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Incumbent Actors in Sectoral Transformations Towards Sustainability

A sociotechnical study of the European
heavy commercial vehicles sector

Benny Behbood Borghei

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Getting a PhD is like running a long marathon race with hurdles in a countryside terrain: it requires perseverance, endurance, and strong self-determination. It involves surprises, accidents, and sometimes even blockade on the trail. Thus, one needs to be flexible, while being committed to reach the final destination. Nevertheless, it is an inspiring journey full of learning and accomplishments.

This journey took me 6.5 years of constant running, falling, sweating, and challenging myself, but the journey also provided me a great chance to see plenty of beautiful sceneries after climbing high peaks and gain treasured experiences along the way. It included substantial time commitment for reading, writing, taking PhD courses, travelling and presenting in different conferences as well as teaching and supervising master's students. It also involved engaging in extracurricular activities as well as advocating for collective interests and obtaining equal rights regarding residence permits for foreign PhD students in Sweden. The latter provided me the opportunity to gain hands-on experience in institutional work and engagement in Swedish politics, and to witness the consequent institutional reforms in real-time. The residency permit for foreign PhD candidates in Sweden had been an enormous hurdle and a complicated question that affected several thousand of highly educated workforce for many years in this country, but it turned out as a great opportunity to put theory into practice and engage in institutional change and gain valuable experiences from the field work. But above all, I gained plenty of valuable advice and support along the way, and a handful of nice colleagues and friends that I will never forget:

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Being a PhD student in the Swedish academic system means that one is both an employee and a student at the same time. This can be both challenging and fruitful; since, on the one hand, there are serious academic responsibilities, such as teaching and supervision of graduate and undergraduate students, but on the other hand, it gives a sense of contribution while in turn being educated to become an independent scholar. It also provides a great chance to work with other university staff as colleagues and co-workers in a friendly, yet professional setting.

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Benny Behrood Berghei
Linköping, Sweden
Summer 2018

ABSTRACT

Industrial sectors need to be transformed in response to the increasing demands for environmental sustainability as one of the greatest challenges in the modern times. In social science research, extensive efforts have been made over the recent decades to formulate comprehensive theories about transformation of various sectors such as energy, manufacturing, agriculture, food and transportation. Accordingly, ‘sustainability transitions’ have emerged as a research field dedicated to the study of far-reaching sociotechnical transformations.

Understanding sectoral transformations and how different actors can get involved in sustainability transitions are in the heart of these efforts. Of particular importance is the involvement of industry incumbents that hold established positions and considerable amounts of knowledge, resources, and technological competence built upon vigorous structures of the existing industrial setup. This in turn calls for more attention to the role of incumbents to actively participate in the transformation of established sectors towards sustainability.

However, despite the potentials to get involved in processes of transformative change, incumbents are often neglected in transition theories, and their role is predetermined to resist the change. Incumbents are widely black-boxed as a homogenous group of actors to the extent that they are conceived as a single entity whose predefined role is to act as the guardians of the existing structures and defenders of the status-quo. While there are legitimate concerns about the power of incumbent firms, such one-sided views do not offer an inclusive approach in formulating multi-actor processes for sustainability transitions. Therefore, the purpose of this thesis is to contribute to a more comprehensive theorization on the role of incumbent actors in sectoral transformations. The main research question is formulated as follows: how can incumbents act to facilitate sectoral transformations towards environmental sustainability?

In answering this research question, the thesis offers an alternative perspective to the dominant view about incumbents in sustainability transition theories. It challenges prevailing assumptions by providing empirical evidence from the heavy commercial vehicles sector in Europe. The research findings show that incumbents are able to adopt various technological strategies ranging from incremental innovations with highly coordinated actions for reducing emission levels based on the established technologies, to the adoption of radical technological choices for introducing alternative propulsion technologies in the market. In fact, the strong position of incumbents can sometimes enable them to introduce radical innovations in established markets. The research findings also indicate that incumbents can act as learning agents or knowledge repositories to overcome the problem of isolation for new technological innovations by transferring knowledge and technologies over the boundaries of time and space. Moreover, incumbents can facilitate diffusion of radical innovations and ramp up the adoption of new technologies through standardization at the industry level.

In addition, incumbents from a range of different sectors have been recognized as integrators for the development of new technological solutions that span over traditional boundaries. Hence, new industrial sectors can emerge through the integration of knowledge and technologies from various established sectors, and incumbents are at the heart of the integration processes due to their knowledge and familiarity of the established sectors.

Finally, the theoretical implications from the thesis invite transition scholars to reconsider the role of incumbent actors in sustainability transitions, while the practical implications suggest that policy-makers need to pay more attention to the diversity of technology strategies of incumbent firms and their alignments for sectoral transformations towards sustainability.

SAMMANFATTNING

Ökande krav på en ekologiskt hållbar utveckling under senare tid pekar på ett behov av omställning i flera industrisektorer. I samhällsvetenskaplig forskning har det utförts mycket arbete i syfte att formulera övergripande teorier som beskriver sådana omställningar inom sektorer såsom energi, tillverkning, livsmedel och transport. Som en följd av detta har 'sustainability transitions' växt fram som ett forskningsområde med fokus på studier av omfattande sociotekniska förändringar.

Förståelsen av industriella omställningar och hur olika slags aktörer kan involveras i förändringar mot ett mer hållbart samhälle är centralt för detta arbete. Särskilt viktigt är hur etablerade företag ('industry incumbents') kan involveras. Dessa aktörer har centrala positioner och betydande kunskap, resurser och teknisk kompetens, som är inbyggd i existerande industristrukturer. Därför är det viktigt att uppmärksamma hur etablerade företag kan spela en aktiv roll i omställningar i riktning mot hållbar utveckling.

Oaktat deras potential att involveras i sociotekniska förändringar, försummas etablerade företag ofta i teorier inom forskningsområdet 'sustainability transitions'. De betraktas som en homogen grupp av aktörer som ofta förutsätts ta rollen som försvarare av det befintliga. Även om en sådan roll är fullt möjlig, riskerar teorier som utgår från den att leda till att alternativa roller inte uppmärksammas. Därmed blir förståelsen för viktiga processer i industriella omställningar begränsad. Syftet med den här avhandlingen är därför att bidra till en mer omfattande conceptualisering av de roller som etablerade industriföretag kan ta i omställningar mot hållbar utveckling. Avhandlingens huvudsakliga forskningsfråga formuleras som: Hur kan etablerade företag agera för att möjliggöra industriella omställningar i riktning mot en ekologiskt hållbar utveckling?

För att svara på denna forskningsfråga erbjuder avhandlingen ett alternativt perspektiv på industriföretag i industriella omställningar, som ifrågasätter dominerande idéer inom forskningsområdet 'sustainability transitions'. Den empiriska grunden för avhandlingen är studier inom transportsektorn, med fokus på tung fordonsindustri i Europa. Forskningen visar att industriföretag inom denna sektor kan anta olika teknikstrategier, från inkrementell innovation med hög grad av industriell samordning för att reducera emissioner på basis av etablerad grundteknik, till anammande av radikalt nya framdrivningstekniker och introduktion av dessa på marknaden. Faktum är att en stark position som etablerad aktör ibland kan göra det möjligt för industriföretag att introducera mer radikala lösningar. Forskningen pekar även på att etablerade industriföretag kan möjliggöra lärande genom att förmedla kunskap över organisatoriska gränser över tid och rum, och därmed påskynda spridningen av radikala innovationer. Etablerade företag kan också påskynda en sådan spridning genom att delta i standardiseringsprocesser på industrinivå.

Dessutom pekar forskningen på hur etablerade företag från olika sektorer kan samverka för att utveckla nya lösningar som spänner över existerande sektoriella gränser. På så vis kan nya industrisektorer växa fram genom integration av olika tekniker och olika slags kunskap, och etablerade företag blir centrala i dessa integrationsprocesser på grund av den kunskap och kännedom de har om de etablerade sektorerna.

Avhandlingens teoretiska bidrag är att den bjuder in forskare inom området ‘sustainability transitions’ till att problematisera kring etablerade industriföretags roll i omställningar i riktning mot hållbar utveckling. Det praktiska bidraget är att den pekar på hur den politiska styrningen behöver ta hänsyn till den diversitet som finns i industriföretagens teknikstrategier i förhållande till en ekologiskt hållbar utveckling.

APPENDED PAPERS

ARTICLES IN PEER-REVIEWED JOURNALS:

PAPER I

Borghei, B., Magnusson, T. (2016), Institutionalization of environmental innovation: Joint development of standards, technologies and actor networks in the European heavy duty vehicles sector, *International Journal of Automotive Technology and Management* 16, 341–364. <https://doi.org/10.1504/IJATM.2016.081614>

PAPER II

Borghei, B., Magnusson, T. (2016), Niche experiments with alternative powertrain technologies: The case of electric city-buses in Europe. *International Journal of Automotive Technology and Management* 16, 274–300. <https://doi.org/10.1504/IJATM.2016.080787>

PAPER III

Borghei, B., Magnusson, T. (2018), Niche aggregation through cumulative learning: A Multiple case study of electric bus projects, *Environmental Innovation and Sustainability Transitions* 28, 108–121. <https://doi.org/10.1016/j.eist.2018.01.004>

PAPER IV

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RELATED WORKS

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- Borghei, B. (2013),** Dancing Giants: Evolution of the European Heavy-Duty Vehicles sector in light of institutionalization of EU emissions standards, EGOS Colloquium, Sub-theme 21: Sustainable Enterprise Evolution: Combining Individual-, Firm- and System-Level Perspectives, July 4–6 2013, Montreal-Canada
- Borghei, B. (2014)** Institutional Change or Institutional Emergence? Comprehending transnational institutional dynamics of the Euro emissions standard for heavy duty vehicles, ETH PhD Academy on Sustainability & Technology, June 8–13 2014, Switzerland
- Borghei, B. (2016),** Cities as transition hubs for accelerating environmental innovation: Multiple case study of electric city buses in Europe, International Sustainability Transitions (IST) Conference 7–9 September 2016, Wuppertal-Germany
- Borghei, B. (2017),** Multi-regime interactions and the emergence of a new industrial sector: A multiple case-study of electric city-buses in Europe, International Sustainability Transitions (IST) Conference 18–21 June 2017, Gothenburg-Sweden

EMPIRICAL REPORTS:

- Borghei, B., Magnusson, T. (2012),** Empirical report on technological advancements in HDVs sector, *Field study report from IAA international commercial vehicles exhibition visit in Hanover*, September 2012-Germany, Available at Diva portal: urn:nbn:se:liu:diva-86777
- Borghei, B. (2015),** UITP World Congress & Exhibition 2015: Compilation of field notes and empirical insights, Available at Diva portal: urn:nbn:se:liu:diva-143201
- Borghei, B. (2016),** Empirical Report: Pioneers in electric city bus transport: STOCKHOLM, GOTHENBURG, UMEÅ, HELSINKI, COPENHAGEN, HAMBURG. Available at Diva portal: urn:nbn:se:liu:diva-143201

بار درخت علم ندانم مگر عمل
Action
is the proper fruit of knowledge

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DEFINITIONS

VEHICLE CATEGORIES

According to the EU vehicles class definition, heavy commercial vehicles consist of motor vehicles with at least four wheels designed and constructed for the carriage of goods or large number of passengers.

EU-CLASSIFICATION OF POWER-DRIVEN HEAVY VEHICLES AND TRAILERS			
EU Category	M3	N3	O4
Definition	Vehicles used for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass exceeding 5 tonnes.	Vehicles used for the carriage of goods and having a maximum mass exceeding 12 tonnes.	Trailers with a maximum mass exceeding 10 tonnes.
Example
<i>Source: Consolidated Resolution on the Construction of Vehicles: ECE/TRANS/WP.29/78/Rev.2 (UNECE) and Vehicle Categories in the Automotive Sector, Growth-European Commission</i> https://ec.europa.eu/growth/sectors/automotive/vehicle-categories_en			

EXHAUST-GAS EMISSIONS

CO (Carbon monoxide): A colorless, odorless and tasteless, but highly toxic gas that is slightly less dense than the air.

HC (Hydro Carbon): A class of burned or partially burned fuel, hydrocarbons are toxins. Hydrocarbons are a major contributor to smog, which can be a major problem in urban areas.

CO₂ (Carbon dioxide): A naturally occurring chemical compound from combustion and one of the main contributors to greenhouse gases.

NO_x (Oxides of Nitrogen gases): Produced from the reaction of nitrogen and oxygen gases in the air during combustions at high temperatures.

PMs (Particulate Matter): Particles emitted from diesel engines commonly referred to as Diesel Particulate Matter (DPM) or soot.

GHG (Greenhouse gases): those that can absorb and emit radiation within the thermal infrared range, but not radiation in or near the visible spectrum such as Carbon dioxide, Methane, Nitrous oxide, Ozone and Chlorofluorocarbon (CFCs).

NOTE: More types of emissions can be found, but in comparison, the abovementioned list is the most common emissions from diesel engines that pose hazard for humans and the environment in accumulated levels and have attracted critical debates in this context.

KEYWORDS

Sectoral transformations; Sociotechnical transitions; Sectoral systems of innovations; Strategic niche management; Multilevel perspective; Transition pathways; Knowledge integration; Knowledge accumulation; Complex product-systems; Environmental innovation; Institutional change; Environmental policy; Innovation and management of technology

THEORETICAL ABBREVIATIONS

IS/SI: Innovation Systems / Systems of Innovation

SSI: Sectoral Systems of Innovation

NIS: National Innovation System

TIS: Technological Innovation System

RIS: Regional Innovation System

MLP: Multilevel Perspective

SNM: Strategic Niche Management

CoPS: Complex Product-Systems

TECHNICAL ABBREVIATIONS

HDVs: Heavy-Duty Vehicles

HEVs: Hybrid-Electric Vehicles

EVs: Electric Vehicles

ICE: Internal Combustion Engine

OEMs: Original-Equipment Manufacturers (*i.e.* automotive producers)

DFP: Diesel Particulate Filter

XPI: Extreme Pressure Injection

SCR: Selective Catalytic Reaction

EGR: Exhaust-Gas Recirculation

ULSD: Ultra-Low-Sulfur Diesel

GHG: Greenhous Gases

CHAPTER 1.

INTRODUCTION

This chapter provides background to the research topic and highlights the importance of the subject of study, which form the basis for formulating research purpose and presenting the main *research question*. Then it will be followed by explaining the criteria for the choices of theoretical framework. Finally, the thesis outline will be presented in a schematic form. The contents of the chapter include the following sections:

- 1.1. Why conducting this study?
- 1.2. Purpose and the research question
- 1.3. Justification on the choices of theoretical framework
- 1.4. Thesis outline

1.1 Why conducting this study?

Background

Today's societies are in need of profound transformations due to intensified depletion of natural resources for extracting and burning fossil fuels, the excessive amount of air pollutions and greenhouse gases (GHG) followed by global warming, rising of sea levels, and the potential consequences of climate change that are increasingly threatening life on this planet (IPCC, 2014). Most societies have already arrived at the conclusion that business as usual is not sufficient to keep humanity and the environment within safe margins and there is a serious need for transformative change in many different sectors of the modern economy (Grin et al., 2010; Brauch et al., 2008). Accordingly, the *Paris Climate Accord*ⁱ was sealed recently by 195 countries, but the remaining challenge is how to properly navigate through the complexities of 'wicked' problems in transforming large sociotechnical systems (Olsson, 2015)

This thesis presents a sociotechnical study that addresses this challenge by analyzing sectoral transformations towards environmental sustainability. A sector is defined as "a set of activities unified by related product groups for a given or emerging demand that share common knowledge and technological basis" (Malerba, 2004, p. 10). It consists of a group of actors, including producers and users, who are involved in developing, generating, and utilizing knowledge, technologies, and artefacts related to the specific characteristics of the sector (ibid). Special attention is paid to the role of established actors (incumbents) in the processes of transformative change. To unfold complexities of sectoral transformations it is vital to have a proper understanding about the key characteristics and specific features of each sector.

Heavy commercial vehicles sector in Europe

Today, transport systems are one of the major corner stones of advanced economies. Especially in Europe, heavy commercial vehicles play a significant role in trade and logistics. According to the International Road Transport Union, trucks are responsible for the delivery of 75% of the total volume or 90% of the total value of all goods transported over the land in Europe (IRU, 2009). This corresponds to an average 100 Kg daily distribution of goods per EU citizen (ibid). Likewise, more than 32 billion passenger journeys corresponding to 55% of all public transport per year are made by urban and sub-urban buses in Europe (ACEA Bus factsheet, 2017). This makes heavy commercial vehicles a critical sector in terms of economic and international trades in Europe.

ⁱ *Accord de Paris* is an agreement within the United Nations Framework Convention on Climate Change (UNFCCC) to mitigate greenhouse gas emissions and the related environmental consequences (i.e. global warming) through the adaptation of different financial incentives and environmental measures starting from 2020 onwards. As of November 2017, 195 UNFCCC members have signed the agreement, and 170 nation-states have become party to it.

Nevertheless, CO₂ emissions from heavy commercial vehicles have increased by 36% during the past two decades (1990-2010) and is currently responsible for a quarter of total GHG emissions from road transport in the EU (EU-Climate Action, 2017). This is due to the increased trade and the elevated demands for road transportation within Europe. Henceforth, European Union has set the target to reduce GHG emissions from transport by at least 60% (from 1990 levels) by 2050. It is a great challenge for the European heavy commercial vehicles sector to accomplish this goal, which requires extensive efforts and adequate actions to be taken accordingly.

Meanwhile, there have been two major sets of challenges and subsequent developments taking place over the past few decades in this sector: Firstly, there is the challenge of improving fuel efficiency (to reduce CO₂ emission), while at the same time reducing exhaust gas pollutions which are often found as paradoxical goals in diesel enginesⁱ. Secondly, there is widespread dominance of diesel technology due to its higher efficiency, power and reliability in this sector, but at the same time there is a necessity to reduce dependency on fossil fuels in response to the increasing greenhouse gas (GHG) emissions from road transportation as well as overall concerns about energy security in Europeⁱⁱ (EU Commission Roadmap, 2011).

The first set of challenges regarding exhaust emissions has been mainly responded to by adopting harmonized environmental measures among EU nations and in particular provisioning Euro emission standards to improve the environmental performance of motor vehicles. The latest Euro standard for heavy-vehicles which came into force in 2014, demands a 95% reduction in noxious gases and a 97% reduction in particulate matter, compared to the first Euro standard implemented in 1992 (ACEA, 2015).

The second set of challenges is being responded to by enhancing the energy efficiency of commercial vehicle fleets and transport systems, substituting fossil fuels with renewable sources of energy, as well as replacing conventional diesel technology with alternative propulsion systems (EU Commission Mobility & Transport, 2017). These nascent technologies however, have a difficult time getting into the mainstream market and competing with the established technologies in this sector. As a matter of fact, there are more than 7 million heavy trucks and buses in Europe with a great majority of them still running on diesel, while the number of vehicles using alternative sources of energy account for less than 2% of the total vehicle fleet in the EU (ACEA, 2017).

ⁱ Diesel engines are designed to operate at very high temperatures where the air is compressed to produce heat so that when it is mixed with the fuel in the combustion chamber, the hot mixture burns immediately. This particular design helps to improve fuel efficiency in diesel engines, but also creates a condition where the combustion of hot compressed air produces nitrogen oxides (NO_x). This is due to the fact that some of the nitrogen molecules available in the air are mixed with oxygen at very high temperatures (typically above 1300°C) and produce different types of oxidized compounds. The quantity and volume of these nitrogen oxides depend on the duration, heat and mixture of the air and fuel in the combustion chamber. This is usually referred to as the diesel paradox where improving fuel efficiency (and the consequent CO₂ reduction) leads to an increase in other types of emissions (such as nitrogen oxides). Some of these nitric compounds (such as NO₂) are considered as major pollutants and components of smog which are very harmful both for humans and the environment. More information can be found on public domains such as: dieselnet.com and clean-carbonenergy.com

ⁱⁱ Europe imports more than 85% of its crude oil from abroad (Source: Eurostat <http://ec.europa.eu/eurostat>)

Transition theories and the forgotten role of incumbents

In parallel with technological struggles discussed above, considerable efforts have been also made within social sciences to improve our understanding of societal transformations in response to global environmental change (Feola, 2015). One of the areas where significant contributions have been made to theorize transformation of various sectors, such as energy, manufacturing, agriculture, food, and transport during recent years is in the field of *sustainability transitions* (Markard et al., 2012; Grin et al., 2010; Schot and Geels, 2008; Smith et al., 2005; Elzen et al., 2004; Geels, 2005a, 2002; Rotmans et al., 2001).

Sustainability transitionsⁱ are generally defined as “sustainable transformation of societies as a response to a number of persistent problems confronting contemporary modern societies” (Grin et al., 2010, p. 1). Many studies in this field have paid considerable attention to sustainability transitions in mobility and transport systems (Schot et al., 1994; Weber et al., 1999; Hoogma et al., 2002; Elzen et al., 2004; Nykvist & Whitmarsh, 2008; Köhler et al., 2009; Geels et al., 2012; Sandén & Wallgren, 2014; Bakker & Konings, 2017).

Transitions concern “far-reaching changes along different dimensions: technological, material, organizational, institutional, political, economic, and socio-cultural. Transitions involve a broad range of actors and typically unfold over considerable time-spans” (Markard et al., 2012, p. 956). By definition, transitions are considered as “multi-actor processes, which entail interactions between social groups such as businesses or firms, different types of user groups, scientific communities, policy makers, social movements, and special interest groups” (Grin et al., 2010, p. 11).

However, studies in this field have largely neglected established actors (*i.e.*, incumbents) and their potential role(s) in facilitating societal transformations. Incumbents are black-boxed as a homogenous set of actors with a pre-defined role in relation to the established industry structures (Geels, 2002; Holtz et al., 2008).

ⁱ A recently published article (viewpoint) by (Hölscher et al., 2018) provided further clarifications on different connotations of ‘transition’ and ‘transformation’, which may result in more convergence between the use of the two concepts interchangeably. In particular, they defined the two concepts in relation to different research communities who adopted various terminologies, but basically refer to the same fundamental meaning. Below is an excerpt quoted directly from the article:

“‘Transition’ is especially used by the sustainability transitions research community to denote fundamental social, technological, institutional and economic change from one societal regime or dynamic equilibrium to another (Rotmans et al., 2001). Research approaches concerned with global environmental change, such as resilience (Olsson et al., 2014) and transformative adaptation (O’Brien, 2012), adopted ‘transformation’ to refer to fundamental shifts in human and environmental interactions and feedbacks ” (ibid p.1).

On clarifying the concept of ‘transformation’, they further explained (quoting directly from the original text):

“Industrial transformation approaches originate from innovation studies and focus on large-scale technological, institutional and environmental change in social-ecological industrial systems (e.g. agriculture, fisheries) to shift towards sustainable economies ” (ibid p.2).

Incumbents are often perceived as the guardians of the existing structures who “tend to stick to old technologies, because of vested interests and sunk investments” (Geels, 2005b, p. 686). This can be explained based on the argument that incumbent actors are privileged by an established industry position and commitment to existing technological systems that provide them access to extensive amounts of resources and capital endowments, exclusive entry rights to markets, existing users and sales channels, as well as earnings from enhanced productivity, which ultimately entrap them into business-as-usual (Unruh, 2000; Walker, 2000). Similarly, it can be assumed that there are pre-defined development trajectories i.e., *path-dependencies* that prohibit incumbents to depart from established structural configurations due to increasing returns and interlocking technological, institutional, and social forces (Sydow et al., 2009; Mahoney, 2000; Arthur, 1994; David, 1985).

These are valid arguments and legitimate concerns, but they do not offer an inclusive approach in theorizing ‘multi-actor processes’ for sustainability transitions. Rigid notions and pre-defined roles on the part of actors can potentially lead to one-sided partisan theorizations that consider incumbents doomed by disruptive innovations and failure when new technologies arrive (Christensen, 1997; Christensen and Rosenbloom, 1995; Foster, 1988). While in reality, actors have different capacities for innovation, and they may have varying degrees of adaptability and different strategies for change; hence, depending on the circumstances, they may act differently. Studies in innovation and technology management have shown that some established firms have the capacity to develop several technological alternatives simultaneously, and they may actively pursue ‘path-breaking’ potentials in their technology strategies (Berggren et al., 2015; Bergek et al., 2013b, 2011; Bergek and Onufrey, 2014; Onufrey and Bergek, 2015; Hobday, 1998). Other studies have shown that incumbents can play an essential role in technological renewal and industry transformations (Onufrey, 2017; Steen and Weaver, 2017; Kishna et al., 2016; Wesseling, 2015; Karltorp and Sandén, 2012; Erlinghagen and Markard, 2012).

