if there won't maybe be another technology, whatever that is, whether that will be fuel cell or regular battery-powered trucks, that maybe in four, five years can easily drive 700-800 or 1000km." "Fuel cell technology, but there it depends a lot on who you ask, but I am a little bit sceptic with functional chains, energy conversion and also in total in the hydrogen demand (…). And I also do not yet see it as technologically as ready for use and robust and affordable as we are externally with electrification." "[We see a synergic advantage specifically for long distances.] Because if then such a[n electric] truck has a range of 200km, then it would have to, if it drives up to Bremen, exit every 200km to charge. That is lost time for the logistics company. Only costs money, not conceivable. That is why we see a great addi-

	tion there, if such a vehicle then gets such a pantograph on top and can then obtain tractive electricity from the overhead line. At some point it exits the highway and then has a range of 200km, that would be a technology where you would say, yes something like that is really suitable for everyday use."
Assessment precision	
The precision of statements around alternative technology expectations was found to be between medium and high. Expectations about technology developments were given in detail but without reference to ratio-based scenarios.	
Theme	*Local emissions and quality of life*
Assessment expectation overlap	Quotes
5 actors mention expectations with respect to local emissions, specifically referring to noise in addition to locally relevant air pollutants. Only two of the five actors, however, make the direct connection to the impact reduction this constitutes for residents.	"If we exchange diesel trucks for electric trucks on the test track, then we reduce the emission of air pollutants and or traffic noise. That does not only serve the quality of life of the people locally (…)." "Decreased pollutant emission, fewer noise emissions and higher efficiency: the expectations towards an electrification of truck transportation are high." "The CT contribute significantly to the noise reduction for the residents (…)."
Assessment precision	
The expectations with relation to such emissions were rated as medium to high in their precisions since they were provided in distinct categories but not with any more specific or quantifiable reduction expectations.	
Theme	*Business opportunities*
Assessment expectation overlap	Quotes
Four industry actors and one governmental actor expect the technology to yield a possible business advantage in the future. The industry actors expect a business case for themselves regarding reduced losses in revenue. One industry and one governmental actor consider the technology a good business case in comparison to alternatives since logistics processes would not have to be changed.	"This electrified truck system (…), can (…) keep these ports, one of our country's major economic drivers, competitive." "[One actor] expects economic and ecologic advantages from the technology. They can, for example, save a detour because they can go through the environment zone (…) with the electric trucks."
Assessment precision	
The precision of these statements was scored as medium to high.	
Theme	*Transport volumes*
Assessment expectation overlap	Quotes
Four of the 17 niche actors, among them three governmental and one industry actor expect transport	-

volumes to grow significantly in the future and connect this to their expectation that the current system could not accommodate such an increase without negative consequences.	

Assessment precision
The expectations around growing transport volumes are put forward at a low to medium precision, since no specific increases or numbers are mentioned and no specific consequences of such a growth.

Theme	*Regulations*
Assessment expectation overlap	Quotes
One governmental actor and three industry actors expect that future regulations will make the technology more necessary.	"Possible inner-city bans on driving for diesel vehicles could become an additional driving factor." "(…) to guarantee secure operation, secure for the future and also with reference to BImSchG ." "[the actor] is convinced of the efficiency, also customers are interested. The demand for emission free and quiet future concepts is present in view of the increasing limitations of access in many inner cities. [use of hybrid trucks for delivery]. 'If the vehicles have antlers, that makes even more sense. Then we are no longer dependent on charging stations, because the vehicle also gets its injection on the way."

Assessment precision
Precision was scored as medium to high since specific legislation and direct effects were mentioned in most cases.

Theme	*Citizen acceptance*
Assessment expectation overlap	Quotes
Two actors expect citizens or residents to be a critical barrier to the implementation of CT, with one referring to the problems with the erection of wind farms in the past. One other actor, however, has received positive feedback from residents who expect less emission and noise impacts and considers residents as a possible positive force for the implementation in the future.	"A lack of communication with the residents in the regions that it concerns [can be a barrier]. That can quickly lead to such modern projects or innovative projects to fail. Because spokes are put in somebody's wheel, that would not have to be, if people are incorporated early on in such developments." "critical citizen behavior" "[Currently] the trucks drive 24 hours per day, 7 days a week, Christmas, New Years, complete always with emissions and with noise and loud and everything. And solely through this message, that this new technology will come there, there was already a lot of

	positive feedback: Oh, finally a bit of relief for the environment from the burden, from the emissions, from noise and all. It is well received, very, very well received by the municipalities or in the municipal environment. And there we should pick them up, include them and explain the technology a bit better to them. But generally, it is very positive.”
Assessment precision	
The precision of expectations was rated as high since very specific actions of residents were imagined as possible drivers or barriers of CT implementation.	