Incumbent firms have organizational capabilities including research and development, problem-solving skills, and technological know-how, as well as a vast pool of highly trained and skilled human capital embodied in routines and processes that are considered as the micro foundations for organizational learning, innovation, and economic change (Levitt and March, 1988; Feldman, 2000; Winter, 2003; Feldman and Pentland, 2003). Those resources could be used for protecting the status quo, as the classic literature suggests, or to engage in industry transformations as the abovementioned empirical findings have indicated. Therefore, it would be wise not to paint all actors with the same brush, especially when it comes to theorizing about sustainability transitions that are supposed to be governed as “multi-actor, multi-domain and multilevel processes” (Rotmans and Loorbach, 2010, p. 150). This brings us to an important discussion on the role of incumbent actors in sectoral transformations towards sustainability and how we may perceive them to act in the process of change. This is further elaborated on in the purpose and research question of this thesis in the next section.

1.2 Purpose and the research question

As mentioned earlier, the classic notion in the existing transition literature often casts certain pre-defined roles on the part of incumbents, as if they are a single entity. In other occasions, they are portrayed as conservative actors with strong inertia and resistance towards change. In brief, incumbents are depicted as defenders of the status quo who strive to maintain established industry orders.

Nevertheless, this notion has been supported by true revelations of the wrong doings that is sometimes committed by incumbent firmsⁱ. However, wrong-doings can be committed by any actor at any time regardless of its size or position in established industries, and that is why effective control and law enforcement mechanisms must be in place in order to sanction negative or illegal behaviors of actors. Such irregularities or incompliance shall not be perceived as the normal mode of behavior or as a reason for total categorizations when it comes to theorizing actors' engagement in sustainability transitions. Such propositions do not hold an inclusive perspective on the supposedly 'multi-actor processes' which entail interactions between different social groups and the engagement prospects of actors and the aspirations for sustainability transitions (Grin et al., 2010, p. 11; Rotmans and Loorbach, 2010, p. 150). Given the vast amount of knowledge and capabilities that incumbent actors have at their disposal in established sectors, it would be wise to think about more comprehensive theorizations of the role of incumbents in transition theories. This constitutes the purpose of this study as the following:

Purpose of the thesis

The purpose of this thesis is to contribute to a more comprehensive theorization on the role of incumbents in sectoral transformations towards sustainability

ⁱ On 19 July 2016, an investigation report from the European Commission revealed that several European truck manufacturers have been participating in a cartel that broke the EU antitrust rules. The allegations concerned the incumbents colluding on their price strategies, the timing of market introduction for their vehicles and passing on the costs for complying emissions standards to their customers. These vehicle manufacturers faced severe fines summing up to the total amount of €2.93 billion in damages. However, it is important to note that, the investigation did not find any infringement on compliance with the emission standard itself but on price coordination for those vehicles and the timing of introduction to the market. More importantly, it was not pertinent to all actors but certain incumbents were indeed found clear from those allegations. In particular, Scania was not found guilty in the EU Commission settlement decision for participation in the cartel in this case. The EU Commission's investigation stated that the collusion was not aimed at avoiding or manipulating compliance with the emission standards, but rather on transferring the costs to customers by coordinating prices at a 'gross level': *'The Commission's investigation did not reveal any links between this cartel and allegations or practices on circumventing the anti-pollution system of certain vehicles-commonly referred to as "defeat devices" (European Commission, 2016).*

One may take this quest for comprehensive theorization on the role of incumbents even further and ask a more concrete question about how could, in practice, the incumbents get actively involved in sectoral transformations towards sustainability, a rather different approach to the pre-defined passive role as the classic literature has considered so far. This constitutes the main research question for this thesis as the following:

Research Question

*How can incumbents act to facilitate sectoral transformations
towards environmental sustainability?*

In the attempt to contribute to answer this question, the thesis first reviews the existing literature and theoretical concepts related to this topic. It is important to consider what the current theories suggest with regards to the role of incumbents in sectoral transformations and the potential areas for theoretical contribution in this field. Upon a thorough theoretical review, it may even be possible to propose more detailed (sub) research questions concerning different aspects of involving incumbent actors in sectoral transformations. Therefore, a collection of related theories will be reviewed in the next chapter.

Before moving to the next chapter, the following Section 1.3 clarifies the choices of the theoretical framework and explains how and why they have been found relevant with regards to the main research question in this thesis. After that, a thorough presentation of these concepts and elaborated theoretical discussions for scrutinizing the role of incumbents in sectoral transformations will be provided in Chapter 2, which may in turn provide the background for proposing more detailed questions geared towards empirical analysis.

1.3 Justification on the choices of theoretical framework

Several streams of literature have been selected and composed together to form the basis of the theoretical framework for this thesis. They can be broadly divided into three categories: 1) sectoral systems of innovation, 2) strategic niche management, and 3) multilevel perspective on sustainability transitions. The criteria on the choices of the theoretical framework have been mainly driven by their relevance and usefulness for understanding the research phenomenon as well as their ability to facilitate the answer to the main research question in this thesis. Those criteria are elaborated on in the following sections:

Sectoral Systems of Innovation — SSI

One of the main reasons for choosing a sectoral perspective in this thesis is that, economy as a whole comprises of various sectors that at any time may develop differently (Nelson, 1994). Moreover, since studying transformations of the whole economy is beyond the capacity of any single scholarship, a sectoral perspective enables the researcher to narrow down the focus on a particular field of study, *i.e. sector*, while still maintaining meaningful systemic linkages. The systemic aspect is an important characteristic of the innovation system approach (Carlsson et al., 2002).

The systems of innovation approach takes into account the structure of production systems as well as institutional setup, which jointly define the cornerstones of the innovative and interactive learning economies of modern times (Lundvall, 2017, 1992). From this perspective, technologies, institutions and actors are considered as the main components of innovation systems (Bergek et al., 2008; Malerba, 2004; Nelson, 1993; Lundvall, 1992; Nelson and Winter, 1982). These components interact through complex relationships that together form specific attributes that characterize the innovation system (Carlsson et al., 2002). The systemic attribute implies that firms, including incumbent actors, do not act in isolation, but rather within the wider institutional and socio-economic structures where they interact with other entities through complex set of relationships (Edquist, 2006). Sectoral systems of innovation can be applied to different levels of aggregation based on the specific research goal and hence provide flexible choices when it comes to the level of analysis (Malerba, 2002, p. 251). SSI also has a built-in geographic dimension that is rooted in several comprehensive studies of established European industrial sectors, such as pharmaceuticals, chemistry, biotechnology, machine tools, IT, and telecom services (Malerba, 2004). It provides an encompassing theoretical framework through which co-evolutionary interactions and long-term sectoral transformations can be studied and analyzed (Malerba, 2006, 2002). It is often applied to established industries, where the components of sectoral system are already formed and can be identified.

But how about new or emerging sectors? Malerba himself raised this question once by asking: “How do new sectoral systems emerge, and what is the link with the previous sectoral system?” (Malerba, 2002, p. 258). He also noted that “sectors change over time; therefore, considerable attention should be placed on their laws of motion, dynamics, emergence and transformation.” (Malerba, 2004, p. 13). From this perspective, the emergence of new sectors can be traced to the advancements in science and technologies in other fields that may spur into established sectors, transforming them from within and eventually giving birth to new sectoral systems of innovation.

This is thanks to the nature of radical technological innovations, which have the potential (if sufficiently developed) to break apart from the pre-defined trajectories of established technologies and industry structures (Garud et al., 2010; Garud and Karnoe, 2001; Van De Ven and Garud, 1987). Nevertheless, some scholars have argued that those radical innovations are quite premature in the beginning and hence need protection spaces, i.e., *niches* that keep them safe from the strong market selection mechanisms, which may destroy their development potential in the early phases (Kemp et al., 2001, 1998). This is where the *strategic niche management* approach comes into the discussion, and one can see why it is an important theoretical concept to be studied in this thesis.

Strategic niche management — SNM

New technologies often have a hard time competing with established technologies in the market. They perform crudely in the beginning and need several rounds of improvement, adaptation, and refinement in the early phases of development to match user needs and improve performance and functionalities until they are eventually able to replace established technologies (Rosenberg, 1976). This is a common problem for many new technologies to bridge the ‘valley of death’ between R&D and the market (Schot and Geels, 2008). Therefore, the concept of a ‘niche’ was adopted in the mid-1990s in collaborative research programs between the University of Twente and Maastricht Economic Research Institute (MERIT) in the Netherlands with the purpose “to help various actors in society to build more constructive relationships with new technologies” (Hoogma et al., 2002, p. ix). Much of the earlier focus of those scholars was on understanding social impact of technologies, devising constructive technology assessment, and developing policy instruments for the early adoption of new technologies with high potentials to contribute to environmental sustainability (Schot, 1992; Schot et al., 1994; Rip et al., 1995; Schot and Rip, 1997; Kemp et al., 1998; Rip and Kemp, 1998; Weber et al., 1999; Hoogma, 2000; Kemp et al., 2001; Hoogma et al., 2002). The aim was to promote a protective space for promising new technologies to grow from experimental phases into fully functioning products, services, or solutions that could be readily launched on the market or to create new markets that could accommodate new technologies or new approaches in using those technologies (Schot and Geels, 2008). In terms of the required technology policies, one of the main assumptions was that creation and development of promising (i.e. sustainable) technologies must be supported through learning processes and experimentations outside the R&D laboratories (Hoogma et al., 2002)

Accordingly, the approach of ‘strategic niche management’ was proposed as a process of “creation, development, and controlled phase-out of protected spaces” with the aim of learning about desirability and user acceptance as well as further enhancements and increasing the rate of application of newly developed technologies (Kemp et al., 1998, p. 186). The SNM approach organizes concentrated efforts for the governance of protected spaces and for articulating different applications of new technologies in which learning is a vital process (Rip, 1992). The key features of SNM hence revolves around devising policies to create opportunities for learning and alignment of goals and interests of different actors involved in the development of new technologies and to facilitate the transition to environmental sustainability (Kemp et al., 2001, p. 294).

However, devising such policies also requires broader perspectives on macro-level changes that take place over long periods of time in societies as well as insights about ongoing patterns in the established market and industry structures and hence their implications on the development of niche technologies. The reason is that: “newly created niches can become utterly useless as a result of unexpected new developments elsewhere. Expectations can be falsified by new developments in the selective environment” (Schot, 1998, p. 198). These are important issues to consider and the question that may arise is how could those macro-level patterns in society as well as mid-range developments and expectations in the selective environment be mapped into micro-level contingencies and policy adjustments for niche developments? This question links the discussion to the next important theoretical concept, i.e. multilevel perspective on sustainability transitions.

Multilevel perspective on sociotechnical transitions — MLP

To properly address contingencies and required policy adjustments in strategic niche management, it is important to make relevant connections between internal niche processes and dynamics of the external environment. The multilevel perspective (MLP) is a theoretical concept that can help to identify such dynamics according to different levels of structuration. The origins of such conceptualization can be traced back to the extensive work of French historian Fernand Braudel (1902-1985), who used this multi-level approach in explaining complexities of social, cultural, economic, and political co-developments in his studies¹.

The multilevel analysis distinguishes three main trajectories of time that co-evolve alongside each other (*see Figure 1*). The bottom line (*fait divers*) records day-to-day events, some of which may become important incidences labeled as *grand events*. The second timeline (*conjonctures*) registers mid-range developments that are accumulated on a higher level than daily events and may construct cyclical processes that are related to mid-term perspectives. The third level (*longue durée*) is the aggregated macro level that represents the structural elements of history associated with substantially long-term and large societal patterns.

According to (Grin et al., 2010), such a multilevel perspective on history not only offers general heuristics for studying long-term processes of multiple-causality and co-evolutionary patterns, it also provides understanding of the context and critical processes in societies.

¹ Fernand Braudel (Alma matter: Sorbonne-France) is mostly known by his first book on Mediterranean history and culture, though he had been writing history book reviews for around 20 years before his first book was published in 1949. His main contribution apart from the rich historical, economic, and social insights into the many aspects of the Mediterranean culture throughout 16th century (particularly during the age of Phillip-II of Spain) was based on multiple layers of analysis (nested hierarchical time frames). He later became an influential figure in a particular style of historiography that specifically dealt with long-term social history analysis, known as the *Annales School*, named after the scholarly journal: *Annales d'histoire économique et sociale*. For more information see (Phillips, 2009; Emeagwali, 2002), and Braudel's original book: *“La Méditerranée et le Monde Méditerranéen à l'Epoque de Philippe II”* (1949), also available in English translation as: *“The Mediterranean and the Mediterranean world in the age of Philip II”* Vol. 1 & 2, London-Collins, 1972.

Figure 1. Multilevel analysis of historical developments
Source: Bertels 1973 in (Grin et al., 2010, p.15)

Similar to Braudel's notion of historical time levels, the MLP framework is also constructed in three structural levels, i.e. *niche*, *regime*, and *landscape* each of which has its own distinct dynamics based on different chronologies, but represent co-evolving multiple time-scales when placed alongside one another. Transition theorists developed the multilevel perspective in order to provide elucidated explanations for sociotechnical transitions (Rip & Kemp, 1998; Kemp et al., 1998; Geels, 2002, 2004b, 2005). While the roots of MLP can be traced back to several theories and concepts in other fieldsⁱ, those scholars later emphasized that any theory of transition should incorporate Braudel's idea of *multiple time-scales* (Grin et al., 2010, p. 15). Thus, transitions are defined in relation to co-evolving multiple time-scales and as the result of interactions that take place within and between the different levels. The three levels in multilevel perspective differ in terms of size and degree of stabilization.

As shown in Figure 2ⁱⁱ, the lowest level of MLP contains *niches* where novelties emerge as the result of interactions between innovators and entrepreneurs or social networks and their experiments with new technologies. Due to the lack of structuration at this level, activities may have a relatively short lifetime, and actors may need to put in great deal of efforts into upholding niches and providing stability to their actions. Nevertheless, this lack of structuration also means that there is less pressure from the selection environment that in turn allows for novelties to emerge more freely and for different actors to get involved in articulating their ideas around new technologies or practices. Moving up to the higher level, *regimes* represent established structures with relatively stable markets, well-founded networks, verified technologies, proven practices, and articulated rules.

ⁱ (Geels, 2005a Ch.2)) lists a wide range of academic literature as the building blocks and classifies them in three main categories:

- 1) System Approaches including Large Technological System, Complex Product Systems and Innovation Systems.
- 2) Technological change including Domestication theories, social mechanisms, SCOT, ANT, technological lifecycles, path dependency, evolutionary economics, etc.
- 3) Co-evolution including STS, Triple Helix, Techno-Economic Networks, Long-term theories and Techno-Economic Paradigms as well as the General History discipline

ⁱⁱ Copyright acknowledgement: Permission for reuse in thesis/dissertation for the graphic objects in Figure 1 and Figure 2 was obtained through Copyright Clearance Center's RightsLink on 17, May, 2018

Figure 2. Multiple levels as nested hierarchies

Source: Geels (2002, p.1261)

The concept of a regime is very close to the earlier works of evolutionary economists who described technological change as cumulative, selective and finalized into specific norms that are heavily influenced by technological paradigms or the so called ‘grammar’ or the rule-sets that shape the direction of research and development activities (Nelson and Winter, 1982; Dosi, 1982, 1988). It is also closely connected to the idea of established industrial sectors that Malerba (2002; 2004) discussed in terms of sectoral systems of innovation. Examples of such rules are the search heuristics of engineers, the investment selection criteria devised by policy-makers and employed by firms operating in the market place, as well as organizational routines, technical and regulatory standards, ownership and intellectual property rights, and patent protection laws. It also includes user practices, habits, norms, and values of society that incentivizes certain uses of technologies and activities around them. These rules are firmly embedded in engineering practices, process technologies, product characteristics, technical skills, institutions, and infrastructures that make up the totality of a technology (such as internal combustion engines in the automotive industry) or a particular form of organization (such as the Fordist regime of mass production). They are an integral part of the structuring forces that drive co-evolutionary processes at this level (Kemp et al., 1998, p. 182).

Finally, at the highest level, the *landscape* consists of broader structural configurations where long-term societal patterns and historical development trajectories are registered. The definition of landscape is largely encompassing and includes ‘mega’ structural configurations that: “in the literal sense it is something around us that we can travel through, and in a metaphorical sense something that we are part of, that sustains us” (Rip and Kemp, 1998, p. 334). Hence, due to their encompassing mega-structural nature, landscapes are generally beyond the immediate influence of regime or niche actors. However, the nested structure of MLP allows for dynamic interactions alongside these trajectories. This is particularly important since transitions take place as the result of interactions across the multiple levels and as a result of pressures and tensions within and between the different levels (Grin et al., 2010, p. 25). This is an important aspect related to sectoral transformations that will be elaborated further on in details in Chapter 2 of this thesis.

1.4 Thesis outline

This is a *compilation thesis*ⁱ or thesis by publication which means that the thesis is built on a collection of research papers already published or in the process of publication. The full manuscripts of the research papers are included in the appendix, while a summary of the findings appear in the thesis.

The rest of this thesis is organized as follows: Chapter 2 presents the theoretical framework, in which existing theories will be further scrutinized in relation to the main research question. In this chapter, important aspects of involving incumbents in sectoral transformations and the potential for further development of existing theories will be examined by posing detailed sub-questions extracted from theory. The literature review also helps to outline the research design and in particular for building theoretical constructs that will be further used in operationalizing the study. Chapter 3 explains this operationalization process and design of inquiry, methods of empirical data collection and analysis, as well as elaborates on the research field, authorship and methodological reflections. It is then followed by Chapter 4 which summarizes results from research papers and describes the process of publication for each paper. Chapter 5 synthesizes results from the papers and in doing so responds to the theoretical sub-questions that have been already posed in Chapter 2. And finally, Chapter 6 concludes the main research findings and in doing so corresponds to the main research question posed in Chapter 1. A schematic representation of the research outline is presented in the following figure:

Figure 3. Thesis outline

ⁱ Thesis by compilation is a well-established format for dissertations in science and technology studies in Nordic countries. In Swedish it is called "*sammanläggnings avhandling*" or aggregation thesis which is commonly referred to as "*kappa*" in the short form meaning 'cover' or 'wrap'. For general information see: https://en.wikipedia.org/wiki/thesis_by_publication

CHAPTER 2.

THEORETICAL FRAMEWORK

This chapter lays out theoretical underpinning of the thesis, which is based on three main streams of literature, namely: sectoral systems of innovation (SSI), strategic niche management (SNM) and multilevel perspective on sociotechnical transitions (MLP). The chapter will end with a theoretical synthesis which summarizes the main theoretical constructs of the thesis and provides the ground to formulate sub-research questions. The contents of the chapter include the following sections:

- 2.1. Sectoral systems of innovation-SSI
- 2.2. Strategic niche management-SNM
- 2.3. Multilevel perspective-MLP
- 2.4. Theoretical synthesis and sub-research questions

2.1 Sectoral systems of innovation (SSI)

The sectoral perspective on systems of innovation is a theoretical lens through which certain aspects of innovation systems can be studied. It offers an integrated geographic perspective by taking into account sectoral boundaries as well as specific features, commonalities, and complementarities related to the spatial concentration of innovative activities (Malerba and Orsenigo, 1997, pp. 109–110).

Theoretical underpinnings of SSI are firmly rooted in earlier theories of evolutionary economics (Nelson, 1995a; Dosi, 1997, 1988; Metcalfe, 1998; Malerba, 2006) and industry lifecycles (Klepper and Graddy, 1990; Utterback and Suárez, 1993; Klepper, 1996, 1997) as well as the notion of Schumpeterian patterns of innovation (Breschi et al., 2000), co-evolutionary processes of change and economic growth (Nelson and Winter, 1982), and diffusion of knowledge and technologies in development blocks (Dahmén, 1988, 1989). Malerba and his colleagues took the earlier works in those fields and constructed the SSI framework based on comprehensive studies of sectoral patterns of innovation among six major industries in Europe (Onida and Malerba, 1989; Malerba and Orsenigo, 1993, 1996, 1997; Breschi et al., 2000; Breschi and Malerba, 2001; Edquist et al., 2004; Malerba and Nelson, 2011).

A sector is a set of activities unified by related product groups for a given or emerging demand, which share common knowledge and technological basis (Malerba, 2004, p. 10). It consists of a group of firms active in developing, generating and utilizing knowledge, technologies, and artifacts. These activities can be accomplished in two ways: through the processes of interaction and co-operation in artifact-technology development, and through the processes of competition and selection in innovative and market activities (Malerba and Orsenigo, 1997, p. 111).

The first set of processes (i.e., interaction and co-operation in artifact-technology development) considers the supply side of innovation, while the later (i.e., processes of competition and selection in innovative and market activities) considers the demand side of innovation. Sectoral systems of innovation consist of three interacting components or building blocks, namely: *knowledge and technologies*, *actors and networks* and *institutions*. Sectoral transformations are the result of co-evolutionary interactions among these building blocks over the timeⁱ (Malerba, 2004). Figure 4 is a conceptual illustration of sectoral elements and the co-evolutionary interactions among them.

ⁱ Sectoral systems of innovation itself has been subject to evolution over time. For instance, earlier versions of SSI included a wide range of sectoral elements such as: 1) knowledge-base and learning processes; 2) basic technologies, inputs and demand with key links and dynamic complementarities among them; 3) type and structure of interactions among firms and non-firm organizations; 4) institutions; 5) processes of generation of variety and of selection. At some point, products have been also proposed to be included into this framework but later was removed (Malerba, 2002, pp. 250–251). Later versions of SSI consolidated all those elements into three main building blocks known as follows: 1) knowledge and technologies 2) actors and networks, and 3) institutions (Malerba, 2004). This is similar to the three interrelated analytical dimensions in transition theories (i.e. systems, actors, rules) suggested by (Geels, 2004b). Those analytical dimensions suggested by Geels was called: 1) Sociotechnical systems 2) human actors, organizations and social groups 3) Rules and institutions (ibid 2004b, p. 903).

Figure 4. Conceptual illustration of the building blocks for sectoral systems of innovation and their co-evolutionary interactions
Source: Author

The spatial (geographic) dimension is one of the key distinctive features of sectoral systems of innovation, which is rather dynamic and not pre-definedⁱ. The reason is that it is sometimes not possible to define the boundaries of innovation systems without considering the strong linkages that exist in geographic space (Breschi and Malerba, 1997). Examples are provided in this regard by Breschi, Malerba, and Orsenigo in their studies of different sectors including machinery tools, automotive, as well as computer and software industries highlighting specific features of each sector in terms of *appropriability* and *opportunity conditions*, *cumulativeness of technological knowledge* as well as the *nature of relevant knowledge-base*.

This was indeed the motivation for the opening of a sectoral perspective to systems of innovation studies because of the need for a framework that would be able to recognize sectoral aspects of sociotechnical regimesⁱⁱ (*i.e.*, geographical concentration of firms and specialization in industrial districts, specific regions or even national borders). While at the same time being able to identify important linkages and interdependencies that often go beyond the local geographical space of the established regimes (Breschi & Malerba, 2001, 1997; Malerba & Orsenigo, 1997).

ⁱ This makes the SSI framework different from national innovation systems (NIS) and technological innovation systems (TIS). While TIS is primarily concerned with functional aspects of innovation systems, the main focus of NIS is instead on identifying specific characteristics of innovation systems at the national level, leaving very limited room to expand beyond the national borders. A similar argument exists in comparison with regional innovation systems (RIS). That is, while RIS and NIS have their system boundaries delineated (fixed) primarily based on corresponding geographical dimensions (*i.e.*, national and regional), the spatial dimension in the SSI is not predefined but is rather based on the geographic distribution of industrial sectors (Malerba and Nelson, 2011). Moreover, SSI 'additionally encompasses products, technologies and processes', which provide analytical advantages when it comes to the study of established industries (Markard & Truffer, 2008: 608).

ⁱⁱ The concept of sociotechnical regime will be discussed further in greater detail in this chapter (see Section 2.3)

Actors and networks in this context can be of human or non-human agents (individuals and organizations), and they may carry out market or non-market interactions for the creation, production, and trade of products. *Knowledge and technologies* are the driving force for innovation and development of new products and services.

Knowledge has a pivotal role in relation to innovation and technological development in evolutionary economics (Dosi, 1997; Lundvall, 1992; Nelson, 1995b). Since actors have different degrees of accessibility to knowledge, they may need to engage in interactions to balance out the disproportion of their knowledge. *Institutions* shape the interactions among actors by setting the rules of the game such as norms, laws, standards and established practices. Institutions also provide stability and a firm ground for sectoral activities to take place (Malerba, 2004). Below, these sectoral elements are elaborated on in detail.

Knowledge and technologies

Sectoral systems are characterized by certain core technologies, i.e., *technological regimes* (Nelson and Winter, 1982) as well as complementarities with other technological fields linked through innovative activities that enable cycles of growth and transformation (Malerba, 2004, p. 19). For instance, the established automotive industry is mainly characterized by the internal combustion engine as the core technological regime (Wells and Nieuwenhuis, 2012; Berggren and Magnusson, 2012), while there are still technological complementarities that provide diversification and variety of choices for firms to develop different technological paths (Wesseling et al., 2015, 2014; Wells, 2010). Knowledge has a cumulative nature, and so technological regimes are also characterized by cumulative learning processes often associated with the presence of a number of large established firms and high degree of barriers for new entrants (Malerba, 2004, p. 12).

However, the dynamic nature of knowledge entails that competition among firms is continually driven by novel combinations of the existing knowledge-base with new technological advancements. Large firms are thus required to master coordination of innovative activities in a wide range of technological fields (Granstrand et al., 1997) as well as adaptive organizational structures (Sanchez, 2012) to maintain effective strategic alignments in their external environment (Magnusson et al., 2003; Magnusson and Berggren, 2011). This brings into consideration one of the most important capabilities that firms need to possess in terms of coordination and the ability to integrate knowledge from different disciplines (Berggren et al., 2013; Brusoni et al., 2001). Knowledge integration becomes one of the core capabilities of innovative firms that enables them to absorb new technologies into their established knowledge base in a process called *creative accumulation* (Tell et al., 2016; Berggren et al., 2013; Bergek et al., 2011; Grant, 1996a). It is an innovative process where incumbent firms persistently seek to exploit new technologies and successfully merge them into their established knowledge base. The sourcing of new knowledge and integrating it with the existing knowledge base, however, present significant challenges since creative accumulation requires fair understanding of both paradigms in periods of discontinuous change.

Actors and networks

Sectoral systems consist of a wide range of actors, which are heterogeneous in nature including public, private, profit and non-profit organizations, as well as diversities in their interactions. Actors may also form networks and associations to serve different purposes. Interactions can be broadly classified into *communication, exchange, cooperation, competition, or command and control* (Malerba, 2004, p. 18). For instance, interactions of firms and legislative bodies is often classified as command and control, while the relationship between firms and their suppliers and customers are of the exchange type. Interactions among actors are dynamic and are subject to change based on different circumstances or emerging issues. Actors may also engage in varying types of interactions simultaneously, which are not necessarily mutually exclusive. For instance, competing firms may sometimes engage in collaborative relationships in order to solve particular issues through alliance and partnership based on shared interests.

From an economic perspective, firms carry out an important task in terms of research and development and innovative activities in sectoral systems (ibid). This may include their own research facilities, laboratory experiments, patenting or acquisition of inventions, and discoveries by other actors through investments in physical and non-physical assets for innovation. Other type of actors, such as universities and research organizations, also have important roles in supporting, shaping, or affecting innovative strategies of firms in sectoral systems of innovation (Edquist and Chaminade, 2006). Studies have shown that “active inclusion of users, policy-makers, researchers and in some cases representatives of a broader public” are crucial for introducing sustainable transport innovations (Weber et al., 1999). Nevertheless, some scholars have criticized sectoral systems of innovation for the lack of a user perspective and being too focused on the supply side of innovation, forgetting the demand side (Geels, 2004b).

At the same time, actors’ behaviors and their interactions can be influenced by institutions that may come in different forms, such as rules and laws, standards or established practices, culture, and cognitions that shape the perception of actors and their understanding of potential changes in sectors (Edquist and Johnson, 1997; Malerba, 2002, p. 257). The role of institutions is further elaborated on in the following section.

Institutions

Despite having a central role among a wide range of innovation, economics, and business studies, institutions are yet so much taken for granted that most studies still treat them as independent constant variables but not as part of the analysis on change and transformation (Scott, 2008, p. 93). Based on Malerba’s definition, institutions include norms, routines, common habits, established practices, rules, laws, and standards, all of which shape agents’ cognition and actions and affect interactions among them (Malerba 2004, p.27). When it comes institutional forces, Scott (2008) has provided perhaps a clearer definition by identifying three main aspects or institutional pillars, namely: *coercive, normative* and *cultural-cognitive* forces. Institutions range from formal (e.g., rules and regulations) to informal (e.g., norms and traditions), and they are negotiated and implemented at different levels of governance (e.g., local, national, and international). However, these features of institutions are not mutually exclusive.

For instance, institutional regulatory forces that govern emissions standards for vehicles in Europe are being set at the European level in the form of EU directives, but when it comes to implementation, they are subject to local adaptations in each member state. Emissions standards force automotive manufacturers to comply with certain environmental performance measures, but at the same time, they often leave the options open on how to reach the required outcomes using different technological solutions (Lee et al., 2011). As one of the most regulated industries, emission standards came in the form of technology-forcing regulations and resulted in significant technological advancements to reduce emissions from motor vehicles during the past few decades (Bauner et al., 2009; Lee et al., 2011, 2010; Mikler, 2009; Boulton et al., 1992; Touchton, 1981). Nevertheless, these advancements still rely on the interactions among a large number of public and private actors at different levels of influence who engage in processes of regulatory provisioning with varying degrees of political impact (Meadowcroft, 2011; Ng, 2006).

Therefore, one of the most important functions of institutions is to provide stability and continuity to sectoral systems of innovation by setting rules and sanctions, regulating relationships between actors and networks, as well as sustaining political and market structures that reduce uncertainty (Malerba, 2004). However, from this perspective, it is possible to think about institutions as both hindering and supporting certain aspects of innovation by limiting actors' behaviors and their expectations of the future or otherwise incentivize favorable search directions and market selection mechanisms, which lead to the development of knowledge and technologies in new directions (Schot, 1992; Nelson, 1994, 1995a).

As once pointed out by the late Nobel laureate institutional economist, Douglas North: "The major role of institutions is to reduce uncertainty by establishing a stable (but not necessarily efficient) structure to the human society" (North, 1990, p. 6). This also means that the stability function that institutions provide does not necessarily favor all kinds of innovative activities, and this is certainly true when it comes to emerging sectors or niche technological innovations. This in turn highlights the importance of policies and practices that could shield niches from institutional pressures and market selection mechanisms at the early stages of development. The next section elaborates further on this topic.

2.2 Strategic niche management (SNM)

The evolution of SNM as a theoretical concept

As mentioned earlier, new technologies cannot immediately compete against mature technologies due to the fact that institutional pressures and market selection mechanisms are often designed in favor of established technologies (Geels et al., 2013). Therefore, strategic niche management was proposed to facilitate the introduction of new technologies by creating protective spaces that can shield external pressures (Schot et al., 1994; Kemp et al., 1998).

Early SNM practitioners proposed *regime transformation* as a bottom-up process where novelties emerge in *technological niches* and then takeover *market niches*, which would eventually transform and replace sociotechnical regimes (Kemp et al., 1998). They defined strategic niche management as “the creation, development and controlled break-down of test-beds (experiments, demonstration projects) for promising new technologies and concepts with the aim of learning about the desirability (for example in terms of sustainability) and enhancing the rate of diffusion of the new technology” (Weber et al., 1999, p. 9)ⁱ.

But later it was realized that expectations about the outcomes and the potentials of niche technologies to transform sociotechnical regimes had been overestimated: “[...] looking back, we see that some assumptions were not confirmed. For one thing, we were certainly over-optimistic about the potentials of SNM as a tool for transition. There is an incongruity between what we expected and what we observed...” (Hoogma et al., 2002, p. 195).

Elsewhere it was stated: “[...] the results showed that many demonstration projects were organized in an overly contained way... Failed niche developments could often be related to either minimal involvement of outsiders in the experiments and a lack of second order learning, or to minimal involvement of regime actors which resulted in lack of resources and institutional embedding... Technology actors such as firms and governments introducing new technologies tend to exclude certain actors and focus on optimizing the technological side first while neglecting other social aspects” (Schot and Geels, 2008, p. 541).

Strategic niche management rests on some key fundamental assumptions: Firstly, introduction of new technologies is a complex social process that is neither fully controllable (contrary to technological determinism) nor is completely random or indiscriminative (contrary to perfect market assumptions). Secondly, it entails co-evolutionary processes with open-ended search and learning mechanisms towards adoption and social embedding of new technologies (Hoogma et al., 2002, p. 4).

ⁱ Reflecting on earlier experiments with 13 different cases of electric road vehicle projects in Europe, Weber, Hoogma, Lane and Schot (1999) developed an extensive workbook on SNM, in which they came up with three different patterns of niche formation and regime shifts. The regime transformation pattern was particularly defined as a situation where: “electric vehicles develop into the dominant form of transport, based on a new combination of public and private transport. Gasoline cars are only used for specific purposes, such as long trips.” (ibid p.22).

Based on those assumptions it would be then self-contradictory to advocate for social embedding of new technologies while isolating them from dynamics of the outside world. This is due to the fact that learning outcomes are often unpredictable, and changing circumstances over the time can make the isolated niches obsolete. As Kemp et al. (2001) pointed out: “when SNM is specified in terms of “do” and “don’t” guidelines, its basic strength is converted - and to some extent betrayed” (ibid, p. 295). This is perhaps another reason why strategic niche management needs to be situated in a reflexive policy making approach to enable constant feedback loops and possibilities for consequent policy adjustments (Rip, 2006).

The dilemma of niche isolation

One particular problem with the earlier SNM conceptualization was that the focus often had been narrowed down to individual niche projects, neglecting the wider context and external dynamics elsewhere (Schot & Geels, 2008). In a practitioner’s view on strategic niche management, Mourik and Raven (2006) concluded that SNM should focus on orchestrating interactions among multiple experiments rather than on single projects. The reason is that learning from niche experiments needs to be articulated and structured towards generic rules and knowledge, which are replicable elsewhere; otherwise knowledge and experiences would remain in the local environment, where they originally come from. To overcome this problem of ‘local stickiness’, Geels and Raven (2006) called for attention to a ‘global niche-level’, characterized by an emerging field or community of actors who can share their experiences and articulate on learning from local practices (see Figure 5)ⁱ.

Global niche-level
(e.g. the emerging
field of PV solar cells)

... is carried by
projects in different
local practices

Figure 5. Locally embedded projects and global-niche level
Source: Geels & Raven (2006: p.378)

ⁱ Copyright acknowledgement: Permission for reuse in thesis/dissertation for the graphic objects in Figure 5 and Figure 6 was obtained through *Copyright Clearance Center's RightsLink* on 17, May, 2018

Towards SNM 2.0 modelⁱ

The earlier problems with niche isolation called for more attention to the wider context and the need to go beyond individual experiments and aggregate experiences on a larger scale. An essential aspect of this ‘local-global’ aggregation process is the development of ‘generic lessons’ and ‘cognitive rules’ that can facilitate the emergence of a new ‘technological trajectory’ (Geels and Raven, 2006). This is what they call a ‘global-level community’ or ‘field’ which consists of shared rules, problem agendas and search heuristics, etc. (see Figure 6).

Figure 6. Emergence of a technological trajectory
Source: Geels & Raven (2006: 379)

Later, Smith and Raven (2012) refined this model and provided a more elaborate definition: “Global refers to an emerging institutional field or proto-regime supported by a network of actors that is concerned with knowledge exchange and resource flows transcending local contexts. This field is constituted by actors such as industry platforms, user-groups and other intermediary organizations and operate partly autonomous from local experiments” (ibid: 1029). Accordingly, typical aggregation activities that take place at this global level include “standardization, codification, model building, formulation of best practices, etc.” (Geels & Raven, 2006, p. 378). This is similar to system building activities proposed by innovation systems scholars (Bergek et al., 2008) and the formation of actors-networks, knowledge-technologies, and institutions, i.e., the structuration process in system formation.

ⁱ The term ‘SNM 2.0’ was used by Rob Raven in a PhD course lecture to emphasize that “single experiments alone do not result in alternative regimes” and in reference to the renewed version of SNM that pays more attention to the following:

- Interactions with existing regime(s)
- ‘Networked experiments’ over longer periods of time

Source: lecture material from PhD course ‘Theories of Sustainability Transitions’, Aalborg University-Copenhagen, 21 May 2015

Niche empowerment

Another important feature of SNM 2.0 is the call for more attention to the interactions with the established regimes. The paradoxical nature of protection versus empowering and the necessity for social embedding of niches has been a central issue in SNM. The very definition of SNM from the beginning emphasized three important functions: i.e., *creation*, *development*, and *controlled phase-out* of protected spaces (Kemp et al., 1998, p. 186). However, most attention in the earlier research and practice has been concentrated on the first two functions through shielding and protection strategies, but has often neglected in one way or another the inevitable ‘phase-out’ and interactions that they have to face with the incumbent regimes (Smith, 2007).

But again, the problem is how and when temporary shielings should be removed. This is a very delicate matter in strategic niche management because on the one hand, early exposure to the harsh selection environment may destroy niches in the early development phases, and on the other hand extended protection may result in perpetuated subsidizing of niches, which in turn may run the risk of rent-seeking behavior. As Schot and Geels (2008) noted: “controlled exposure to selection pressures has been central to SNM research from the start. Yet we agree that more attention should be devoted to ways in which protection is provided and can be lifted in a phased way. The managing of selective pressures is not only an issue of specific measures, such as subsidies, but also one of niche expansion and the emergence of a new set of stable rules and routines” (ibid: 543). In an attempt to address the problem of niche expansion and the emergence of stable rules, Smith and Raven (2012) proposed a new dimension to the functional properties of protective spaces. Their ‘niche empowerment’ proposition entailed that niche actors need to link their activities to the wider processes of social change outside protective spaces, and they suggested two different approaches to do so:

- ❖ Empowerment to *fit-and-conform*: is the approach that empowers niches to become more competitive through structuration so that they can keep up with strong demands and *fit* into the selection environment by *conforming* to relatively unchanged selection criteria of the existing regime.
- ❖ Empowerment to *stretch-and-transform*: by contrast this method seeks to empower niches by enabling them to influence the established criteria by *stretching* into the selection environment and *transforming* it and restructuring the existing rule sets.

Each of these empowering strategies has its own benefits and drawbacks. The fit-and-conform strategy makes niches competitive towards mainstream practices, but it is also criticized for bending and complying with the existing rule sets, which might not be necessarily favorable to niches. Therefore, the radical potentials of niche technological innovations are reduced to the existing practices and established criteria of selection environment. To alleviate those drawbacks, Smith and Raven (2012) suggested two complementary actions that can be taken in parallel to the fit-and-conform approach: 1) institutional reforms that transform incumbent regimes in the meantime; and 2) building political capacity to avoid the protective space being captured by mainstream forces.

The stretch-and-transform strategy, on the other hand, is more favorable for empowering radical niche innovations aiming to transform the institutional environment and restructure existing regimes. But the challenge is that reforming institutions or creating new institutions requires enormous power and immense resources, which are often not at the disposal of niche actors. Here, the important role of incumbents who have considerable amounts of resources, power, and legitimacy becomes clearer. As Smith and Raven (2012) stated: “the process and content of stretching and transforming will not be entirely internal to the niche, but will rely upon other processes of change within the regime and in the broader society and economy” (ibid: 1030). In particular, the role of incumbents who have a foothold at the existing regime and may find interest in niche developments is even more critical. The reason is that incumbents can act as translators and link processes of local-global knowledge transfer into the existing regime rule-sets and mediate between different institutional logics through boundary spanning activities that provide resources to niches and at the same time open up regimes to novelty and eventual transformations (Smink et al., 2015; Smith, 2007). Meanwhile, unfolding processes that can facilitate regime transformation is a very important issue. This is the topic of the next section.

2.3 Multilevel perspective on sociotechnical transitions (MLP)

Perhaps one of the greatest benefits of adopting a multilevel perspective on sociotechnical transitions is the ability to contextualize niche technological innovations in relation to developments in the external environment. In order to take an appropriate approach in niche empowerment, niche-internal strategies need to be understood in relation to broader changes and dynamics of regime transformation at larger scales. As Schot and Geels (2008) pointed out: “niches are to be perceived as crucial for bringing about regime shifts, but they cannot do this on their own. Linkages with ongoing external processes are also important. Niche-internal dimensions needed to be complemented with attention to niche external processes. The multi-level perspective proved useful for contextualizing SNM” (ibid 537).

Multilevel perspective and sustainability transitions

The multilevel perspective (MLP) has been widely used in relation to sustainability transitions and technological renewal of regimes with environmental aspects at the center of attention. Sustainability transitions are generally defined as: “radical transformations towards a sustainable society as a response to a number of persistent problems confronting contemporary modern societies. These persistent problems express themselves into crises, such as food, water, mobility and health as well as energy and climate change” (Grin et al., 2010, p. 1). The MLP framework enables us to analyze alignment of trajectories both within and between different time frames (*technological niches, sociotechnical regimes, and sociotechnical landscapes*), where transitions take place as a result of co-evolutionary interactions across the three levels. Figure 7 shows these three levels of structuration and their interactions mapped on the multilevel perspective.

Figure 7. Multilevel perspective on technological transitions
 Author's re-drawing based on Geels & Schot (2007, p.401)

As illustrated with bottom-up arrows in the picture, novelties, and small initiatives created at the niche level may end up, at some point, at higher levels of structuration if they manage to break through dominant structures that guide sociotechnical regimes. These novelties and small initiatives are considered as the seeds for future potential alternatives and they reside within niches, which act as incubation rooms against the mainstream market selection forces of sociotechnical regimes (Grin et al., 2010, p. 22).

Regimes are defined as: “the rule-sets or grammar embedded in a complex set of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artifacts and persons, ways of defining problems—all of which embedded in institutions and infrastructures” (Rip and Kemp, 1998, p. 340). The notion of regime embraces structural dimensions that provide stability and at the same time lock-in situation for existing sociotechnical systems. The regime concept has been used similarly to SSI, since both are defined at similar empirical levels, i.e., at the level of industries or sectors (Markard and Truffer, 2008, p. 608). From this perspective, established sectors, and in this case, heavy commercial vehicles sector in Europe, are classic examples of sociotechnical regimes.

The highest level of structuration in multilevel perspective includes sociotechnical landscapes, which are considered exogenous and beyond the direct influence of niche and regime actors, such as macroeconomic changes, deep social and cultural patterns, as well as macro-political developments (Geels and Schot, 2007a). Changes at the landscape level sometimes push pressure on sociotechnical regimes, which may open windows of opportunity for niches to break in (ibid). However, it is important to consider that fundamental changes to sociotechnical regimes do not come about swiftly, but rather in a timely manner. It requires not only changes in technological dimensions but also changes at the level of governing structures (Kemp, 1994). And it is here that the critical question is raised as to how system-wide changes including sectoral transformations actually take place. The answer lies in the MLP’s nested hierarchical arrangements and the interactions across different structural levels that result in the formation of transitions. The next section opens up different patterns of change by explaining transition contexts.

Transition contexts

The tendency to associate transitions merely to the niche level initiatives found to be limited and became the subject of debate in transition theories (see: Smith et al., 2005; Geels & Schot, 2007; Genus & Coles, 2008; Geels, 2011). Based on Braudel’s multiple layers of analysis, the key to understanding societal transformations is to consider the interplay of dynamics that take place at different chronological levels. The argument is that, transitions take place through the interaction of processes amid the three levels of the MLP framework (Geels and Schot, 2007b, p. 400). A theoretical contribution that has provided a better understanding of sociotechnical transitions in relation to the multilevel perspective is transition contexts. According to Berkhout et al. (2004), all transformations are to some extent a mixture of deliberate and non-deliberate actions, i.e., envisioned change and responses to external pressures.

In addition to deliberate actions, comes the degree to which means of change are available to the members of the incumbent regime. This entails whether resources required for effective regime transformation such as factor endowments, capabilities and knowledge are located (or being internalized) within or outside the established boundaries of the incumbent regime (Smith et al., 2005, p. 1492). It should be noted that, from a knowledge-based theory perspective, the firm is conceptualized as an organization for integrating ‘specialized knowledge’ (Grant, 1996b). Hence, more emphasis is placed on the ‘soft’ aspects of resources, particularly knowledge, technologies, and organizational capabilities, such as the capacity for learning new sets of skills and the ability to integrate them into the existing knowledge-base (Bergek et al., 2013a; Berggren et al., 2013; Tell et al., 2016). The importance of this perspective on the nature of transformation is that when the required knowledge, technologies, and capabilities are internally available within regime, then transformative changes would rather take place in a cumulative character (Smith et al., 2005, 2004).

Based on this argument, transition contexts are formulated in two dimensions: coordination (deliberate actions) and the locus of resources (means of change). The coordination dimension determines the degree to which the intended change or response is coordinated among incumbents. The locus of resources is the degree to which the means of change, such as knowledge, technologies, and capabilities are available or internalized within the existing regime. These two dimensions form a 2x2 matrix in which the coordination dimension (low/high) is located on the horizontal axis, and the locus of resources (internal/external) is located on the vertical axis (Table 1).

Table 1. Transition contexts based on Berkhout et.al. (2004)

Transition Contexts		Coordination <i>(deliberate actions by incumbent actors)</i>	
		Low	Hi
Locus of resources <i>(means of change)</i>	Internal	Reorientation of trajectories	Endogenous renewal
	External	Emergent transformation	Purposive transition

The matrix presents four different situations or scenarios for regime transformation which Berkhout et al. (2004) and Smith et al. (2004, 2005) referred as transition contextsⁱ. Each of these transition contexts have distinct characteristics and pre-conditions which are elaborated as the following:

ⁱ Geels and Schot (2010) introduced a similar concept to explain different transformation scenarios known as ‘transition pathways’. They used other criteria to explain their typology which include timing of niche maturity (*hi/low*), and nature of interactions between regime and niches (*competitive/symbiotic*). They also provided a taxonomy of landscape pressures including *Disruptive, Reinforcing, Shock, and Avalanche*. In this thesis, I have decided to use transition contexts for its relevance to the research questions, but I have previously provided an elaborated discussions and comparison on both concepts which can be found in my Licentiate thesis (Borghei, 2015a, pp. 23–28).

- ❖ *Reorientation of trajectories*: takes place when there is a low level of coordination among regime actors for change, but the resources required for change are available internally; thus, the response is eventually formed within the regime. The rapid and wide-scale adoption of combined-cycle gas turbines by incumbent firms as a viable technological and more sustainable alternative to the then coal and nuclear power generation is an example of unintended and unanticipated change that nevertheless transformed the electricity segment from within in the UK (Berkhout et al., 2004).
- ❖ *Endogenous renewal*: is the conscious effort by incumbent actors using internal resources in response to the pressure or perceived threats to the regime. The intention for changing the established regime is thus the result of high coordination among regime actors. Due to high coordination for change by incumbents themselves, the cognitive structures and problem-solving routines are still steered in the existing regime, hence decisions about alternative technological choices would be guided by prevailing values and the past experiences. The most important indication of this type of transition is the incremental change and highly coordinated moves by incumbents in a very controlled and cumulative type of change (ibid).
- ❖ *Emergent transformation*: is the situation where change is not coordinated by members of the existing regime while resources are not internally available either. This is the classical ‘doomed’ situation because in the absence of enough resources and lack of coordination or willingness from incumbents, there are limited choice for survival of the existing regime. Examples of such situations involve disruptive changes where incumbents are drifted away by the increasing waves of new entrants who would eventually wipe out the established regime (Christensen, 1997).
- ❖ *Purposive transition*: The distinction in this scenario is that although resources are not internally available within the boundaries of the existing regime, incumbents are still able to construct coordinated responses to perceived threats or pressures and pull resources from outside. Thus, purposive transitions reflect the broader set of interests that are largely located outside the boundaries of the existing sociotechnical regime.

What is important to note here is the degree to which incumbents can coordinate and pull resources together in order to respond to the increased pressure or perceived threats from outside. This is determined by the incumbents’ adaptability to new conditions or their ability to overcome sources of external threat, which is identified as ‘*adaptive capacity*’ (Berkhout et al., 2004; Smith et al., 2004, 2005). Hence, the adaptive capacity of a regime is defined as: “[the] ability to recognize its vulnerability to competitive threats...and to reduce its vulnerability to those threats...through innovation, reconfiguration, or by influencing the regulatory environment” (Berkhout et al., 2004, p. 64).

Berkhout et.al. (2004) outlined the description of adaptive capacity based on the existing concepts in systems of innovation literature. From this perspective, the adaptive capacity of a regime is determined by the degree to which its members can effectively deploy innovative processes, such as knowledge development and entrepreneurial experimentation (Bergek et al., 2008; Jacobsson & Bergek, 2004; Jacobsson & Johnson, 2000).

Adaptive regimes are thus the ones that are able to perform those functions more effectively. Therefore, we expect that over time, more adaptive regimes would maintain or survive longer, while those regimes with less adaptive capacity would be demolished or substituted by new sociotechnical configurations (Smith et al., 2005).

2.4 Theoretical synthesis and sub-research questions

To conclude this chapter, a brief summary and synthesis about the choices of theoretical framework are provided here. After reviewing literature on three streams of literature (i.e., SSI, SNM, and MLP), several key concepts have been introduced, which are extracted and are being presented as the theoretical constructs of the thesis in the following table:

Table 2. Theoretical constructs of the thesis

Theoretical framework	Theoretical constructs
<i>Sectoral systems of innovation (SSI)</i>	<ul style="list-style-type: none">• Knowledge and technologies• Actors and networks• Institutions
<i>Strategic niche management (SNM)</i>	<ul style="list-style-type: none">• Protective spaces (niches)• Local-global structuration (SNM 2.0)• Niche empowerment strategies<ul style="list-style-type: none">◦ <i>Fit and conform</i>◦ <i>Stretch and transform</i>
<i>Multilevel perspective on sociotechnical transitions (MLP)</i>	<ul style="list-style-type: none">• Niche, Regime, Landscape• Transition contexts<ul style="list-style-type: none">◦ <i>Locus of resources</i>◦ <i>Coordination</i>

These theoretical constructs are important building blocks of the study, and they will be further employed to guide the rest of this thesis in the remaining chapters. In particular, the niche and regime concepts will be used further for defining the research design and scope of study in the next chapter. They also help to navigate through the research field by guiding the search process. This is particularly reflected in the formation of the sub research questions. As mentioned earlier, the main research question has been formulated as follows:

Main RQ:

How can incumbents act to facilitate sectoral transformations towards environmental sustainability?

An important follow-up question would be that, what kind of resources are available or required for such transformations? As discussed earlier, transition scholars, such as Berkhout et al. (2004) and Smith et al. (2004, 2005) responded to this question by suggesting that resources could be available internally, or they may exist outside the boundaries of the incumbent regime.

They also stated that all transformations are to some extent a mixture of deliberate and non-deliberate actions (Berkhout et al., 2004, p. 66). Therefore, based on the *locus of resources*, the roles of incumbents in processes of transformative change could generally fall into two main spheres of action:

- ❖ *Internal locus* of resources for regime transformation: These resources include core knowledge, technologies and capabilities that are available within existing regime (*i.e.*, within established sector in this study) which can be employed for endogenous transformation.
- ❖ *External locus* of resources for regime transformation: when sources of knowledge and technologies are primarily located outside the traditional boundaries of existing regime (*i.e.*, niches or emerging sectors), then it can be considered as exogenous transformation.

Hence, based on Berkhout et al. (2004) and Smith et al. (2004, 2005), what needs to be considered is how incumbents can engage in deliberate actions to facilitate sectoral transformations within or outside these two spheres. That is, how can incumbents facilitate transformations in established sectors (*i.e.*, endogenous transformations) or otherwise to facilitate transformations outside traditional boundaries through developing niches or emerging sectors (*i.e.*, exogenous transformations). Hereby, these two important spheres of action are formulated as the sub-research questions for this thesis:

<p style="text-align: center;"><u>Sub RQ I:</u></p> <p style="text-align: center;"><i>How can incumbents act to facilitate transformations in established sectors?</i></p>
<p style="text-align: center;"><u>Sub RQ II:</u></p> <p style="text-align: center;"><i>How can incumbents act to facilitate transformations through engagement in emerging sectors?</i></p>

These are important questions that need to be answered in order to make the role of incumbent actors more clear with regards to sectoral transformations. Therefore, they can be formulated as sub research questions in this thesis. Figure 8 illustrates more clearly how the purpose, main research question, and sub-research questions are related to each other:

Figure 8. Research purpose, Main research question (RQ), and sub-research questions

Through the literature in this chapter, two sub-research questions have been defined that break down the main research question into two main spheres of action for incumbents: i.e., transformations within or outside the boundaries of established sectors. The sub-questions also guide research design, scope of study, and operationalization by identifying roles of incumbents within each spheres of action. The next chapter will elaborate on methodological aspects of the research in details.

CHAPTER 3.

METHODOLOGY

This chapter starts by explaining the overall structure of the entire research-education that has resulted in this doctoral thesis. This structure consists of two separate, yet related research studies (Study-I and Study-II). It will then explain the scope and research design for each study. Design of inquiry and sources of empirical data are then explained and two different analytical approaches are introduced. The chapter will be concluded with methodological reflections and self-assessment. The contents of the chapter include the following sections:

- 3.1. Two research studies
- 3.2. Scope of research characteristics of the empirical field
- 3.3. Research design
- 3.4. Design of inquiry
- 3.5. Sources of empirical data
- 3.6. Analytical approach
- 3.7. Methodological reflections

3.1 Two research studies

Decisions about research methods are not merely limited to data collection and analysis, but should cover the entire process of conceiving and engaging in the research field and operationalization through informed theoretical choices. Research design cannot be understood independent of theory; hence, it must reflect an informed theoretical approach that shapes and guides the entire research enterprise (Poole et al., 2000, p. 112). Based on the two sub research questions presented in the previous chapter, the overall structure of this thesis is divided into two distinct phases or research studiesⁱ:

❖ **Study-I: Regime-level study**

The first phase concerned the study of established industry settings related to heavy commercial vehicles sector in Europe. The main focus in this phase was regime level structures and endogenous (*i.e.*, regime-driven) sectoral transformations.

❖ **Study-II: Niche-level study**

After understanding existing structural settings in this sector, the second study focused on emerging technologies for alternative propulsion and the potentials for niche-driven transformations.

Each study is guided by certain theoretical constructs as defined in Chapter 2 (see Table 2). In the first study, the main objective was to understand how the sector responded to increasingly stringent environmental performance requirements through the adoption of emission treatment technologies over the past few decades. This helped to have a better understanding of the past transformations and co-evolutionary interactions that have shaped the existing structures in this sector up to now. Hence, the historical and co-evolutionary processes were particularly important in this phase. Choices of theory for this study included *sectoral systems of innovation-SSI*, *institutional theory* and *multilevel perspective-MLP*. The study was concluded by defending a Licentiate degree thesis at the end of this phaseⁱⁱ.

The second study concerned the emergence of niche technological innovations (in the form of electric propulsion technologies) that in the mid- to long-term future could provide alternative solutions to the dominant technological paradigm based on the internal combustion engine-ICE.

ⁱ According to the Swedish Higher Education Ordinance for third-cycle education, pursuing research education towards a PhD can be done in two distinct phases: A Licentiate degree program corresponding to 120 ECTS (including a 60 ECTS Licentiate thesis) followed by the admission to a Doctoral degree program upon successful completion of the first phase. In total, PhD education in Sweden corresponds to 240 ECTS (equivalent to at least four years of full-time education including 90 ECTS PhD courses) in addition to teaching and administrative duties, which extend the total academic years (see Appendix 5 on PhD courses). More information about third-cycle education (doctoral studies) in Sweden is available at: www.studera.nu/startpage/doctoral-studies

ⁱⁱ The Licentiate thesis was presented in a public session on 26 February 2015 and consequent to acceptance from the defense, the candidate was admitted to the next phase for continuation of research education towards doctoral degree. The published Licentiate thesis is available at Linköping University library: Borghei, B. (2015), '*Sustainability Transitions in Established Industries: The case of European Commercial Transport Vehicles*', Linköping Studies in Science and Technology, Thesis no. 1707, ISSN 0280-7971 available at Linköping University Library <http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-114399>

Choices of theoretical framework for Study–II included: *strategic niche management–SNM* to address the nurturing and empowerment of niche technological innovations as well as SSI and MLP in order to map out contingencies of niches in relation to the established structures. Of course, other relevant theoretical perspectives have been considered, in particular discussions related to institutional change as well as topics on knowledge development and knowledge integration. However, in order to avoid replication, discussions around those topics have been enveloped as integral parts of the SSI framework (*i.e.*, *actors & networks, knowledge & technologies, and institutions*). Figure 9 illustrates the overall structure of the two research studies and the corresponding theoretical frameworks mapped on the PhD education timeline.

Figure 9. The process of PhD education mapped on the two research studies

The timeline in Figure 9 shows the entire process of doctoral studies from writing a research proposal for admission (appendix to the Licentiate thesis) to the final PhD defense. What is commonly shared between the two studies in terms of theoretical perspective is SSI and MLP frameworks that together address the overall topic of this thesis *i.e.*, *sectoral transformations*. Later in this chapter, there will be more elaborations on how the studies have been operationalized based on this research design and using theoretical constructs that guided empirical data collection and analysis. It is also important to clarify the scope of research and what issues have been covered in each study. This is elaborated on in the next section.

3.2 Scope of research and characteristics of the empirical field

The automotive industry is by and large one of the biggest industries in Europe, and it employs around 12.6 million of the EU workforce and generates around 396 € billion in tax payments across 15 countries (ACEA, 2017). The automotive industry is also the largest private investor in R&D in Europe, accounting for over 50€ billion annual investments in a wide range of knowledge and technological fields. To have a better understanding of this vast industrial complex, one may need to break it down into smaller segments, each of which representing specific characteristics and certain features of their own.

Firstly, the automotive industry can be broken down into commercial and private vehicles. Secondly, each segment can be broken down into more specific areas of operation as shown in Figure 10. The scope of this thesis comprises of commercial vehicles of which heavy vehicles are the main focus of both studies. Thirdly, the operation areas of heavy commercial vehicles can be divided into goods transport (STUDY-I) and passengers transport (STUDY-II).

Figure 10. Delineating scope of studies

Figure 10 illustrates the scope of the two studies: the first study investigates transformations that took place at the regime level over the past few decades, while the second study covers recent developments with regards to electric propulsion as an emerging niche in city bus applications. The dominant powertrain technology in this sector has long been centered around the diesel combustion engine commonly shared between the two segments as the main source of power for all heavy commercial vehicles (i.e., trucks and buses).

It is only recently that electric propulsion has started to emerge as an alternative powertrain in city-bus applications. This makes the major difference between the two studies: i.e., established technologies at the regime level (STUDY-I) versus emerging technologies at the niche level (STUDY-II).

Another difference is that, the first study involves *ex-post* analysis of past events, while the second study involves analysis of contemporary niche developments and their potential implications into the future. It is also important to point out distinctive features of the heavy commercial vehicles sector and its specific characteristics that make it an important field of study. These features are elaborated on in the following section.

Characteristics of the empirical field

High performance, reliability, and uptime are the most important requirements in daily operations of heavy commercial vehicles. Established technologies as such are often intertwined with established user practices and highly structured industry configurations, organizational routines, and sophisticated means of governance (Rip and Kemp, 1998). Therefore, transformations in this field entail multifaceted implications across the established systems and industry structures, the existing knowledge-base and user practices, as well as related infrastructure.

Meanwhile, high technology intensity and system complexities associated with heavy commercial vehicles, closely characterize them as Complex Product-Systems (CoPS). Complex product-systems are high-value, high-technology and highly engineering-intensive types of products that—for their inherent complexities—span over a wide range of knowledge and scientific disciplines (Davies et al., 2011). For instance, emission treatment technologies and the vast amount of sub-systems in the advanced heavy duty vehicles of today sometimes weigh up to one ton and they need to be properly integrated so that the overall functioning of the whole system is securedⁱ. This in turn requires extensive knowledge integration capabilities across different domains as well as high levels of understanding about the emergent properties of the systems (Davies & Hobday, 2005; Hobday et al., 2005).

Another important characteristic of this field is that institutional arrangements, i.e., rules, regulations, standards, and safety requirements related to heavy commercial vehicles are highly in favor of the established technology (i.e., diesel engine); hence, diffusion of alternative propulsion technologies require substantial institutional changes. Nevertheless, these institutional arrangements are in turn highly complex and call for more attention both by academic scholars and policy-makers (Bakker and Konings, 2017).

ⁱ According to the interview with resident engineer from MAN at the IAA Commercial Vehicles Exhibition in Hanover, the sheer amount of emission treatment technologies installed on modern trucks to comply with the Euro-VI standard is comparable to a 'mini chemical-refinery plant' (Lopez, 2012).

Yet there is a lack of empirical research in this field. This might be due to the fact that these vehicles primarily function in a B2B (*business-to-business*) context in contrast to B2C (*business-to-consumer*) context, which is more relevant for private vehicles (cars). Due to the large number of users and customers, private vehicles are more visible in the society and probably has been more accessible to researchers as an intriguing empirical field of study.

As pointed out by Kemp et al. (2012), other important aspects, such as personal mobility, traffic, and congestion problems, as well as alternative niche technologies, such as hydrogen fuel cell vehicles (HFCVs), and its wider aspects, such as hydrogen society, are equally important issues related to transformation of automotive industry in general.

However, the scope of niches in this thesis is delimited to electrification in heavy commercial vehicles for passenger transport (city buses in this case), which still covers a wide range of alternative propulsion technologies from *hybrid-electric vehicles* (HEVs) to *plugin electric vehicles* (PEVs) as well as *battery-electric vehicles* (BEVs). This delimitation is intended to narrow the focus of the niche study to hybrid/electric powertrain technologies, in the potential shift from internal combustion engine (Pohl, 2010) or as the “bundle of niche activities within an area of innovation” to deviate in differing degrees from the current mobility regime (Nykqvist and Whitmarsh, 2008).

Upon delineating the scope of thesis and important characteristics of the empirical field as discussed above, it is also important to consider the design characteristics of the research, which are elaborated on in the next section.

3.3 Research design

Research design is an important aspect of conducting empirical studies in social science. It comprises of a process that entails defining and clarifying fuzzy notions or thoughts into more tangible and distinguishable concepts that could be empirically observed, traced, or examined. The process starts with conceptualization (*i.e.*, refinement and specification of abstract concepts) and then development of specific research procedures (*i.e.*, operations) that would result in empirical observations representing those theoretical concepts in the real-world environment (Babbie, 2011, p. 146). Strategies for planning the empirical research have followed the two main theoretical concepts that also shaped sub research questions in this thesis: *i.e.* Regime (Study-I) and Niche (Study-II). Differences between the two studies in terms of research scope and characteristics of the empirical field have been clarified in the previous section. While the first study is focused on retrospective analysis of sectoral transformations in order to understand structural configurations of the established sector up to the recent time (*i.e.*, *ex-post facto*), the second study concerns contemporary developments at the niche level and the potential transformations they may bring in the future. Nevertheless, these two concepts shall not be taken rigidly when it comes to data collection strategies. For instance, while a major part of empirical data in the first study came from archival sources (Bowman, 1984, 1978), contemporary sources such as interviews and field visits also provided valuable insights. It involved asking interviewees to reflect upon past events, thereby cross-checking through archival studies. Similarly, data collection strategy in the second phase did not completely rely on contemporary sources but also complemented with additional data from archival sources and historical data in order to understand the origins of today's trends in the development of niche technological innovations. Figure 11 illustrates the situation as follows:

Figure 11. Research design mapped on the two research studies (ex-post and contemporary)

The figure shows the overlap between the two studies: the first study concerns analysis of the established industry structures that continue to exist today, while the second study concerns analysis of contemporary trends that have some roots in the past, but at the same time, they have the potential for breakthroughs into future developments.

Table 3 summarizes the research design process starting from conceptualization of theoretical constructs to data collection strategies and finally to the data processing and analysis (left-to-right arrows) for Study-I and Study-II (top-down arrow). The arrows show chronological order in both directions.

Table 3. Design of research from theoretical construction to data collection strategies and data analysis

	Theoretical constructs	Data collection strategies	Data processing and analysis
<div>Study I</div> <div>(ex-post)</div> <div>↓</div> <div>Study II</div> <div>(contemporary)</div>	SSI theoretical constructs: +actors & networks +knowledge/technologies +institutions	The data collection was primarily guided by the theoretical constructs of the SSI framework. Retrospective approach was employed in data collection strategy that included historical inquiry and archival studies.	Using SSI framework, it was possible to analyze interactions among sectoral elements in order to explain sectoral transformation. Cross-checking was made between different sources of data during the analysis.
	MLP theoretical constructs: -niche +regime +landscape	When dealing with theoretical constructs of MLP during Study-I, most attention was paid to regime and landscape dynamics since niches were still at the very immature stage at this point of time.	The MLP framework guided the structural analysis of the established sector and its dynamics in relation to landscape pressures for reducing emissions
	MLP theoretical constructs: +niche -regime -landscape	The data collection strategy at this stage was mainly guided by the niche concept in the MLP framework.	Pattern-matching was employed to trace development of niche technological innovations across time and space
	SNM / SNM 2.0 +local & global +fit & conform +stretch & transform	Contemporary approach was employed in data collection strategies which mostly relied on field visits and direct participation in the development of niche projects related to electric bus systems in Europe.	Vinnova bus project was used as an arena for observing interactions among actors representing established sectors for development of electric bus systems i.e. energy, automotive, power equipment, and the public transport sector

As the table shows, each study has distinct characteristics which has implications on the choices of theoretical framework and the following data collection and analysis. The next section takes the discussion forward by elaborating on the design of inquiry and explaining how different choices of design may result in different outcomes.

3.4 Design of inquiry

Design of inquiry concerns an important aspect of research design in terms of the nature of inquiry, research strategy, and design of cases. The following sections elaborate on these aspects and the reasons for particular choices of design for empirical inquiry for different parts of research included in this thesis.

Qualitative inquiry

“Not everything that can be counted counts; and not everything that counts can be counted”
(Albert Einstein)

A qualitative inquiry ought to provide answer to the questions of why, how or what instead of how-much, how-many, or how-significant (Patton, 2002; Van De Ven and Poole, 2000, 1990; Van De Ven et al., 1989). Moreover, qualitative research is the appropriate choice when a problem or issue needs to be explained and, when there is a need for ‘complex’ and ‘detailed understanding’ of the issue (Creswell, 2006, pp. 40–41). Furthermore, it is appropriate when the researcher wants to ‘understand the contexts or settings’ or describe ‘some aspects of social life’, the purpose of which is to generate words rather than numbers (Patton, 1987). Having considered the qualitative aspects of the research question in this thesis, the qualitative method of inquiry was found to be more appropriate than quantitative inquiry. Nevertheless, it does not exclude possibilities for collecting quantitative types of data, such as statistics and numerical data, but the analysis and processing of such data are handled using qualitative methods that are further elaborated on in the coming sections.

Case study

Creswell (2006) identified five different types of qualitative research inquiry, namely: *narrative research*, *phenomenological research*, *grounded theory*, *ethnography*, and *case study*. Among these five choices of qualitative inquiry, the case study is considered appropriate “when the inquirer has clearly identifiable case(s) with boundaries and seeks to provide an in-depth understanding of case(s)” (ibid 2006, p. 74). Moreover, if the research question requires an ‘in-depth’ description of a social phenomenon or the focus is on understanding a social phenomenon, (qualitative) case study is considered to be an appropriate means of empirical inquiry. Following the discussion provided in Chapter 1 on the purpose and the research question, the main subject of this thesis is primarily driven by a particular social phenomenon (*i.e.*, incumbents’ involvement in sectoral transformations). Hence, qualitative case study was found to be more appropriate in this context. Nevertheless, when it comes to case studies, there are still other important aspects to consider, including the case study design. These aspects are further elaborated on in the next section.

Case study design choices

Formal case study design is often overlooked in qualitative case studies. Robert K. Yin is among the few methodologists who addressed this problem and provided a formal classification for variations in case study design (Yin, 1984, 1989, 2013), which nevertheless was appreciated and found to be very useful by other methodology scholars (Creswell, 2006, p. 196). In his typology for case study design variations, Yin (2013) identified four different choices which can be positioned in a 2x2 matrix. The horizontal axis represents case entities that can vary between *single* or *multiple* case study choices, and the vertical axis varies between *unitary* or *embedded* units of inquiry. These case study design choices are illustrated in Figure 12.

Figure 12. Case study design choices
Adapted from Yin (2013)

The main difference between single and multiple case study design choices lies in the different contexts in which cases are embedded. In multiple case studies each case is identified with a specific context, subject, or entity that the research examines. When it comes to the unit of inquiry, the difference is that embedded design allows for different sub-units to exist within the case study (Yin, 2003). Perhaps the simplest example is provided by Yin as the following: A *single case study* might be about how and why an organization implemented certain staffing strategies, but the study also might include data collected about a group of employees—whether from a sample survey, from an analysis of the employees’ records, or from some other source (*the embedded level*). If the study is limited to a single organization, you would have an *embedded, single-case study*. If two or more organizations are studied in the same manner, you would have an *embedded, multiple-case study* (Yin, 2012, p. 7)

Different types of case study design variations are included in this thesis (applied to the appended papers). Both single and multiple case studies were designed based on different research entities. For instance, in Paper-I, the European heavy-duty vehicles sector (goods transport) was defined as a single case, while in Paper-III, several niche projects related to fast-charged electric buses were studied in which, each city represented a separate case within the multiple case study setting. Then, different units of inquiry were defined based on related theoretical constructs in each case. For instance, in Paper-I and Paper-IV, the units of inquiry were defined based on theoretical constructs from sectoral systems of innovation, while in Paper-II and Paper-III, units of inquiry were driven by the theoretical constructs from the multilevel perspective. Table 4 shows case study design variations mapped on different papers.

Table 4. Case study design variations applied in the appended papers

Case study design choices	Case entity	Unit(s) of inquiry *	Outcome
Embedded single case study (Type 3)	European heavy-duty vehicles sector defined as a single case	Knowledge & technologies Actors & networks Institutions	Paper-I
Embedded single case study (Type 3)	Electric city-buses in Europe defined as a single case	Actors in MLP/SNM setting	Paper-II
Multiple case study (Type 2)	Niche projects on fast-charged electric buses defined in a multiple case study setting	Actors in SNM 2.0 setting	Paper-III
Embedded multiple case study (Type 4)	Comparison of different system configurations: slow-charged vs fast-charged systems in Europe defined as multiple case study	Knowledge & technologies Actors & networks Institutions	Paper-IV

* Units of inquiry have been defined by theoretical constructs introduced in Chapter 2 (see Section 2.4)

As the table shows, the case entity has been mainly influenced by the characteristics of the empirical setting, while the unit of inquiry has been primarily defined by the choices of theoretical constructs. The last column of the table shows that various case study design choices have resulted in different outcomes in terms of the four papers. These papers will be presented in Chapter 4, but before that, it is important to elaborate on the sources of empirical data in the two phases of the PhD study (Study-I and Study-II). Sources of empirical data and their differences across the two studies are further described in the coming section.

3.5 Sources of empirical data

There are different ways of collecting empirical data in qualitative research and prominent methodologists have provided different classifications for it. For instance, Patton (2002, p.4), has broadly classified them into three main categories, namely: *interviews*, *documents*, and *observations*. Creswell (2009, p.180) provided a similar classification, but also added modern means of qualitative data collection involving multimedia sources, such as *audio-visual materials*. Yin (2009, p.101) identified six sources of ‘evidence’ for qualitative research including: *documents*, *archival data*, *interviews*, *direct observation*, *participant observation*, and *physical artifacts*. Merriam (2007, p.69) also provided the same classification as Yin, but was more specific to the case study applications in the field of educational research. Flick 2009 (ch. 4-5), on the other hand, divided qualitative data in two broad categories each of which contains different sources of empirical data, namely: verbal data (*i.e.*, interviews, narratives, focus groups) and observational & mediated data (*i.e.*, observation & ethnography, visual data, documents and online sources).

Despite such differences, it might be still possible to draw some conclusions on different ways of collecting empirical data in qualitative research. Table 5 provides a synthesis across different classifications for qualitative data as described above.

Table 5. Synthesis of different classifications for qualitative data (based on Patton, Merriam Creswell, Yin and Flick)

Patton (2002) Merriam (2007)	Creswell (2009)	Yin (2009)	Flick (2009)
Documents	Documents	Documents Archival data	Documents
Interviews	Interviews	Interviews	Verbal data: -interviews -narratives -focus groups
Observations	Observation Audio/Visual materials	Direct observation Participant observation Physical artifacts	Observation Ethnography Visual data Online sources

However, there are two important aspects to consider here: first is that, the above table contains the most common sources of qualitative data, but qualitative research is not always limited to these sources and may include other types of qualitative data, such as *projective techniques*, *proxemics*, and *kinesics* (Yin, 2009, p. 101) or even quantitative data, such as numbers and statistics (Patton, 1987, p. 8). Nevertheless, the outcome of qualitative research is always expressed in qualitative terms, such as words or descriptive accounts of the phenomena rather than quantitative scales (Pratt, 2009). Secondly, no single source has a complete advantage over the others; rather, combinations of different sources of empirical data that together serve the purpose of the study have the potential advantage over any single source (Yin, 2009, p. 114).

This research has benefitted from various sources of empirical data. As mentioned in the research design (Section 3.3), there have been different approaches in Study-I (regime study) versus Study-II (niche study) in terms of theoretical constructs as well as the nature of empirical data and analysis. Sources of empirical data collection (and partly the process of analysis) for these studies are elaborated on in this section. Further elaborations regarding different approaches in the analysis of data will be dealt with later in this chapter when describing the analytical approach (Section 3.6).

Documents and archival data

As mentioned earlier, Study-I relied more heavily on archival data due to the nature of the study that demanded retrospective analysis of emissions reduction during the past few decades in the established sector. An important aspect of understanding sectoral transformations and the role of incumbents in processes of transformative change was to find out about the behavior of the established firms and their technology strategies to facilitate environmental innovations to reduce emissions. For this purpose, the annual reports (including environmental and emission policies) of the five (out of seven) major established firms in this sector have been collected that covered at least two decades of environmental enhancements, sometimes going back as far as early 1980s. These incumbent firms together covered more than 70% of the total EU market for heavy duty vehicles, including Daimler, Volvo, Renault Trucks (part of Volvo Group since 2001), MAN, and Scania. Table 6 shows the production and sales volume as well as the market share of the incumbent firms by the time of Study-I:

Table 6. European heavy vehicle manufacturers (EU incumbents) and their market share, Source: KPMG International (2011)

OEMs (EU incumbents)	Truck production (+6 ton)	Truck production (+16 ton)	Unit sales EU market (2010)	EU market (share)	Study range (annual reports)
DAIMLER	266,300	232,200	46,700	23.3%	1979–2012
AB VOLVO + RENAULT TRUCKS	141,200	133,000	42,200	21%	1980–2012 2001–2012
MAN	115,500	77,500	31,300	15.6%	1989–2012
SCANIA	61,100	61,000	20,500	10.2%	1996–2012
DAF	78,900	74,000	27,500	13.7%	No response
IVECO	46,600	33,500	26,000	13%	No response
TOTAL	709,600	611,200	194,200	96,8%	70,1%

The annual reports came in different formats including PDF documents and in some cases in the form of hard copies (magazines), which then were converted into searchable documents for text mining and analysis. Specific terminologies that are widely used in the industry, such as “emission treatment”, “Euro standard”, “air pollution”, etc. have been chosen as the keywords to analyze the frequency and the context of using those terms over the years in the reports. The goal was to arrive at an appropriate approximation of the past events through the means of recorded history (Bowman, 1984, 1978).

The analysis of these documents were conducted based on the *systematic combining* approach that involves continuous interaction between theoretical and empirical worlds as suggested by (Dubois and Gadde, 2002). The empirical data from annual reports were also complemented with other forms of documented data related to this topic, such as EU directives on emissions regulation for HDVs, policy papers, emission standard documents, consulting and policy research publications, public announcements by industry associations or joint announcements of companies regarding their strategies towards emissions reduction in this sector, as well as news and media sources that covered important issues related to this topic.

The process took around two years starting in early 2012 with the search for an appropriate theoretical framework while sending requests to the companies for access to the empirical data. The theoretical approach included both literature reviews and library search as well as presentations and feedbacks at different conferences and academic gatherings, which finally resulted in the selection of sectoral systems of innovation (SSI) as the appropriate framework by mid-2012 (Section 4.2 will provide more details on this process). Meanwhile, empirical data collection was going forward, and the process of analysis started as soon as the theoretical framework was chosen; hence, by the mid-2014 most of the research findings had already concluded for Study-I.

With regards to Study-II, documents and archival data was useful as complementary sources. As mentioned earlier, the contemporary nature of this study did not allow so much use of the archival data due to the need to understand concurrent developments rather than recorded history. Nevertheless, documented data have been used to the extent they were available to the researcher. In particular, the announcements from heavy vehicle manufacturers regarding their technology strategies towards alternative propulsion as well as industry white papers that provided roadmaps to the future have been studied. One of the most useful sources of such data was provided through the European Consortium on Zero Emission Urban Bus Systems (ZeEUS), which gathered information about niche project experiments across a large number of cities and capitals in Europe (ZeEUS, 2017, 2016) as well as third party reports on the development of electric propulsion technologies such as The Swedish Knowledge Center for Public Transport (K2, 2016).

An additional source of data came from the supervision of two master's students from Germany who came to know about my research and showed interest in participating as part of their student project for a master's degree in the field of industrial engineering. The supervision involved relocation of the students to Linköping university for a period of 5 to 6 months each during 2014 and 2015 for continuous guidance and close interactions on empirical data collection (involving online sources, document analysis and phone interviews) about technological advancements and market developments for electric buses in Europe and Germanyⁱ.

ⁱ Stefan Förster (2014), Überblick über die Marktentwicklung und technologische Förderung in der Industrie elektrifizierter Busse (English Title: Overview of Market Development and Technological Advancements in the Electrified Bus Industry), Studienarbeit in M.Sc., Technologiemanagement Matriculation No. 2831714 (Universität Stuttgart), Supervisor: Benny Borghei, Examiner: Thomas Magnusson, Presented at Linköping university, 25.06.2014.

Fabian Ludwig (2015), Overview of Market Development in the Electrified Bus Industry with focus on Germany, Studienarbeit in M.Sc., Technologiemanagement, Matriculation number: 4475884 (TU Braunschweig), Supervisor: Benny Borghei, Examiner: Thomas Magnusson, Presented at Linköping university, 12.06.2015

Interviews

Interviews constitute an important part of both studies. In Study-I, the interviews mainly functioned as a means of triangulation and cross-checking for the archival studies. To better understand the value of this cross-checking technique between the written and verbal types of data, one may consider the following situation: Organizations articulate important decisions or strategic plans based on the contingencies of certain circumstances at the time being or based on the expected results in the future, which are mostly unpredictable and subject to change until the time is passed and the consequences of those decisions become clear. In such situations the cross-checking technique was very helpful to compare the past decisions based on future expectations with the results of those decisions at the later stage. For that reason, interviews were conducted with several key decision-makers in charge of R&D and technology strategies at the incumbent firms. List of those interviews are available in Appendix 1.

In addition to the interviews with key decision makers, a number of interviews were conducted with middle managers and representatives of companies in order to have a better understanding of the organizational rationalities at different levels. Often times, interviews were recorded by means of digital voice recording devices, but in some instances, sound recording was not possible due to the high levels of ambient noise, or the lack of recording memory capacity, or the low battery on the device. But in any case, interview notes were taken during each session regardless of digital voice recording. Afterwards, the interview notes were reviewed, summarized and cross-checked with other participants (if present during the interview), or in weekly meetings with the supervisor.

Interviews have been facilitated by prepared protocols i.e., interview guidelines designed around on the characteristics of the interviewees as well as the issues or questions at hand. Apart from the hierarchical position of the interviewees in the organization, one of the major differences between the key decision-makers and middle managers was in the preparation process for the interview guidelines. In the case of key decision-makers, interview questions were prepared based on the background and the role of the person in that organization with regards to important technology decisions and environmental innovation strategies of the firm. This in turn required some research about the person in charge and getting to know about him or her before the interview, so that interview questions could be designed to specifically target certain questions related to that person. While in the case of middle managers or staff, the interview took more of a spontaneous nature with standardized questions suitable for a wider range of respondents. Several examples of the interview guides that have been used in various contexts are provided in Appendix 2.

Participant observations

Participant observation was a valuable method for collecting first hand and rich primary data. It also provided the opportunity to learn about different trends in the industry and getting to know about major challenges in technology development and environmental innovation as well as various solutions being presented by different actors in that context. The participation also provided the chance to get into spontaneous interview occasions with a wide range of attendants in those events including technology developers, sales and marketing representatives, users, and suppliers.

The researcher also attended regular meetings organized by Swedish Electromobility Center and its doctoral student networkⁱ. The center acts as a central node for interactions between industry, academia and society on developments related to electromobility in Sweden but also involves a wide range of international companies and scholars from different parts of the world related to at least one of the center's five themes of research and development: system studies, electric machines, energy storage, vehicle analysis and fuel cells. The researcher regularly attended presentations, conferences, and PhD network events organized by the center, which provided the possibility to stay informed about recent developments as well as the potential to get insights through interviews or informal discussions with participants.

The participant observation method was employed in both studies, but the timing was an important factor in collecting empirical data on the development of niche technological innovations related to electric propulsion during Study-II. The timing was important because developments started to boost significantly by early 2015 in this field, which then was followed by urban experiments of those technologies in real time operations across many European cities. Meanwhile, the ZeEUS consortium had been planning demonstration activities for electric buses since late 2013 but the implementation started to take off by late 2014 with core demonstration cities followed by a large number of observatory and user groups during 2015–2017. This also led to the possibility of conducting direct observation of electric bus demonstration project sites and data collection on the development of physical artifacts related to the niche technologies (see the next section on direct observation and physical artifacts).

The participant observation method was also used for data collection from focus group meetings during Study-II. The focus group meetings were part of the *Miljöbuss* project sponsored by the Swedish Innovation Agency (VINNOVA) to study the potentials of developing environmentally enhanced public transport solutions including electrification of city buses. The focus group consisted of a number of representatives from local public transport authorities, electric bus manufacturers, local and international energy companies, academic scholars as well as representatives from the local municipality in Linköping.

The project participants met frequently (3–4 times per year) between 2016–2018, and the meetings followed specific agendas that had been sent to the participants before each meeting. Notes of the meetings were recorded and shared with project participants on the internal website dedicated to the project documentationⁱⁱ. There were a number of presentations and feedbacks in those meetings including presentation of the empirical report on pioneering cities in electric bus transport in Europe (Borghei, 2016), the electric bus simulation study (Lindgren, 2017), actors analysis (by another PhD student in the project), and several other presentations by senior researchers at Linköping University.

ⁱ The Swedish Electromobility Center (formerly known as Swedish hybrid center–SHC) is a national center of excellence for research and developments related to electric and hybrid vehicles and its related infrastructure. The center was founded by the Swedish Energy Agency in partnership with Swedish automotive industry and in close collaboration with academia. For more information visit: www.emobilitycentre.se

ⁱⁱ Notes of the meetings are stored internally and shared with project participants with login access to the Office 365 SharePoint platform provided by Linköping University (Lisam). Access can be provided upon request to Carina.Ekhager@liu.se

The project meetings with the focus group also included a half-day scenario workshop involving around 24 attendants from different established sectors and public authorities to study alternative scenarios for future public transport solutions. The purpose was to involve a wide range of actors in discussions around different transition pathways and ask them to present and reflect upon their opinions and concerns. A summary of focus group meetings is provided in Appendix 3.

Direct observations and physical artifacts

Direct observation is different from participant observation in the way that the researcher does not (or cannot) become a participant in the context or interfere in the regular activities of participants, but rather stays as an unobtrusive observer in the field (Yin, 2003, p. 92). The situation mostly took place when attending field configuring events (Hardy and Maguire, 2010; Jolly and Raven, 2016) or niche project experiment sessions and demonstration activities in the field as an external body. This is also why direct observation is placed together with physical artifacts in the same section here because both activities entailed the researcher watching rather than taking part in the activities in the field.

The physical artifacts often entailed equipment, machineries, system components, and infrastructure related to environmentally enhanced heavy vehicles. It was also useful as a means of familiarizing with the research context at the beginning phases of the empirical search during both studies. It involved dedicated hours (sometimes consecutive days) of continued presence and participation in industry events, policy meetings, as well as test and demonstration activities.

Direct observations and physical artifacts helped to have a better understanding of technologies, terminologies, and getting to know about technical challenges in the field. Again, the timing was a critical factor for such observations. For instance, there was a time period (2012–2014) during Study-I when it was the highest time for the introduction of the latest emission standard in this sector, which many companies including OEMs, suppliers, and other actors considered as the most stringent emission standard that seriously challenged the established technology. It was very useful during that time to get familiarized with the technical challenges in the field, especially when collecting data on the later stages of implementing emission treatment technologies for the Euro-VI standard as one of the major happenings in this sector. Figure 13 illustrates several example photographs of the physical artifacts related to technological advancements in the established sector during Study-I.

Nonetheless, direct observation and physical artifacts as a method of data collection and familiarizing with the field was not limited to the established sector. An important part of direct observations during Study-II included demonstration site visits, where electric buses have been tested or in operation as part of the daily traffic. Several field visits were made to different cities in Europe including Hamburg, Gothenburg, Helsinki, Umeå, and Stockholm (Figure 14). During the visits, field notes were taken together with photographs and sometimes video recording, which were summarized and complemented with additional information from other sources, such as interviews, slides shows, and online sources. On other occasions, field visits occurred in test centers and simulation labs for electric buses in Finland (VTT) and Sweden (VTI). Field visits for both studies can be found in Appendix 4.

Figure 13. Direct observations and physical artifacts from Study-I (Photos from IAA exhibition in Hanover, Benny Borghei)

- Top-left:** Selective catalytic reduction-SCR package for Euro-VI emission treatment on heavy vehicles
- Top-right:** Diesel particulate filter (DPF) used in advanced diesel engines to capture very tiny exhaust particles
- Bottom-left:** The Hi-eSCR solution provided by FIAT as the only catalytic solution to meet Euro-VI requirements
- Bottom-right:** An advanced diesel engine complying with Euro-VI emission standard for heavy vehicles

Figure 14. Site visits and field experiment observations from Study-II (exemplary photographs, Benny Borghei)

- Top left to right:** VTT test center (Finland), Linker bus in fast charging station (Espoo, Finland), ZeUS project (Stockholm)
- Bottom left to right:** Volvo/Siemens Hamburg Innovation Line (Germany), Hybricon bus in fast charging station (Umeå, Sweden)

Following, Table 7 provides a summary of the sources of empirical data for Study-I and Study-II in this thesis:

Table 7. Sources of empirical data

Sources of empirical data	STUDY-I (regime-level)	STUDY-II (niche-level)
<i>Documents & Archival- data</i>	Euro emissions standard documents, EU policy papers, industry white papers, consulting and policy advice research publications, industry associations' joint announcements, news, media, and online sources Annual reports from 5 major European HDV manufacturers and their environmental reports	ZeEUS reports on the electric bus developments in Europe; K2 reports on electric bus market in Europe Heavy vehicle manufacturers' announcements about alternative propulsion technologies Studies of electric bus market developments in Europe and Germany (Förster, 2014; Ludwig, 2015)
<i>Interviews</i>	Employees and official delegates from European HDV manufacturers, industry representatives, public authorities and EU policy representatives (Table 1 - Appendix 1)	Interviews with incumbent actors and new comers to the electric bus market in Europe (Table 2-Appendix 1)
<i>Participant- observation</i>	Swedish electromobility center and PhD events to present early findings, GERPISA automotive conference	Nordic Electric Bus Initiatives (NEBI) in Gothenburg (2015) and Helsinki (2016) Miljöbuss project focus group meetings
<i>Direct- observation & Physical- artifacts</i>	HVTT (Stockholm), IAA (Hanover), Company visits (Scania, Volvo, VTI) industry and policy summits at the EU premises, European Commission and EU Parliament procedures on the legislative process	UITP (Milan) BusWorld (Kortrijk), Transport forum conference, ZeEUS demonstration events and conferences Field observations in Gothenburg, Hamburg, Helsinki, Stockholm, Umeå
<i>Digital- sources & audio-visual materials</i>	Education materials (e.g. on diesel technologies, electric powertrain, emissions treatment technologies, the EU institutions and regulatory systems, etc.) Promotional and exhibition materials provided by automotive manufacturers (or their affiliated associations) on their specific solutions for reducing exhaust gas emissions or electrification technologies	

Data synthesis and empirical report compilations

In both Study-I and Study-II, findings from different sources have been compiled together in the form of empirical reports published on the university library database (Diva). These reports however did not appear in the form of published academic papers, but as freely accessible reports from research which together formed a coherent compilation of the otherwise scattered 'micro data' such as photos, anecdotes and personal contacts that could have been dispersed here and there. Indeed, some of these empirical reports have been downloaded more than the published academic papers got formally cited; perhaps because some readers found them more insightful and rich in 'raw' data or more elaborative about what is really going on out in the fieldⁱ.

The writing of those empirical reports mostly took place after certain amounts of data was collected from different sources or when saturation reached from specific sources of data. For instance, the visit to one of the major events for heavy commercial vehicles in Europe (IAA nutzfahrzeuge) during Study-I provided access both to the physical artifacts as well as possibilities to conduct spontaneous interviews with representatives of companies during the exhibition. It was also complemented with further information from side-events such as conferences and policy sessions during the exhibition as well as interviews with suppliers and other actors during the event. After digesting and discussing those findings with my supervisor, the empirical data were compiled in a report and were uploaded on the university library database for public access (Borghei and Magnusson, 2012). Similarly, the empirical findings during Study-II were compiled once a certain amounts of saturation reached from interviews, observations and field notes collected during the empirical research (Borghei, 2016, 2015b).

The empirical reports have been also useful to keep a record of the research process, i.e., *audit trail* (Lincoln and Guba, 1985, p. 319), and later they were used as the empirical repository in the process of writing the published academic papers. An important aspect of writing academic papers is the analytical approach applied in the use of empirical data and in relation to the research questions. In particular, there are two different analytical approaches in innovation studies, each of which produces different outcomes. Both approaches have been adopted in this thesis for different purposes in the analysis of empirical findings during Study-I and Study-II, which in turn have resulted in different research papers. These two approaches are further elaborated in the next section.

ⁱ For instance, the following empirical report on the UITP exhibition field notes have been downloaded more than 1,000 times from the university library by the time of writing this thesis: <http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-121835> (June 2018)

3.6 Analytical approach

The analytical approach in this thesis is based on the work of (Van De Ven and Poole, 1990, 2000) on innovation processes resulting from an extensive research program at the university of Minnesota¹. Based on the results of the Minnesota research program, two distinctive approaches have been identified in the study of innovation activities of firms (Van De Ven and Poole, 2000):

❖ **Process approach:** *study of sequential change processes over time*

The process approach helps the researcher to understand change and transformation processes by tracing developments or sequences of events related to a certain phenomenon over the course of time. Hence, process studies by nature are historical or longitudinal (involving the time perspective), and they involve observations or the analysis of sequential stages of developments over certain periods of time.

❖ **Variance approach:** *study of important factors or interrelationships regardless of time*

The variance approach in contrast is mainly concerned with finding out differences (variances) among variables or establishing causal relationships among them in order to understand a certain phenomenon regardless of time. In other words, the variance approach takes a snap-shot of the subject or the research phenomenon observed at a certain point in time; such as, finding causalities among several factors at a certain point in time, which nevertheless are subject to change over time.

Both approaches are useful when serving the right purpose, and both approaches could very well benefit from either qualitative or quantitative (or combination of both qualitative and quantitative) means of data collection and analysis. The variance approach works best for identifying important factors, making comparisons between different entities or investigating relationships among them, while the process approach is mainly concerned about explaining sequential change processes and developmental studies that require the time dimension to be taken into account. The variance approach could be more appropriate to answer the question of *what*, *when*, *where*, or *who* (by analyzing causal relationships or differences among entities at a certain point in time), while the process approach is more suitable to answer the question of *how* or *why* (by providing an analysis about the sequences of social events and unfolding developments over time).

Both analytical approaches have been employed in this thesis. The process approach was employed to trace the developmental sequences and thereby explain the co-evolutionary sectoral interactions over the period of two decades in Study-I, and later it was utilized to capture interactions among niche projects with regards to the development of fast-charged electric bus systems in Study-II. The variance approach was also employed for the actor analysis and to

¹ The Minnesota Innovation Research Program (MIRP) began in 1983, consisting of 30 faculty members and doctoral students in close collaboration with different industry actors involved in innovative activities in a wide range of fields such as IT, nuclear safety, advanced electronics, naval systems, government strategic planning, as well as hearing health, therapeutic aphaeresis, multi-hospital systems and hybrid wheat development. The aim was to develop an understanding about the processes involved in innovative activities of firms (Poole et al., 2000).

identify strategies of manufacturers with regards to electric propulsion as an alternative powertrain technology for city buses. It has been also employed to conduct structural analysis of established sectors that are involved in the development of electric bus systems as an emerging sector in Europe.

The application of the two analytical approaches have resulted in the four papers appended to this thesis. Table 8 summarizes the two analytical approaches and how they have been employed in this this thesis by mapping with the appended papersⁱ.

Table 8. Analytical approach and mapping of the papers

Analytical approach	Paper–I	Paper–II	Paper–III	Paper–IV
Process approach	Process approach is employed to capture co-evolutionary interactions and developments in the established sector over two decades	N/A	Process approach is employed to trace niche developments related to electric bus systems over a period of 10 years	N/A
Variance approach	N/A	Variance approach is employed for structural analysis of actors and their strategies on electric propulsion for city bus applications	N/A	Variance approach is employed for structural analysis of established sectors involved in the emergence of electric bus systems as an emerging sector

ⁱ A summary of each paper is provided in Chapter 4 and the full text is appended at the end of this thesis.

3.7 Methodological reflections

Assessment criteria for qualitative research

There is a continuous debate whether quantitative measures, such as validity and reliability are equally applicable to qualitative research. Some scholars have extended this debate to the realm of ‘positivistic’ inquiry and have posed a more fundamental question whether there is an ‘objective’ reality in social systems to which such measures could be universally applied (Berger and Luckmann, 1967). However, the debate over positivism, interpretivism, or social constructivism does not necessarily refrain qualitative researchers to conduct good research. This has resulted in endeavors by methodology scholars to provide alternative measures that are more applicable in qualitative research. For instance, Lincoln and Guba (1985) suggested ‘trustworthiness’ for assessing goodness of qualitative research. Their framework consists of four criteria including *credibility*, *transferability*, *dependability*, and *confirmability*, which correspond to the subsequent criteria in quantitative research (*i.e.*, *internal validity*, *external validity*, *reliability*, and *objectivity*). The following table introduces these criteria for trustworthiness in qualitative research together with definitions and remarks.

Table 9. Criteria for assessing qualitative research (trustworthiness) based on Lincoln and Guba (1985)

Trustworthiness in qualitative research	Definition and remarks
Credibility «internal validity»	Confidence in the truth of the study <i>i.e. whether it studies what it is supposed to study</i>
Transferability «external validity»	Applicability of the study results <i>i.e. whether the results are useful or applicable elsewhere</i>
Dependability «reliability»	Consistency of the study <i>i.e. whether there is a consistent and traceable logic in methodology</i>
Confirmability «objectivity»	Objectivity of the study <i>i.e. whether there is neutrality in the analysis and conclusions</i>

The text in «punctuation marks» refer to the corresponding measures for assessing quantitative research

The table provides the four dimensions or criteria for trustworthiness in qualitative research introduced by Lincoln and Guba (1985). In the next section, these criteria will be applied to this thesis in order to make some reflections and self-assessment of the research quality.

Trustworthiness of the research

Adopting Lincoln and Guba (1985)’s definition for trustworthiness in qualitative research, the following criteria are elaborated on in details and the conditions to meet each of the four criteria will be explained in relation to this thesis.

Credibility

Lincoln and Guba (1985) placed emphasis on credibility as an important measure to ensure that the research indeed studies what it is supposed to study in the first place. They introduced several techniques ranging from triangulation and peer debriefing to early familiarization and prolonged engagement in the field in order to ensure the credibility of qualitative studies. Another important aspect of credibility relates to the perspective of participants in the research and whether they can find it relevant. This research has benefitted from a number of feedback channels, such as focus group meetings and their feedbacks as well as regular meetings, peer-debriefing and review processes. In particular, the research commenced with early familiarization of the field through direct or participant observations during both phases and then continued with regular presentation of findings in different feedback settings, such as conferences, internal review sessions, Brown Bag meetings at our division (PIE), as well as monthly reports and supervisory feedback sessions—thus exposing the researcher to external assessments and feedback. These are different feedback channels that helped the researcher to reflect upon the direction of the research along the way. Table 10 summarizes these measures as follows:

Table 10. Credibility measures for trustworthiness of the research

Credibility measures	Means to achieve credibility
Early familiarization with the field of study	Writing up a research proposal subject to evaluation, receiving feedback and discussions on possible avenues and research questions before embarking on PhD studies. Studying the existing literature and available theories before entering the empirical field. Mapping out industry characteristics, main actors, existing technologies, influential networks. Studying technical manuals and engineering data; participation in professional networks: <ul style="list-style-type: none">• STUDY-I: study of diesel engine public knowledge and emissions treatment technologies; attending established industry networks, such as GERPISA, IAA, FFI, HVTT• STUDY-II: study of alternative propulsion technologies for heavy vehicles such as battery electric/hybrid-electric technologies; membership in industry PhD networks, such as the Swedish electromobility center; attending industry networks, such as UITP, BusWorld, Automotive Megatrends, etc.
Prolonged engagement in the field	PhD student has been engaged in the field for more than 6 years Study of sectoral evolution over time (through the process analysis approach) Employing direct and participant observation methods in the field
Peer-debriefing & Member-checking	Internal presentations, supervisory sessions, monthly reports Doctoral colloquiums, PhD conference presentations Development of field observation audit trails such as publicly available empirical reports Presentations and feedback in established industry networks and focus group meetings

Transferability

The degree to which the findings can be generalized (i.e., transferred) to other studies in qualitative research is highly dependent on the context to which the study findings are going to be applied. The closer or more compatible the study settings are, the more the research findings might be applicable or transferrable between them. It is important to note that, in qualitative research, transferability is primarily the responsibility of the one who is generalizing the study results, but it is also the duty of the researcher to provide adequate details about the original context in order to facilitate the transfer of the study results. This is why methodology scholars often advise thick descriptions of the empirical settings and clarification of the context in qualitative research (Stake, 2005). To improve transferability, several measures have been adopted including the description of the context in the empirical reports as well as description of the sources of empirical data and how the empirical data was obtained. Another important aspect of increasing transferability was to explain the assumptions and theoretical basis of the analysis, so that other researchers would be able to make an evaluation of whether the study results are transferrable to similar conditions or to other research contexts. This also includes Section 1.3 with the justification on the choices of theoretical framework that are used as the basis for theoretical assumptions and the analysis of empirical results. Nevertheless, it is still advisable to successive researchers to carefully examine contextual factors across both fields in order to ensure the transferability of study results between the source and destination. Table 11 summarizes the measures for improving transferability of the research findings:

Table 11. Transferability measures for trustworthiness of the research

Transferability measures	Means to achieve transferability
Clarification of the context	Laying out the context of the two research studies (Section 3.1) and the prevailing assumptions about the scope of research (Section 3.2) Identification of the established sector and its sectoral elements (Paper-I) Identification of the emerging sector and its features (Paper-IV)
Thick descriptions	Description of the theoretical assumptions of the research Laying out the study context in the empirical reports and published papers
Note on transferability of study results	Study of transformations in industrial sectors is broad enough to encourage other researchers in their attempt to transfer findings to other empirical settings in the future. However before such generalizations can be made, it is advisable that researchers first study the contextual factors prevailing in those fields and their adaptability to the main assumptions (both theoretical and empirical) in this study. This may include the analysis of actors' constellations, institutional settings, and sectoral dynamics in both fields.

Dependability

An important aspect of assessing dependability in qualitative research is the consistency of measures and the ability to trace the logic of the analysis, so that if the study is replicated, the same results would be obtained. However, there is an important point that should be noted when conducting research in social science disciplines. The point is that, conducting research about social systems (or sociotechnical systems in the context of this research) often involves the study of human agents or human-devised structures (such as networks of actors, organizations, and institutions) and their reciprocal interactions that are dynamic, but not stable over time. Therefore, it is not possible to measure the same social phenomenon exactly twice due to evolving nature of social systems (Marshall and Rossman, 2010). Another reason is that our understanding of social systems also evolves over time; therefore, our perceptions of the research findings are subject to change at different points in time. However, in order to minimize misconceptions, it is possible to report on how the research was conducted the presumptions made, and the intentions behind the research design as well as operational details of data collection to demonstrate if the study methods were consistent. Dependability can be also improved through ‘overlapping methods’ such as diversity in the sources of data (triangulation) and the use of different methods for empirical data collection (Lincoln and Guba, 1985). Table 12 summarizes measures to improve dependability in this research.

Table 12. Dependability measures for trustworthiness of the research

Dependability measures	Means to achieve dependability
Description of data collection and analysis	Description of the research design (Section 3.3) and the design of inquiry (Section 3.4) Elaborations on the sources of empirical data and the process of data collection (Section 3.5) Theoretical explanations on the analytical approach (Section 3.6) Description of the synthesis between theoretical constructs, data collection strategies, as well as data processing and analysis
Triangulation and the use of various data collection methods	Archival data (annual reports) and corporate announcements, policy documents, consulting reports, public statements by industry associations or joint announcement of companies, as well as news and online media sources Dedicated and ad-hoc (spontaneous) interviews with senior executives and middle managers Field visits including direct and participant observations Online and digital sources
Clarifications on changes during the study	Explaining changes that occurred during the research and the process of publication for research papers (see Section 4.2)

Confirmability

The aim with confirmability is to ensure that the study is not subject to personal bias or misjudgment of the researcher in the analysis and conclusions of the study. It is the degree to which the study results can be confirmed or corroborated by others. There are several measures to improve confirmability, such as the use of established theories that are widely accepted and can guide the researcher throughout the study, so that personal bias is reduced. Nevertheless, the use of theories may also carry the risk of presumptions that are often shared or shaped at the research community level. Thus, the researchers must be also critical to the established theories of the field at the same time. Peer examination, external reviews and development of *audit trails* and sharing them with other scholars within or outside the community are other ways of enhancing confirmability (Schwandt and Halpern, 1988; Malterud, 2001). This study has benefitted from a range of measures including the use of theory (theoretical constructs) as the main guide throughout the study, while trying to stay critical to the established assumptions in the field and the use of triangulation in methods and empirical sources to increase diversity. Publishing the results, public presentations, and exposing oneself to external feedback and trying to be transparent in the procedures of research were also important measures for enhancing confirmability. Table 13 summarizes these measures as follows:

Table 13. Confirmability measures for trustworthiness of the research

Confirmability measures	Means to achieve confirmability
Theory-driven research	Literature review before entering the field PhD courses and research training related to innovation and knowledge integration, transition theories, systems of innovation, and qualitative methods, etc. (see Appendix 5) Development of theoretical constructs that shaped the research questions and the overarching structure of the two research studies (Section 2.4) Theoretically informed design of inquiry and choices of case study design (Section 3.4) Theoretically informed empirical data collection and analytical approach (Section 3.6)
Peer-debriefing & Member-checking	Internal presentations, supervisory sessions, monthly reports (see Section 4.2 for elaborations) Doctoral colloquiums and PhD conference presentations (see the list of conference papers) Development of field observation audit trails, such as publicly available empirical reports Presentations and feedback in established industry networks and focus group meetings
Triangulations	Diversity in empirical data collection, i.e., document analysis, interviews, field visits, etc. Use of both primary and secondary sources of data Using documents from public and private institutions, consulting firms, industry white papers, etc. (Section 3.5)
Measures to enhance transparency	Clarifications on the presumptions in the study (Section 1.3, 3.2) Clarifications on methods and analytical assumptions (Section 3.3, 3.6) Clarifications on the process of publication and authorship (Section 4.2) Monthly progress reports on the status of the research project, including literature reviews, empirical data collection and analysis as well as teaching and learning activities during the PhD education

CHAPTER 4.

RESEARCH FINDINGS

This chapter presents a summary of the empirical findings that are reflected in the appended papers. The papers are already published or in the process of publication as peer-reviewed articles in scientific journals. The full manuscripts of the papers can be found at the end of this thesis.

The chapter starts summary of empirical data and research findings from the appended papers and then goes on to explain more details on the process of writing and publication as well as authorship for each paper. The chapter will be concluded with a summary of the research findings.

This chapter consists of three main sections as follows:

- 4.1. Findings from the appended papers
- 4.2. Authorship and the process of publication
- 4.3. Summary of the research findings

4.1 Findings from the appended papers

This section provides a summary of research findings from the appended papers. These findings are published in the form of peer-reviewed articles in scientific journals or in the process of publication (Paper–IV). The full manuscripts of the papers can be found in the concluding part of this thesis as they appeared in journals. This chapter provides a summary and synthesis of research findings from the papers.

Paper–I: Institutionalization of Environmental Innovation

The first paper is an attempt to understand transformations in established sectors. Considering the stringent environmental requirements for modern heavy-duty vehicles (HDVs), the paper aimed to explain processes that led to the introduction and implementation of emissions standards for HDVs in Europe. The paper used sectoral systems of innovation as the main theoretical framework to identify ‘building blocks’ and the analysis of sectoral evolution in response to emission standards over the past two decades (1992–2012). It should be noted that the extent of empirical data covered even further period of time, going as far back as the late 1970s. But for the sake of consistency in the empirical setting those data have been used as background to the pre-developments prior to the introduction of the Euro emission standard in this sector. This is explained more in details in the *pre-development era* in the following paragraphs.

The paper took a *process approach* (Poole & Van de Ven, 2000; Van De Ven & Poole, 1990) in order to understand development processes related to the adoption of Euro standard for HDVs. Time is a very important aspect in this regard because changes and transformations of sectoral systems are the result of co-evolutionary interactions among the building blocks over the course of time (Malerba, 2005). The paper presents a retrospective analysis of sectoral elements and their co-evolutionary interactions which gradually led to the current state in this sector. Due to the historical nature of the inquiry, an archival study was employed that involved collecting empirical data about important developmental processes that took place during the period when the first Euro standard came into force (1992), until the introduction of Euro-VI standard (2012) which currently demands 95% reduction of nitrogen oxides (NO_x) and 97% reduction in particulate matters (PMs). The archival data collection also covered background information about prior developments and the processes that eventually led to the introduction of harmonized emissions standards in Europe (1970s-1990s).

The institutionalization of Euro emissions standard and the subsequent responses by the actors were investigated through the documents and archives in the European commission portals, industry reports, as well as interviews with managers from major European OEMs and through participation in European policy-making and industry summits such as ACEA and EU policy meetings and expert panels in EU premises in Brussels.

Development of sectoral knowledge and advancement of emission treatment technologies were collected through technical reports and documentation from technology-developing firms and suppliers as well as observations at key exhibition events, such as IAA Commercial Vehicles,

field visits, and interviews with representatives from HDV manufacturers. The co-evolutionary account of interactions among sectoral elements were taken into consideration through the lens of retrospective analysis (i.e., reflections on the course of development of the past events) throughout the study.

To trace actors and networks, activities of five major European HDV manufacturers (incumbents) were taken into account: Daimler, Volvo, Renault, MAN, and Scania. Taken together, these incumbent firms represent around 70% of the entire European HDV market. R&D investments and technological advancements related to emissions treatment technologies were reflected in the annual reports of these companies, and it was considered a good proximity to their investments in response to environmental regulations. At some point, when the stringency of standards started to take off, some of these firms initiated new lines of investment on emission treatment technologies and even specified annual reports dedicated to the issues related to environmental regulation.

The study showed that the more stringent emission standards, the wider the scope of integration in terms of knowledge and technologies to meet the environmental requirements. For instance, requirements for the earlier versions of the Euro standard could be simply met through adjustments and sometimes adoption of auxiliary technologies at the engine level (such as exhaust gas recirculation-EGR). However, with the increasing demands, HDV manufacturers had to seek additional emissions reduction solutions outside the traditional scope of the engine, including exhaust gas after-treatment technologies (such as selective catalytic reduction-SCR). Meanwhile, additional fuel savings and performance efficiencies were sought by extending the scope of improvement from powertrains and transmissions to body modifications to further enhance vehicles.

Based on these findings, a process model consisting of four stages of development was suggested in this paper. The process mapped out transformation of sectoral elements through co-evolutionary interactions over time represented as the following eras of development:

1) Pre-development era (1970-1992)

This phase was mostly characterized with fragmented efforts through local legislations and uncoordinated actions throughout Europe. In the beginning, there were no harmonized regulations regarding environmental pollution and occasionally HDV manufacturers needed to adapt themselves to certain requirements in different markets. Later in this phase, efforts were made to introduce harmonized regulations in Europe thanks to prior developments in the other members of the automotive '*triad*' (i.e. US and Japan), but still requirements were too low to make any particular challenge for HDV manufacturers.

2) Era of formation (1992-2000)

Earlier efforts during the previous stage and the formation of a single European market eventually materialized in this phase and resulted in the formation of harmonized regulatory institutions at the EU level and the introduction of Euro emission standards that demanded equal environmental performance requirements across all EU states. Meanwhile, new test methods were introduced,

and certification became mandatory in order to access the EU market. In the meantime, different types of industry trade associations and coordinating networks started to form, and collaborations among incumbent actors increased. In terms of technology, the EGR solution and advanced fuel injection systems were partly adopted while requirements for the diesel fuel quality increased.

3) *Era of stringency (2000-2008)*

This era was most characterized with technology-forcing requirements that demanded substantial reductions in exhaust gas emissions. This resulted in increased R&D investments in emission treatment technologies and further integration of electronic control units, as well as catalytic solutions into the advanced diesel engine. The incremental step-wise approach in reducing emissions resulted in the prospects of continuous improvements and raised expectations among actors to be prepared for further stringent requirements. Another feature of this era was consolidation efforts by vehicle manufacturers (i.e. incumbents) to increase economies of scale and the introduction of common engine platforms by developing family engines that could be shared among a large number of products in order to overcome the increasing costs of emission treatment technologies in this sector.

4) *Era of realization (2008-date)*

The era of realization entails the most stringent environmental requirements ever demanded in this sector, to the extent that many actors have admitted that they could not believe high demanding requirements to realize in such a short period of time if they were told this 10-15 years agoⁱ. Some new technologies, such as extreme pressure injection (XPI) are highly integrated with emission treatment technologies in order to comply with the tough requirements of the new standard. The Euro-VI standard have become the emblem for clean and environmentally enhanced vehicles not only in Europe but also elsewhere in Western Asia, in the Middle East, and in Oceania. Moreover, the EU standard has become closer to that of the US and Japan with the vision to aim for worldwide harmonization of emissions standardsⁱⁱ.

Furthermore, advanced test and certification procedures have been developed to ensure regulatory compliance during operations and real-time performance measurement tools such as on-board diagnostic (OBD) that have been integrated into the criteria for the type approval of new vehicles.

ⁱ This was an anecdote from the interview with the former CEO of Volvo Group.

ⁱⁱ There are still differences among the triad with regards to the implementation of standards, compliance test regimes, as well as local emission standard requirements, especially among the light trucks and passenger cars (DG Internal Policies, 2016). But with the introduction of Euro-VI, the aim was to get one step closer to the worldwide harmonization of emission standards for heavy duty vehicles.

The empirical findings from the paper suggest that, while emission standards have provided the force and context for sectoral evolution, the role of incumbent actors have also been instrumental in advancing emission treatment solutions and coordinating technological renewal in this sector.

Therefore, the paper concludes with a proposition that contrasts the classic perspective about incumbents' response to the increasing threats of new technologies or what is known as the *sailing-ship effect* in transition theories (Geels, 2002). The reason is that, regime response, or in this case the European HDVs sector, was not threatened by any substituting powertrain technology during transformation over the past few decades. Of course, there were regulatory pressures, but there was no threat of substitution from the niche level. This is in contrast to the private vehicles market where the threats of electric cars and alternative propulsion technologies are way more fierce and advanced (Dijk, 2014).

Heavy duty vehicles (i.e. trucks and trailers) are still primarily dominated by the presence of diesel engine technology due to understandable customer requirements for power, uptime, and reliability (specially in long-haul heavy goods transport). The dominance of incumbent firms in this sector and their coordinated actions for endogenous transformation of the sociotechnical regime through adaptation and innovation were spelled outⁱ. This was considered as a case of institutionalization of environmental innovation which is due to the high adaptive capacity of the regime (sector) to enhance environmental performance.

ⁱ The highly coordinated actions among incumbent actors may have also contributed to certain negative impacts such as colluding strategies for vehicle pricing, the timing of market introduction, and passing on the costs for complying emissions standards to their customers. However, it should be noted that according to the investigations, there was no evidence of avoiding or manipulating the compliance with emission standards but rather on transferring the costs to customers by coordinating prices at the gross level (European Commission, 2016). This problem is already acknowledged in the formulation of the research purpose with regards to the possibility of wrong doing by incumbents –or any other actors for that matter (see the footnote in Section 1.2). Unfortunately, these revelations came too late to the knowledge of the researcher since the article had already been published by that time; otherwise it would have been addressed. Nevertheless, the enormous financial amount of the penalties enforced by EU authorities in this case and the severe damage to the reputation of those incumbents are expected to prevent future incidences like this in the future. For more details visit: http://europa.eu/rapid/press-release_IP-16-2582_en.htm

Paper-II: Niche experiments with alternative powertrain technologies

The focus of this paper was particularly placed on a small segment within the European heavy commercial vehicles sector, where the possibilities of emerging alternative propulsion technologies are relatively higher. The city bus application is where the prospects of efficiency gains by recuperating energy from repeated stop-start operations, and concerns over local air pollution in urban areas—together with the aspirations of presenting a green image by public transport authorities—are reinforced in favor of alternative propulsion, such as hybrid/electric technologies¹. With regards to recent developments and the forecasts for further expansions in this market in the near future (P&S, 2017), this paper aimed for a better understanding of the situation and the role of actors involved by conducting an actor analysis in the emerging electric bus market in Europe.

Due to the changing environment and rapid entry/exit of different actors into this market during what is known as the *era of ferment* (Anderson and Tushman, 1990), the focus of the paper was on the structural analysis of the situation—at that time; therefore a *variance approach* was found to be more appropriate in this case (Poole & Van de Ven, 2000; Van De Ven & Poole, 1990). The focus is on the analysis of actors with regards to their position in the incumbent regime (i.e. established heavy commercial vehicles sector) or the emerging niche (i.e. hybrid/electric propulsion technologies). This is different from the process approach where the analysis of events or sequences of developmental processes are mainly concerned (such as in Paper-I). In this case, the theoretical constructs from the multilevel perspective (i.e. regime and niche) were useful because it allowed structural analysis of actors by identifying their roles in relation to their position in the sociotechnical system.

Empirical data was collected from activities of hybrid/electric bus manufacturers in their efforts for early market introduction in Europe. The emphasis on market introduction was an important aspect of selecting actors in this paper because internal R&D and prototyping *per se* do not represent technological readiness or maturity of a product; rather, market introduction or live demonstrations were considered as serious attempts for early market introduction in this study. To do so, primary empirical data were collected from different sources including field configuring events, field visits or direct observation of demonstration projects, and interviews. It was further complemented with secondary sources of data, such as publicly available info sheets and public announcements, media sources, and published research data in academic journals.

The structural analysis showed that a variety of actors both from the incumbent regime as well as new-comers are actively involved in this emerging niche market. The paper provided a classification of actors in the hybrid/electric niche market in three categories as follows:

¹ The term 'Hybrid/Electric' refers to a wide range of configurations from series to parallel and power-split as well as plugin-hybrid and battery-electric or full electric propulsion. However, the criteria for electrified vehicles in this paper included those with charging capability that represent a greater step away from combustion engines, i.e. plugin hybrids or fully electric buses.

1) *Integrated bus and truck manufacturers*

These are the classic incumbents producing heavy-duty vehicles (HDVs) that have been already studied in Paper-I. Examples of such incumbents are Volvo, Scania, and MAN. However, at the time of this study, only Volvo was actively present in the niche segment. As shown in Paper-I, these incumbents are very few in number with very powerful and influential roles and they make substantial R&D investments in the established sector. The main characteristic of this group of incumbents is that they have in-house capabilities of producing both body and powertrain. Therefore, they could benefit from economies of scale by common engine families and powertrain systems (based on diesel engine technology) shared between their bus and truck production lines. This could explain why many of them were reluctant to enter this emerging niche market at the time this study was done.

2) *Specialized bus manufacturers*

These incumbent firms are mostly traditional bus (body) manufactures in Europe some of which have more than 100 years of history in producing carriage vehicles and buses. Their specialty is in producing body, chassis and customized or made-to-order bus vehicles for different purposes. These actors range from very small local manufacturers to internationally operating manufacturers like VDL, Solaris and VanHool. Yet, what makes these incumbent actors different from the first group is that they do not produce their own powertrain but rather outsource it to special engine manufacturers, such as Deutz or Cummins, or they may even turn to the first group (integrated bus and truck manufacturers) to supply their powertrain. In either case, they have the option to choose what kind of propulsion system they want to use based on customer orders, or based on their own internal strategies.

3) *Newcomers*

The third group of actors are *newcomers*, which may consist of new technology-based firms (NTBFs), such as Ebusco (an academic spin-off from TU/Eindhoven Science Park) and Hybricon (a domestic electric bus manufacturer in the Northern city of Umeå in Sweden). Another group of newcomers consist of actors from outside Europe or even incumbents from other sectors entering this emerging niche. A clear example is BYD, which is a large conglomerate and an established battery producer from China with electric car and bus production lines recently added to its existing production facilities. The company entered into the European market with its K9 e-bus model. The main characteristic of this group of actors is that they solely focus on electric propulsion for their vehicles and have limited background in the established automotive regime.

The empirical data also showed that in contrast to Paper-I, where the potentials of substitution from niche technologies were marginal (due to technological limits and customer requirements for uptime, power, and reliability), here the possibilities of substituting diesel engine with hybrid/electric propulsion in city bus applications are much higher. The paper also challenged the normative perspective on actors and their perceived role in transition theories. It showed that, incumbents do not always act coordinately as a unified entity (as was the case in

Paper-I), but could sometimes act very differently as a heterogeneous group of actors who come in different sizes, with different capabilities, and a diverse range of interests or strategic alignments. It also challenged the dichotomy of incumbents as the guardians of the existing regime, versus newcomers as the representatives of novelty.

In particular, it was shown that contrary to the common understanding about the role of niche actors, the newcomers in this case favored *fit-and-conform* strategies, which meant that not only did they not challenge the established norms and practices of the existing regime, but also imitated them in order to gain access to the market. This was evident in the practice of BYD as a newcomer trying to mimic diesel bus operations by fitting electric buses with large amounts of batteries, even at expense of losing both energy efficiency and passenger capacity. This was to avoid the need for re-charging electric buses during the day, thus making sure that they do not impose any challenge to the established practices in public transport sector (such as scheduling, refueling, and depot management).

In contrast, it was incumbents who turned to *stretch-and-transform* strategies by demanding adaptation of existing practices and established technologies (i.e. instigating changes in the existing infrastructure) in favor of niche criteria. This can be explained by the fact that newcomers often suffer from a lack of resources, legitimacy, and access to established market channels, and in that sense, they bear the liability, which limits their capacity to challenge the existing regime. While in contrast, incumbents had the courage to challenge the status quo by offering radical new solutions. This was clear in the case of Volvo offering a fast-charged solution, which entailed greater challenges in urban planning, charging infrastructure as well as re-scheduling for bus operations.

The analysis also suggests that incumbents could be active at both regime and niche levels simultaneously, and in this way, they can act as a catalyst to facilitate interactions between the two levels. In this capacity, incumbents are also able to act as translators who can transfer (i.e., translate) knowledge and experiences between regime and niche levels. But how can they do that? This is the question that will be answered in the next paper, which specifically deals with the processes of transferring knowledge and experience by unfolding niche aggregation activities in different projects across time and space.

Paper-III: Niche aggregation through cumulative learning

As explained earlier in the theoretical framework (Chapter 2), one of the main concerns of the SNM literature is how to bring niche innovations from a state of demonstration to the commercial stage, as innovations are often limited by the isolating nature of protective space (Hoogma et al., 2002). The SNM 2.0 literature in particular emphasizes cyclical patterns of learning and aggregation to facilitate global-niche formation (Geels and Raven, 2006; Geels and Deuten, 2006). This paper was an attempt to find an answer to the question of how learning processes support niche aggregation. The paper studied niche projects with electric bus demonstrations in several places in Europe and in doing so brings together strategic niche management and theoretical concepts derived from literature on learning in project-based organizations.

A review of the existing literature in project management and project-based organizations showed that niches have many similar characteristics with projects. These similarities can be summarized in four main categories: *purposefulness*, *uniqueness*, *temporarily*, and the need for *resources*. The literature review in particular showed that, like niches, projects have also suffered from the negative effects of temporality and isolation. The literature review also pointed out differences in the processes of *knowledge sharing* versus *knowledge accumulation*, where the former focuses on inter-organizational knowledge transfer, and the latter emphasizes processes of accumulating and preserving knowledge within an organization. Finally, the literature review on project-based organizing resulted in a theoretical model on how to understand projects in their context by linking local niche projects across time and space (see Figure 15). This model was then applied to the empirical findings in order to trace linkages among multiple niche projects in the study.

Figure 15. Niche projects and contextual parameter across time and space
Source: Author's drawing based on Engwall (2003)

The empirical data for this paper was collected from niche demonstration projects with fast-charged electric buses from five different cities: *Umeå*, *Helsinki*, *Copenhagen*, *Gothenburg*, and *Stockholm*. Additional data was collected from another project in *Hamburg* to better understand linkages and the niche aggregation process for this emerging niche in Europe.

The reason to focus on fast-charged electric buses is that it entails greater challenges to the established practices of the existing regime. Empirical data regarding the demonstration projects and their local contexts were collected through field studies and interviews with key project members and stakeholders. Other sources of data included secondary sources, such as reports on project results, policy documents and press releases about the projects.

Similar to Paper-I, a process approach was adopted in this paper in order to explain aggregation and learning processes across local niche projects over time. The difference, however, is that Paper-I involved retrospective analysis of past events through the study of archival sources, while in this paper, the process mostly involved collecting contemporary and in some cases real-time data about concurrent projects.

Each case was described separately and background information was provided about niche projects and their connections to the past, present and ideas about the future. The case description starts in 2010 with a local initiative in the small city of Umeå in northern Sweden, where the earlier entrepreneurial experiments with electric vehicles for public services by *Hybricon* led to the first purchase order from the municipality to produce electric buses for local transportation. One of the main reasons for electrification was local air pollution due to diesel smog in the city center and in particular the inversion effect during cold winters. *Hybricon* joined forces with another entrepreneurial company from Spain called *Opbrid*, and they came up with an innovative solution for fast-charged electric buses using pantographs, a rather old and established technology from the rail transport industry. The borrowed solution from the rail industry was adapted to this new application, and they started running electric buses already in 2011. Upon promising results from the first project, *Hybricon* received additional orders from the municipality, but later ran into cash liquidity problems and the Umeå municipal company (UKF) finally decided to bailout *Hybricon* in March 2013. Upon survival from the crisis, the company started over in July 2013 under a new board and management team.

Meanwhile, a local test project for electric buses was initiated in Gothenburg, where Volvo, together with *Opbrid*, advanced the same concept that was tested earlier in Umeå. The project ran from 2013 to 2014 on Line #60. Based on learning and experiences from that project, Volvo entered into a collaboration project with Siemens and came up with a proof concept for fast-charged electric buses using the inverted-pantograph that was implemented in Innovation Line #109 in Hamburg, which started operation in early 2015. Later that year, Volvo and Siemens brought the same concept back to Sweden, where the fast charging by the inverted-pantograph was adopted to the ZeEUS project in Stockholm and then in the *ElectriCity* project in Gothenburg. This solution became part of daily operations across three cities as a result of collaborations between Volvo and Siemens. Consequently, successful results from test and demonstration projects in Hamburg, Stockholm, and Gothenburg led Volvo, Siemens and ABB to initiate an open platform for fast-charging technology using the inverted-pantograph called *OppCharge*, which could be shared by different types of commercial vehicles regardless of manufacturer, brand or operator. Later, other actors also joined the platform including companies from automotive, power equipment, energy, and public transport sector.

Meanwhile, there were test and simulation efforts as part of the Electric Commercial Vehicles (ECV) program sponsored by the Finnish innovation agency (Tekes) and coordinated by technical research center of Finland (VTT) since 2011. These efforts resulted in the emergence of a new technology-based company called *Linkker*, which similarly to Hybricon, received the first purchase order for fast-charged electric buses from public transport authority in Helsinki. The ECV pre-commercial phase started in late 2015 and later led to additional orders in the commercial phase. In 2016, Linkker was able to secure its place in tendering process for electric buses to be operated on Line #3 in Copenhagen, which previously had tested slow-charged BYD buses but later decided to run fast-charged electric buses instead.

The paper showed important linkages among the niche projects by applying the ‘time-space’ theoretical model in the analysis. Using this model, we could visualize connections among local niche projects and describe how the aggregation process looks like in the making. Figure 16 illustrates these linkages across time and space among the niche projects.

Figure 16. fast-charged electric bus systems in five cities (continuous lines) and linkages between projects involving critical actors (hatched arrows)

An important finding of the study is the role of incumbents in transcending local knowledge by first absorbing lessons learned internally and then taking those lessons with them elsewhere.

In that role, incumbents can act as knowledge repositories or learning agents by internalizing knowledge and experiences in their established routines and organizational processes (Nelson and Winter, 1982, 1993, 2002).

This is an important aspect in niche aggregation process that had been overlooked in transition theories, but it was highlighted in this paper. By adding an organizational perspective to the existing literature on strategic niche management, the paper was able to point out a crucial point in the niche aggregation process by differentiating between knowledge sharing that takes place externally (between organizations), and knowledge accumulation that takes place internally (within organizations).

The process of knowledge accumulation enables the firm to absorb knowledge and experiences from isolated and temporary niche projects and preserve them into its internal routines, which then can be deployed to other niche projects elsewhere. This mechanism facilitates the absorption of lessons learned from protective spaces so that niches can be built upon previous experiences.

The process of knowledge sharing is in contrast geared towards the (external) transferring of those lessons learned from one organization to another. Nevertheless, it is argued that both mechanisms are necessary and the niche aggregation is a cyclical process that depends on both knowledge accumulation and knowledge sharing which are mutually reinforcing.

The paper also shows that incumbents can be active both at regime and niche levels simultaneously, and they can work side-by-side other actors, whether incumbents or newcomers. In this way, incumbents can use their resources and legitimacy to facilitate diffusion of niche technological innovations to the established markets using their knowledge and experiences.

Paper-IV: Isolated or integrative learning?

This paper is in the process of publication—revised version submitted 15 June 2018

As explained in the previous paper, electromobility is emerging as an alternative solution to the century-old combustion engine, and it is evident in city bus applications today that electrification is beneficial due to (nearly) zero-emission air pollution, lowered noise in urban areas, as well as higher energy efficiency in frequent stop-start driving cycles due to regenerative braking. The previous paper analyzed the process of niche aggregation for fast charged electric buses in Europe over the recent decade and identified two important learning processes as the key mechanisms that are mutually reinforcing: knowledge sharing (inter-organizational) and knowledge accumulation (intra-organizational).

This paper takes it one step further and focuses on learning at the system level. The reason is that the shift towards electromobility opens up new possibilities and challenges that are radically different from the existing ones. That is, while electromobility changes the overarching principles of the motor vehicles, it may also require a chain of transformations in other established sectors. Based on the study of the emerging electric bus sector in Europe, the purpose of this paper is to analyze the implications of different technology configurations on learning processes at the system level, involving interactions among several established sectors, including public transport; automotive and vehicle production; energy; and power automation systems. To provide structural analysis of the emerging sector, the paper takes a variance approach (Poole & Van de Ven, 2000; Van De Ven & Poole, 1990) and using innovation systems as the theoretical lens, the paper seeks an answer to the following research question: How can the involvement of established sectors facilitate learning processes in an emerging sector?

The paper provides a theoretical review on system-level learning from the crossroads of existing literature in systems of innovation, systems interactions and knowledge integration. It starts with an important reminder from Lundvall (2010), who identified two grounding assumptions in systems of innovation: 1) the most fundamental resource in learning economy is knowledge and accordingly learning is the key process to create new knowledge; and 2) learning is predominantly an interactive process. This interactive process is at the heart of the innovation system literature (Hekkert et al., 2007; Negro et al., 2007; Bergek et al., 2008).

Thereafter, the paper identifies three main building blocks of innovation systems that are commonly conceded among different scholars in this field i.e.: 1) technologies, 2) actors and networks, 3) institutions. These building blocks are similar to that of Malerba (2004, p.18), which was explained in Chapter 2 in this thesis (see Section 2.1). These building blocks reciprocate through evolutionary learning processes. The paper then highlights knowledge development as a critical learning process in systems of innovation literature (Bergek et al., 2008). It elaborates that the knowledge development function includes learning processes (internal to the system), which are demarcated by technical structures and institutions that create boundary conditions that the innovation systems need to adapt to (Stankiewicz and Carlsson, 1991).

However, what is often neglected is that sociotechnical transitions are the result of multi-system interactions, but not merely internal learning processes (Geels, 2007a; Raven, 2007; Raven and Verbong, 2007; Konrad et al., 2008; Smith et al., 2010). The literature review in the paper suggests that this negligence is perhaps due to the inward focus and the dominating single-system approach that often overlooks external dynamics and parallel contingencies in other sociotechnical systems (Markard and Truffer, 2008, p. 610). Recent empirical findings have shown evidence of linkages across systems and highlighted the importance of multi-system interactions in emerging fields, such as the electromobility (Haley, 2015; Stephan et al., 2017). Based on the review of the previous literature, the paper argues that the interaction between established sectoral systems may give rise to innovation and emergence of new sectors. This is in line with Malerba's hypothesis about the emergence of new sectoral systems as the result of interactions among the established sectors (Malerba, 2002, p. 258). Accordingly, the paper takes in the argument from Konrad et al. (2008) that multi-system interactions may facilitate transformations of utility sectors, such as electricity, gas, water, and telecommunications. This is similar to Raven (2007) who showed how the co-evolution of waste management and electric power systems facilitated the emergence of organic waste as an alternative source of energy in the established energy sector as well as Raven and Verbong (2007), who described how the integration of previously separated systems for heat and power have made it possible to gain efficiency through combined heat and power. These examples demonstrate that there are structural couplings where incumbent firms engage in new innovation systems to develop and commercialize novel technologies, while retaining their position in established sectoral systems (Elzen et al., 2012; Berggren et al., 2015; Steen & Weaver, 2017; Apajalahti et al., 2018; Heiskanen et al., 2018).

To explain this phenomenon, the paper uses the concept of knowledge integration to describe a critical learning process that entails capabilities to combine differentiated knowledge from various disciplines that can be effectively integrated into properly functioning systems (Berggren et al., 2013). Knowledge integration is mainly driven by the increasing specialization and division of labor (i.e. expertise) in the era of post-industrialization (Tell et al., 2016). Modern sociotechnical systems have become increasingly complex containing sub-systems and technologies from various specialized fields; hence, the process of knowledge integration has become particularly important, as it primarily deals with the coordination of immaterial resources (i.e., specialized knowledge) across different disciplines (Hobday, 1998; Prencipe, 2000; Stefano Brusoni et al., 2001; Hobday et al., 2005). It also entails combining the structural building blocks of established sectors in new ways and thus stretching the boundaries of an emerging innovation system to transform established sectors. This is similar to what Smith and Raven (2012) theorized as the process of *stretch-and-transform* among the empowering strategies for niches.

To put those theories into practice, the paper then brings in empirical data on the development of electric bus systems as an emerging sector in Europe. It analyzes the implications of different architectural configurations on learning processes at the system level. Unlike the previous paper, this paper considers both fast-charged and slow-charged electric bus solutions and the corresponding technological pathways that each of the two choices provide in terms of knowledge and learning scenarios. The primary sources of empirical data for this paper have been collected through participant observations during the focus group meetings in the *Miljöbuss* project.

As mentioned earlier, *Miljöbuss* is a collaborative research project that investigated possibilities for implementation of electric buses. In connection to the research project, a focus group was formed that aimed to hear voices of different local organizations involved in possible electrification scenarios including public transport authorities (PTAs), municipal government agencies, local municipality-owned energy and electric utility, state-owned and internationally operating electric utility companies, truck and bus manufacturer representatives and two technical universities. In total, 24 hours of focus group meetings were conducted over eight sessions (8x3hrs) as well as a half-day scenario workshop where a broader range of representatives were invited to work on different public transport scenarios and discuss challenges and opportunities related to each (of the three) scenarios. In that way, the project meetings and the scenario workshop acted as arenas of development (Jørgensen, 2012; Jørgensen and Sørensen, 1999) where actors could meet and negotiate on different transition pathways regardless of their position in the structural levels of the sociotechnical system.

The empirical data from focus group meetings have also been complemented with direct observations at demonstration sites and project implementations in several other cities in Europe. Other sources of data included interviews with senior executives (providing the macro level visions and challenges), mid-level managers, project engineers and representatives involved in the daily works (providing the micro level visions and challenges) in order to have an overall picture of the emerging sector and its opportunities and challenges. These empirical data were then processed through structural analysis (*variance approach*) in order to provide implications of different configurational settings on processes of learning at the system level i.e., not describing the process itself, but analyzing structural implications. Hence, the paper is based on a structural analysis of different technology pathways rather than a process description of sequential events.

Taking the innovation system as the main theoretical framework, the paper then identifies building blocks of the emerging sector that are borrowed from the four established sectors: public transport, automotive, energy, and finally the power and automation equipment. The building blocks of the emerging sector and the corresponding elements that it has borrowed from the established sectors are summarized in Table 14 (next page).

Slow-charged versus fast-charged system configurations

The paper then analyzes different system configurations and the corresponding learning scenarios. Here, the differences between slow-charged and fast-charged electric bus solutions are elaborated and the opportunities and challenges for each scenario are identified. Where as the slow charging solution provides a quick fix and a rather easy to adopt alternative to the combustion engine, the fast-charging solution is found to be more challenging due to the required investments and changes in the existing infrastructure. The main reason is that, the slow-charged electric buses are equipped with large batteries and the over-night charging at the depot site does not require any changes to the existing operating schedules; hence, electric buses can run for the entire day without the need to recharge, which makes them less dependent on dedicated charging infrastructure. The slow charged solution also adopts the established interfaces such as the Combined Charging System (CCS/CCS2) standards already available for electric vehicles (cars).

Table 14. Building blocks of the emerging European electric bus sector

	Technologies	Actors & Networks	Institutions
Public transport sector	Computer-assisted simulation and optimization: vehicle fleet management and public transport service planning and operation	Public transport authorities Bus operators International association of public transport (UITP)	Vehicle standards and safety requirements Public procurement and tendering regulations Service availability requirements, cost and revenue structures Key performance indicators (KPIs)
Automotive sector	Vehicle structure and dynamics; design, configuration and manufacturing. Electric powertrain technologies including electric machines, power electronics, batteries and control systems	Integrated bus and truck manufacturers Specialized bus manufacturers Specialized electric bus manufacturers Component and sub-system suppliers European automobile manufacturers association (ACEA)	Standards, rules, regulations and routines pertaining to vehicle safety, dimensions, performance, reliability and maintenance
Energy sector (electricity)	Electric distribution grid planning, construction, configuration and load balancing	Distribution grid operators Electricity retailers Union of the Electricity Industry in Europe (Eurelectric) European Committee for Electro-technical Standardization (CENELEC)	Standards, rules, regulations, and routines to ensure grid stability and safety, grid access and connection, as well as competition on deregulated markets
Power and automation sector	Electric power, control and automation technologies Charging system development and manufacturing: conductive and inductive technologies	Manufacturers of charging systems Union of the Electricity Industry in Europe (Eurelectric) European Committee for Electro-technical Standardization (CENELEC)	Standards, rules, regulations, and routines pertaining to electric equipment safety, dimensions, performance, reliability and maintenance

The fast charging solution, on the other hand, adopts a different technology strategy by reducing the amount of batteries installed on the vehicles. The main reason is that the slow-charged solution ends up carrying batteries rather than people. Moreover, the high battery costs as well as the environmental impacts related to the energy-intensive processes of producing batteries from earth materials may result in a suboptimal solution for the slow-charged buses over the long run (Lajunen and Lipman, 2016). By comparison, in the case of the fast-charged system, the size and weight of the battery packs are reduced, resulting in potential efficiency gains and cost reductions. The downside however, is that this technological configuration requires frequent charging as well as changes in the existing operation schedules to allow for charging times during the day. Therefore, in order to shorten the charging time, power system manufacturers have introduced fast and ultra-fast charging systems by raising the power and automizing the charging procedure, which is generally known as ‘opportunity charging’. Thus, the adoption of fast charging requires development and installation of dedicated charging infrastructure and more integrative efforts among the established sectors for the sake of higher efficiency gains. For example, public transport authorities need to develop new tender and ownership procedures for the required investments in charging infrastructure, while operators need to change their established timetables and performance criteria to allow for frequent recharging and uptime, which in turn may require development of new business and revenue models that are more compatible with this particular choice of technology.

The paper shows that, these two technological configurations result in two different knowledge and learning outcomes at the system level. Whereas the slow charging solution is a quick fix that can immediately substitute the existing combustion engine technology, the fast charging solution rather takes extensive efforts for installation of charging infrastructure and integration among the established sectors to make it work. The fast charging solution also requires the established sectors to undertake necessary changes in existing technologies and prevailing norms and practices in order to adapt to the performance requirements of the emerging sector.

Isolated versus integrative learning

The analysis shows that the slow charging solution is analogous to the fit-and-conform strategy due to similarities with the prevailing practices in the combustion engine regime (i.e. established sector). That is, the slow-charged electric buses try to fit into the existing regime by conforming to the established performance criteria of diesel buses. The fast charging solution in contrast takes the stretch-and-transform strategy by introducing changes and necessary adaptations to the established sectors in favor of the niche performance criteria (i.e. the emerging sector). Moreover, the slow charging solution represents isolated learning where the knowledge and related learning processes are largely limited to the boundaries of the emerging sector, while the fast charging solution represents integrative learning where the boundaries of the emerging sector stretches beyond and requires changes in the structures of the established sectors involved. These two learning scenarios are illustrated in Figure 17 below:

Figure 17. Structural configuration of learning scenarios for the emerging electric bus sector
slow-charged i.e. *isolated learning* (left) versus fast-charged i.e. *integrative learning* (right)

The analysis also points to another important implication of the two system configurations in terms of knowledge and learning. The slow-charged configuration implies that learning is isolated to the emerging sector; hence the focus of actors is to understand how the electric bus system can operate within a framework defined by the existing boundary conditions and knowledge development is primarily focused within the emerging innovation system (Bergek et al., 2008; Hekkert et al., 2007).

By contrast, the fast-charged solution calls for reconfiguration of the established sectoral systems. This means that the established sectors will not only constitute a context for the electric bus innovation system—they will also constitute the very core of it. This is necessary to facilitate a process of knowledge integration, which combines differentiated but complementary fields of knowledge in new ways (Berggren et al., 2013; Tell et al., 2016).

The study results suggest that the cross-boundary knowledge integration of the fast-charged solution and the isolated knowledge development of the slow-charged solution present different scenarios for a further evolution of electric buses as an emerging sectoral system. While the conforming characteristic of the slow-charged system allows electric buses to quickly enter the market, the integrative characteristic of the fast-charging system makes it possible to transform the existing structures to create new inter-sectoral linkages (Konrad et al., 2008; Raven, 2007; Raven and Verbong, 2007; Smith and Raven, 2012).

In conclusion, the most important theoretical contribution of the paper was to make a distinction between the process of *knowledge development* versus *knowledge integration*. Whereas the former describes an interactive learning process primarily taking place within the emerging innovation system (i.e. isolated learning scenario), the latter is defined as cross-boundary integrative process that goes beyond the boundaries of the emerging innovation system and requires structural changes in the established sectors (i.e. integrative learning scenario).

4.2 Authorship and the process of publication

This section elaborates on the details of how different parts of the papers including empirical data and analysis were turned into manuscripts and then into full papers for publication. Each section starts with a brief paragraph on the authorship of each paper and then goes into details on the process of early formation of ideas to the final papers.

Paper-I

The first experience: a long journey from data collection to publication

As a PhD student in charge of my research, I was responsible for both theory development and empirical data collection. In some occasions, my supervisor also took part during field visits (such as the IAA motor show in Germany) and interviews with senior managers (such as meeting with the previous CEO of Volvo, Senior Vice President of Scania, or the Head of Public & Environmental at Volvo). But otherwise, the empirical data collection and analysis data were collected by myself. I was also responsible for the actual writing of the paper, but continuously discussed issues with my supervisor and received comments on how to improve the manuscript. During the analysis phase my supervisor was also involved to provide guidance. Following, the process of publication will be explained in details.

The initial idea for this paper was formed in conjunction with the research project on environmental innovation sponsored by the Lars Erik Lundberg Foundation for Research and Educationⁱ, which also financed my Licentiate degree research education between 2012-2015 (STUDY-I). The project aimed at investigating dynamics of innovation and emissions regulation for heavy commercial vehicles. A first step was to understand the basic industry settings and grasping an overall picture of major actors, institutional bodies and existing technologies as well as the past and present dynamics of the industry. This was done both through library search and empirical data collection starting from mid-2012, which often coincided and complemented each other. Meanwhile, I was also taking PhD courses in research methodology, theories of innovation, knowledge integration and technology management as well as other related fields as part of my research training activities (see Appendix 5). Library search covered previously published articles related to emissions regulation in the automotive industry as well as innovation studies related to policy and technology strategies related to heavy vehicles. The amount of material available from heavy commercial vehicles and the industry settings were more scarce than the rest of the automotive industry. Therefore, the library search process was complemented with empirical data gathered directly from the field. For instance, the visit to the IAA exhibition (International Motor Show) for commercial vehicles in September 2012 in Hanover-Germany provided the opportunity to get access to a vast number of commercial vehicle manufacturers and their suppliers all over Europe and beyond.

ⁱ <http://www.lundbergsstiftelserna.se>

Several interviews and field observations were conducted, contacts were made and several industry seminars in other parts of Europe were attended. On other occasions, industry policy summits and important events related to Euro emissions standard meetings were attended at the EU premises during 2012 and 2013.

Nevertheless, diversity of theories and the increasing amount of empirical data were getting out of hands and became very difficult to handle after a while. A wide range of theories were explored in the first stages of research. This included for instance, existing theories on innovation and technology management, industry dynamics, technology-forcing regulations, political economics and varieties of capitalism (VoC), institutional theory, actor-network theory (ANT), sociotechnical studies (STS), etc. Each of these theories could well describe some parts of the phenomenon, but the main problem was to find an integrative framework where different pieces of theory could be placed together to form a coherent and meaningful description of reality. It did not happen very early, and I struggled for the first 6–9 months of my PhD studies, jumping from one theory to another exploring different realms of the theoretical world.

But then good advice came from a senior colleague (Anna Bergek) during an internal presentation of my ongoing work in what was called *Brown-Bag* meetings at the division for Project Innovation and Entrepreneurship (PIE) in mid-2012, where I was introduced to the works of Malerba and his colleagues on sectoral systems of innovation. Almost immediately after the session I conducted a library search, and found some articles about SSI and upon reading them I realized that it was indeed the integrating framework I was looking for since the beginning. The main reason was that SSI contained some of the most important theoretical constructs that I needed in one place (i.e. actors & networks, knowledge & technologies, institutions) as well as the strength of explaining co-evolutionary interactions and sectoral transformations at the same time.

As soon as the theoretical framework was set, the process of data analysis started, which also structured the remaining processes of empirical data collection using the theoretical constructs mentioned above to form the first PhD paper. Due to the extensive length and scope of the paper in the beginning (ca 12,000 words), it went through several rounds of internal reviews and several modifications to condense it down to 7,500 words. The paper was initially targeted for publication in the special issue on Technology Strategy and Technology Policy in *Technovation* journal, which had a timely plan starting from early 2013 for the submission of abstracts followed by two rounds of revision and the submission of final manuscript due 31 July 2014 and final production in late 2014 or early 2015. In the first step, the abstract was submitted in January 2013 and upon review by the special issue guest editors we have been invited to send a full paper. In the next step the full manuscript was submitted in 15 August 2013 and it went through two rounds of reviews. But then the process got complicated and we did not hear anything from the guest editors until Chief Editor of the journal took over the process and the paper was finally rejected in July 2014 due to the lack of ‘a clear fit with the special issue’ and it was referred to an ‘Environmental, Transport or Policy Journal’ instead. Taking the Chief Editor’s advice, we later took the paper to the *International Journal of Automotive Technology and Management* where it went through another round of refereeing process by two different reviewers. Upon revision and re-submission, the paper was accepted in May 2015 and it was finally published in January 2016.

Paper-II

Student projects and field configuring events led to publishing the second paper

Similar to the first paper, I was responsible both for theory and empirical data collection in this paper. Like the previous paper, I was able to receive support from my supervisor in the analysis and the process of publication. He also took part in the actual writing of the paper, but I was mainly responsible for the complete manuscript as the corresponding author. In the following, it will be explained how the idea for this paper initiated and the journey it took until it was published.

The idea for this paper was formed after defending the Licentiate thesis in early 2015 and in connection with the new scope of study i.e. to focus on niche technological innovations with plugin hybrid/electric propulsion as alternative technologies to the dominant diesel powertrain in city bus applications (Study-II).

In the meantime, I was involved in supervising two master's students from Germany who were interested in carrying out their graduate research project (studienarbeit) related to the automotive industry with us. The first study had already started back in spring 2014 with an overview of the market development and technological advancements on electrified buses in Europe. The study in particular showed that, on the one hand, truck manufacturers were not generally interested in developments regarding electrification in the heavy commercial vehicles sector because they could not see any immediate application of this technology as a substitute for diesel engines back then. On the other hand, the entry barriers for new entrants were quite high especially with regards to the high prices of electric buses which would not be able to compete with diesel buses without substantial government subsidies or public funding that could pay off extra expenses (Förster, 2014).

A year after, in the spring semester of 2015, another student from Germany came to visit us in Linköping and carried out his student project in a similar context. In that study, the focus was on market developments of hybrid/electric buses in Germany and a follow up of the previous study to see how the market had developed since then. The study showed that, while the market had expanded mostly through public funding and government programs in Germany, it was still very much fragmented in terms of alternative propulsion technologies (Ludwig, 2015).

For instance, preliminary analysis from different cities showed that there were more varieties than similarities across different geographic locations in terms of hybrid/electric configurations as well as charging technologies and the related infrastructure and interfaces. Tracing back my notes in the monthly progress reports, several implications were found earlier in time which later shaped the foundations of Paper-II. Some of those reflections are listed below:

- ❖ *Learning experiences are difficult to be transferred between local projects*
- ❖ *Reaching economies of scale is difficult*
- ❖ *As the quantities are still low, prices would remain high and difficult to justified*
- ❖ *Producers still heavily rely on government subsidies for producing advanced technology vehicles and thus difficult to scale up*
- ❖ *The prolonged subsidies and yet high costs for advanced technology vehicles can turn into a vicious cycle. That is, low quantities result in higher costs, and higher prices would result into lower quantities and so on. However, the breaking point would be a sharp reduction in the price/performance ratio of any particular technological alternative or if influential actors such as governments or big OEMs show interest or express expectations about certain technologies.*

Excerpt from monthly progress reports to the supervisor (May, 2015)

Empirical findings from the student projects led to further investigation of the emerging market for electric buses in Europe. Later that year I conducted several field studies including visits to some of the world's largest events where niche technological innovations related to electric propulsion for city buses were presented such as the UITP World Congress & Exhibition in Milan-Italy (June 2015) and the Bus World exhibition in Kortrijk-Belgium (October 2015). It is worth mentioning that merely demonstration of new technologies *per se* was not considered as the ultimate indicator for the development or maturity of niches; because many of those prototypes still needed to pass the infamous 'valley of death' between R&D and the market (Schot and Geels, 2008). What was important to note in such events was the formation of shared understanding among actors about the future potentials of technological fields towards the creation of new markets or the emergence of new industries. This phenomenon is referred to as Field Configuring Events (FCEs) which is defined as "specific arrangements in which diverse range of actors come together and engage in intensive interactions and exchange of ideas and information over a short period of time" (Lampel and Meyer, 2008; Meyer et al., 2005). I came to know about the idea of FCEs through a published paper by another PhD student in the Netherlands who recently conducted a similar field study on the development of photovoltaic cells in India (Jolly and Raven, 2016).

During those field configuring events I had the opportunity to make valuable industry contacts and conduct interviews with several manufacturers and suppliers of e-bus technologies as well. These were summarized in the field notes and findings in the empirical report which is available for download at the university library¹.

¹ Borgheti, B., 2015. UITP World Congress and Exhibition 2015, Compilation of field notes and empirical insights. Available at Diva portal: <http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-143201>

Like the previous paper, I was mainly responsible for data collection and the writing of paper, but received guidance from my supervisor in analyzing the empirical data as well as reviews and comments on theoretical analysis and conclusions of the paper.

Meanwhile, we came to know about the call for a special issue on the low carbon vehicle sector in the *International Journal of Automotive Technology and Management*ⁱ. We found the call suitable and very close to our study and decided to submit a manuscript. It turned out that the paper was in line with the special issue criteria and after two rounds of reviews, including feedback from two anonymous peer-review commentators who helped us improve the quality of the manuscript, the paper was finally published in early 2016.

ⁱ The call for Special Issue on 'Comparative Policy Approaches in the Regional Development of the Low Carbon Vehicle Sector' is available in its original form at: <http://www.ircres.cnr.it/images/callforpapers/rsa2015.pdf>

Paper-III

Study of European pioneering cities in electric bus transport

This paper went through several rounds of change in terms of theoretical basis. It started with empirical observations and like previous papers I was responsible for data collection which was done through field visits, conferences, and interviews. This resulted in an empirical report and presentation of European pioneering cities in electric bus transportationⁱ. The empirical report grounded the data foundations of the paper in later stages. For the analysis of data, several theoretical frameworks have been tried out until we found an appropriate match between the empirical world and theoretical explanations. My supervisor was partly involved in the process of data analysis and later in revising some parts of the final paper. He also helped out with several rounds of internal reviews and comments on the early drafts of the paper. The following paragraphs elaborate on the development of the paper and the process of publication in details.

The idea for this paper was mainly shaped in connection with the research project on environmentally enhanced city buses funded by the Swedish Innovation Agency i.e. the *Miljöbuss project*ⁱⁱ. The funding also sponsored my research education from Licentiate to Doctoral degree. The project consisted of three sub-parts, in which I was the main responsible for the part one: to conduct case studies of different electric city bus demonstrations and comparative sociotechnical analyses.

Empirical data were collected mainly through field visits or direct contact with the representatives of demonstration projects. Among the main cities chosen for this study were Stockholm, Gothenburg, Umeå, Helsinki, Copenhagen and Hamburg. Other important events included Nordic electric bus initiative in Gothenburg in 2015 and the Transport forum which was held in Linköping in 2016. On some occasions, the supervisor was also involved in field empirical research such as the visit to Umeå electric bus lines and the electric bus factory (Hybricon) together with two representatives from public transport authority in Linköping who took part in the *Miljöbuss* project. Meanwhile, the EU-sponsored initiative ZeEUS (Zero Emission Urban bus Systems) was formed to promote commercialization of electric buses in Europe, which was quite in line with the ongoing *Miljöbuss* research project.

The primary sources of data were complemented with secondary sources such as project reports and presentation materials from project representatives or public reports on electric bus developments in Europe such as ZeEUS consortium on implementation of zero emission urban transport systems (ZeEUS, 2017, 2016).

ⁱ Borghei, B., 2016. Empirical Report, Pioneers in electric city buses (STOCKHOLM, GOTHENBURG, UMEÅ, HELSINKI, COPENHAGEN, HAMBURG), Linköping university, Available at Diva portal: <http://liu.diva-portal.org/smash/record.jsf?pid=diva2:1159490>

ⁱⁱ VINNOVA project number 2015-03536 ‘Vad är en miljöbuss egentligen? En socioteknisk scenariostudie’

There were several theoretical lenses through which the empirical data have been analyzed. The spatial dimension, which has been previously absent in transition theories, was considered as an important aspect (Coenen and Truffer, 2012; Boschma et al., 2017; Sengers and Raven, 2015; Coenen et al., 2012). The empirical data collected from different projects showed that geographic conditions and local characteristics led to differences in how each city adopted a different approach and developed niches according to their needs and specific requirements. This further highlighted the importance of integrating a spatial dimension related to the geographic location.

Another important theoretical lens was to consider cities as the arenas where different actors engage in the development and experimentation of niche technologies (Bulkeley et al., 2010; Bulkeley and Castán Broto, 2013; van Buuren and Loorbach, 2009). From this perspective, cities can be seen as the arenas where knowledge is shared among actors who are engaged in the development of niche experiments (Polk, 2015; Dool et al., 2011). This is also close to the idea of cities as living labs i.e. ‘urban laboratories’ where real time experimentations can be tested out for sustainability transitions and new ways to carry out urban design and development (Evans et al., 2016; Evans and Karvonen, 2014; Karvonen and van Heur, 2014; Evans and Karvonen, 2011). An earlier version of this paper was developed based on those theoretical concepts and it was presented in the IST (International Sustainability Transitions) conference in 2016¹.

Based on the comments received from the IST conference presentation, and in consultation with my supervisor, I decided to target *Environmental Innovation and Societal Transitions* (EIST) journal to publish this article. During discussions and review sessions we realized that transition theories could benefit from theoretical advancements in the field of project-based organizing. In particular, we realized that strategic niche management shares a great deal of practices with the established field of project management. Therefore, we turned our focus to the analysis of electric bus projects using a new theoretical lens by adopting the project-based view and trying to understand how knowledge is shared within and between niche projects across time and space.

At this point, we started to formulate an early draft of the paper for a special issue. But after two rounds of review and modification, we realized that the length of the paper was still too long mainly due to the extensive amount of empirical data for presenting multiple cases. The original data consisted of six cases including Stockholm, Gothenburg, Umeå, Helsinki, Copenhagen and Hamburg, but later we had to exclude Hamburg in order to reduce the total word count; however we contextualized Hamburg as part of the aggregation process. This time we aimed for an ordinary issue at the journal of *Environmental Innovation and Societal Transitions* (EIST). When we sent in the manuscript for peer review in June 2017, we had to condense it again before going through several rounds of revisions until spring 2018. At the end we received positive feedbacks from the reviewers and the process of publication went much faster than expected. The paper was finally accepted for publication in 16 January 2018.

¹ Borghei, B. (2016), Cities as transition hubs for accelerating environmental innovation: Multiple case study of electric city buses in Europe, International Sustainability Transitions (IST) Conference 7-9 September 2016, Wuppertal-Germany

A common request from both reviewers was to clarify the process of niche aggregation. Among many other comments, this particular request resulted in an important theoretical contribution by differentiating between *knowledge sharing* and *knowledge accumulation* in the process of niche aggregation. The argument is that both learning processes are necessary and they are mutually reinforcing in the process of niche aggregation, but further analysis of the empirical observations showed that there are differences that could be spelled out. Whereas the former enables sharing of knowledge across organizational boundaries, the latter entails accumulation of knowledge and experiences gained from various niche projects inside the incumbent organization. That is, *knowledge sharing* is an inter-organizational mechanism that enables knowledge and experiences to be transferred beyond the local niche projects, while *knowledge accumulation* has intra-organizational characteristics which implies that the temporary knowledge and experiences gained from the temporary niche projects to be accumulated and preserved through the more enduring means such as organizational processes, routines and procedures. This entails a cyclical process of knowledge conversion from tacit to explicit and vice versa as suggested by Nonaka (1994).

Paper-IV

The idea of multi-regime interactions and the emergence of a new sector

This paper is in the process of publication—revised version submitted 15 June 2018

As the PhD student with some experience in writing papers and the process of publication, I was responsible for data collection and theory as a solo author in the beginning, and my supervisor provided feedback and comments on different versions of the paper. However, in later stages, he also made further contributions in the form of editing and restructuring of the paper, which resulted in a co-authorship paper in the final version. The process is elaborated in details below.

The initial idea for this paper emerged from the observations of electric bus demonstration projects across different cities, which showed that there are a number of incumbent actors from various established sectors who have been engaged in the development of technologies and standardization processes for further diffusion of electric bus systems in Europe. Gradually, it became apparent that incumbent actors mainly from four established sectors have been closely involved in those developments. These four established sectors include the automotive sector, which produces vehicles; the energy sector, which provides electricity; the power and automation equipment sector, which produces charging equipment and systems; and public transport sector, which consists of established norms, practices and institutions for governing public transportation.

Moreover, it was realized that the emerging electric bus sector in Europe had started to take off more vigorously since the Study-II had been initiated back in early 2015. This was also reflected in ZeEUS annual reports on the development of electric buses in Europe (ZeEUS, 2017, 2016).

However, differences in technological configurations have been an important issue to consider for further development of electric bus systems in Europe. Hence, the idea of analyzing technological configurations and the consequent differences between the slow versus fast charged solutions came to my attention as the main idea for this paper. Then I started to collect further empirical data on this particular issue and presented the first draft of this paper at the PIE-PhD Academy at Linköping University in May 2017. It provided the opportunity to present the paper in its earliest form and the ideas regarding multi-regime interactions related to the emergence of electric bus systems in Europe were discussedⁱ. The paper was reviewed by another PhD student as well as a senior colleague (as part of the peer-reviewing process), and they provided constructive comments and further discussions on how to develop the manuscript into an academic article for publication.

ⁱ Borghei, B. (2017), Multi-regime interactions and emergence of a new industrial sector: The case of electric bus systems in Europe, PIE-PhD Academy, 24 May 2017 Linköping university-Sweden

Later that year the paper was presented at the IST conference 2017 in Gothenburgⁱ. Presentation at the IST conference provided the opportunity to get more detailed feedback and suggestions on how to improve the paper as well as making academic network contacts who were interested in this particular subject (i.e. multi-regime interactions) and have already published some papers related to this subject (Haley, 2015; Andersen, 2015).

Different theoretical lenses have been considered for the analysis in this paper. Especially, the integrative perspective that combines systems of innovation with MLP as suggested by Markard & Truffer (2008) was an important theoretical lens through which the emergence of the electric bus systems could be explained in the backdrop of various established sectors in Europe. Similarly, the more recent paper by Bergek et al. (2015) on contextualizing structural elements and the interaction dynamics of innovation systems in particular was interesting and relevant with regards to the interactions among the established sectors. Theoretical propositions about multi-regime interactions and the development of niches against the backdrop of multiple regimes was indeed interesting and very much related to this case (Raven, 2005, p. 264;270). Other studies have also been found that extend this approach even further by providing empirical evidences of multi-regime interactions (Geels, 2007; Verbong and Geels, 2007; Raven, 2007; Raven and Verbong, 2007; Verbong et al., 2008; Konrad et al., 2008). Some theoretical advancements in this field have also resulted in proposing a typology of transitioning system interactions and the resulting niche development and transition pathways (Papachristos et al., 2013). These theoretical concepts provided the backbone of the earlier versions of the paper.

Meanwhile, there was a call for special issue on *learning in transitions* in the journal of environmental innovation and societal transitions (EIST) in which a number of key issues have been raised including: ‘niche-to-niche and niche-to-regime interactions’ as well as ‘learning in experimental processes’ and similar topics. The idea of multi-regime interactions in the form of established sectors resulting in the emergence of electric bus sector in Europe was considered relevant for this special issue. This was particularly formulated in the pretext of innovation systems and learning economies suggested by Lundvall (2010; 2017). The paper was written by myself as a solo-author and it was submitted to the special issue in September 2017 and went through the review process. By March 2018, comments were received from the editor and two anonymous reviewers which, among other requests for improvement, demanded that the paper should be more explicitly connected to the topic of learning. Furthermore, the extent of comments entailed major overhaul in terms of structure and the contents of the paper.

In the meantime, the ongoing *Miljöbuss* project was moving forward with representatives of the established sectors involved in electrification of public transport who provided insights and valuable empirical data through the focus group meetings. By spring 2018, at least 24 hours of focus group meetings had been conducted (8 sessions, 3 hours each), and the notes of the meetings were stored and shared with all participants through individual login access to the project database. In addition, a scenario workshop was held on 2nd of May 2018 involving 24

ⁱ Borghei, B. (2017), Multi-regime interactions and the emergence of a new industrial sector: A multiple case-study of electric city-buses in Europe, International Sustainability Transitions (IST) Conference 18-21 June 2017, Gothenburg-Sweden

representatives from 11 different organizations invited to work on different transition pathways regarding electrification in public transport. In this way, the project acted as an arena where various actors gathered and discussed over the issues related to the emerging sector. This provided the opportunity to benefit from the focus group meetings and scenario workshop as the primary source of empirical data, and the previous sources of data (i.e. interviews and field visits) as complementary sources for the revised version of the paper.

At this stage, my supervisor also joined as co-author and contributed by restructuring and improving the contents for the revised version. The revised paper particularly put emphasis on the structural configurations of the emerging electric bus sector in Europe and the implications in terms of learning at the system level (i.e. isolated versus integrative learning).

Moreover, since knowledge and learning are two important entangled concepts in systems of innovation literature, new insights have been added to differentiate between *knowledge development* versus *knowledge integration* in the revised version of the paper. The paper was finally re-submitted on 15th of June 2018 for the second round of review to the special issue and awaits response from the reviewers.

4.3 Summary of the research findings:

Table 15 provides a summary of the research findings from appended papers on the actions of incumbents in different situations that may facilitate sectoral transformations. Based on these findings, next chapter provides elaborated discussion on the role of incumbents in sectoral transformations:

Table 15, Role(s) of incumbents in different situations based on the research findings from appended papers

Related papers	Actions taken by incumbents in different roles	Empirical instances
Paper I	Incumbents can act as a homogenous group of actors to support endogenous renewal of sectors.	Incumbents forming strong alliances and networks (ACEA)
	Incumbents can cultivate high adaptive capacity in response to stringent environmental regulations.	Adoption of advanced emissions treatment technologies in Euro-V and Euro-VI emissions standards
	Incumbents can coordinate actions to institutionalize environmental innovations.	EU/ACEACLEPA/IRU/IFRTT
Paper II	Incumbents can appear as a heterogeneous group of actors who do not necessarily act in a coordinated manner in developing or promoting radical technological solutions.	Incumbent in the established European bus market fragmented: 1) <i>Integrated bus/truck mnfctrs</i> 2) <i>Specialized bus manufacturers</i>
	Incumbents can act as catalysts to increase interactions between regime and niche, and as translators who are able to speak both languages.	Solaris/VDL/VanHool/Volvo/...
	Incumbents have the power to challenge the established performance criteria at the regime level. For instance, new entrants to the emerging niche market rather pursued fit-n-conform strategy to gain legitimacy and copied the established criteria of the existing regime.	BYD and some other e-bus producers copied the existing performance criteria of diesel buses to enter European market
Paper III	Incumbents can work side-by-side with non-incumbent actors (e.g. newcomers, NTBFs, etc.) to promote niche technological innovations.	Volvo, Opbrid, Hybricon
	Incumbents can use their resources and access to established markets to facilitate diffusion of niche technological innovations.	Volvo took the innovative solution of Opbrid/Hybricon and took it to international markets
	Incumbents as learning agents or knowledge repositories who can overcome the problem of niche isolation and facilitate local-global knowledge transfer through <i>Knowledge Accumulation</i> and <i>Knowledge Sharing</i> as mutually reinforcing mechanisms for niche aggregation.	Volvo/ABB/Siemens took the local experiences and transferred it across time and space through knowledge sharing
Paper IV	Incumbents from established sectors can facilitate adaptation of new technologies and practices in favor of the niche criteria.	Standardization of fast-charged electric bus systems initiated by Volvo/ABB/Siemens...Incumbents from energy sector: <i>Vattenfall/Endesa/SSE/Fortum...</i>
	Incumbents can facilitate the emergence of new sectors by providing resources and structuration to niche technological innovations	Incumbents from power systems: <i>Siemens/ABB/Stenman/Shunk...</i>
	Incumbents can act as knowledge integrators among established sectors in the process of new sectoral emergence.	Incumbents from public transport: <i>Transdev, Keolis, Arriva...</i>

CHAPTER 5.

DISCUSSION

This chapter provides analysis and discussion on the empirical findings and in doing so aims to answer the sub-research questions. The first section elaborates on the spheres of action for incumbent actors (i.e. within and outside the existing regime) by briefly reviewing the literature from transition contexts and the subsequent research questions. Following that, Section 5.2 corresponds to Sub-RQ.1 (Study-I), and Section 5.3. corresponds to Sub-RQ. 2 (Study-II).

The main headings of the chapter include as the follows:

- 5.1. Spheres of action for incumbents in sectoral transformations
- 5.2. Role of incumbents to facilitate transformations in established sectors (Study-I)
- 5.3. Role of incumbents to facilitate transformations in emerging sectors (Study-II)

5.1 Spheres of action for incumbents in sectoral transformations

The previous chapter provided empirical data and research findings on the actions that incumbents can take in different situations. Table 15 provided a summary of these findings from the corresponding research papers. In this chapter, role of incumbents in sectoral transformations will be discussed in relation to the main spheres of action that have been earlier discussed in the theoretical framework. Building upon the works of Berkhout et al. (2004) and Smith et al. (2004, 2005), two main spheres of action have been identified based on the locus of resources needed for transformation (i.e., knowledge, technologies, capabilities, etc.). As mentioned earlier, these resources are located either within or outside established boundaries of the existing regime (i.e., established sector). Thus, the role of incumbents in sectoral transformations could generally fall into two main spheres of action, which constitute the structure of the two studies and the corresponding research questions in this thesis:

Study–I: Role of incumbents within the established boundaries of the existing regime

*RQ: How can incumbents act to facilitate transformations
in established sectors?*

Study–II: Role of incumbents outside the established boundaries of the existing regime

*RQ: How can incumbents act to facilitate transformations
through engagement in emerging sectors?*

Now, the following Sections 5.2 and 5.3 in this chapter will answer the abovementioned questions based on the research findings presented earlier in Chapter 4.

5.2 Role of incumbents to facilitate transformations in established sectors

STUDY-I considered the role of incumbents in endogenous transformations where the locus of resources is internal to the established sector. The study involved ex-post analysis of transformational changes in the European heavy vehicles sector over time. Empirical findings showed high degrees of coordination among incumbent actors in technological renewal of the established sector and significant enhancements in environmental performance. The result was substantial reduction of toxic emissions, including a 95% decrease in nitrogen oxides (NOx) and a 97% cutback in particulate matters (PMs). This was achieved through incremental steps described in the four stages or eras of development presented in Paper-I:

- ❖ *Pre-development era (1970–1992)*: predevelopments (yet fragmented efforts) among several European nations prior to the adoption of Euro-wide emissions standards;
- ❖ *Era of formation (1992–2000)*: network formation and materialization of previous efforts which resulted in the provisioning of the Euro-I and Euro-II standards;
- ❖ *Era of stringency (2000–2008)*: technology-forcing regulation through the adoption of Euro-III and Euro-IV standards, and increased R&D investments beyond the traditional combustion technology;
- ❖ *Era of realization (2008–date)*: adoption of Euro-IV and Euro-VI standards as an important step towards harmonization of emission standards among the triad, stringent requirements that resulted in widening the scope of improvements beyond the vehicle.

However, the more important implication is that there was no presence of serious alternative solutions for the established technology (i.e., combustion engine) in the process of transformation in this study. Even supposing niche technologies existed, they could not provide viable potentials to replace the established technologyⁱ. Hence, taking the multilevel perspective into account, transformation in this study cannot be associated with the bottom-up pressure or threat of substitution from the niche level. On the contrary, the high degree of response and coordination by the incumbent actors have been found as the main driver for technological renewal of the established sector. Having said that, one should pay attention to the importance of stringent environmental regulation in the form of European emission standards as the key driving force, rather than the threat of niche substitution in this study.

ⁱ For instance, the initial development of micro-turbine for application in vehicular systems emerged as a niche technology with high expectations to substitute combustion engines back in 1990s. Automotive industry incumbents such as Volvo, Ford, Toyota and Mitsubishi considered microturbine for onboard electricity generation in hybrid-electric vehicles. This was mainly a response to the expected environmental regulations and in particular the highly debated Zero-Emission Vehicle (ZEV) mandate in California (Magnusson, 2003). In the early technology experiments, Volvo demonstrated several hybrid electric vehicles using microturbine in a car, bus and truck while in the United States the Californian based turbine manufacturer Capstone received development orders from Ford Motor Company and several other vehicle manufacturers. With high expectations for the emerging niche, Volvo made a joint investment with ABB and founded Turbec, a turbine manufacturing company for multiple applications. However, after several years of experiments, the interest in microturbine for vehicular applications dropped because it failed to deliver promising results both in terms of fuel economy (in comparison to the superior efficiency gains in modern combustion engines) as well as cost issues and fuel availability (*ibid*). The experimented hybrid electric vehicles powered by microturbine are now resting in Volvo Museum in Gothenburg (www.volvomuseum.com).

This was materialized by what is called ‘institutionalization of environmental innovation’ and the formation of networks and structural arrangements that perpetuated an endogenous type of transformation in this sector. This type of transformation can be associated with *endogenous renewal* (Berkhout et.al., 2004), where incumbent actors deploy internal means of change in response to the increasing pressures from outside. This is illustrated in the following table as the case of incumbent-driven transformation:

Table 16. Incumbent-driven transformation or *endogenous renewal* (Berkhout et.al., 2004)

Transition Contexts		Coordination <i>(deliberate actions by incumbent actors)</i>	
		Low	Hi
Locus of resources <i>(means of change)</i>	Internal	Reorientation of trajectories	Endogenous renewal
	External	Emergent transformation	Purposive transition

The table shows endogenous renewal, which is the result of a high degree of coordinated response (i.e., deliberate actions by incumbent members) using internal means of change. In this type of transformation, niches are not considered as a threat, but could rather be used as complimentary resources to the existing regime. For instance, supplier networks of emission treatment technologies did not compete to substitute the diesel engine in heavy vehicles but instead improved its environmental performance. Hence, the most important feature of this type of transformation is the incremental change and highly coordinated actions by incumbents in a very controlled and cumulative type of change. It involves maintaining the established cognitive structures and problem-solving routines steered by regime actors (Berkhout et al., 2004; Smith et al., 2004, 2005). This was clearly evident through the step-wise and incremental stringency process and highly coordinated response by the incumbent actors in this sector.

To answer *Sub.RQ.1* on how incumbents can act to facilitate transformations in established sectors, their traditional role as a homogenous group of actors (as perceived in transition literature) is indeed found to be true; though not to resist the change but rather to enable it. This happened in the absence of bottom-up forces or threat of substitution from the niche level. Therefore, the adoption of advanced emission treatment technologies and extending the scope of innovation beyond the traditional boundaries in response to the increased landscape pressure can be associated with the *adaptive capacity* of incumbent actors, who coordinated actions and pulled in resources and the means of change for endogenous transformation of the established sector (Berkhout et al., 2004, p. 64).

5.3 Role of incumbents to facilitate transformations in emerging sectors

STUDY-II considered the role of incumbents in exogenous transformations through engagement in new sectoral emergence. Taking the concept of transition contexts into account (Berkhout et al., 2004; Smith et al., 2004, 2005), this is a type of transformation where the locus of resources or the means of change are largely located outside the existing regime. The study focused on electrification of city bus transport and the use of alternative propulsion technologies as the emerging niche in the cross-boundaries of various established sectors including energy, automotive, public transport, and power automation systems.

Empirical observations showed the presence of incumbents alongside new entrants in this emerging niche. However, the main difference with STUDY-I is that incumbents are quite fragmented here, and the degree of coordination does not seem to be as high. Moreover, bottom-up pressures and the threat of niche substitution exists, at least in the areas where new entrants have already accessed the established market in Europe and provide off-the-shelf solutions with slow-charged battery electric buses as quick fix to replace conventional combustion engine buses.

Taking the typology of Berkhout et al. (2004), the external locus of resources combined with low coordinated response from the incumbents (due to heterogeneity of actors and the variety of their technological choices), the *emergent transformation* would be a likely scenario. However, due to the ongoing changes, it is not yet clear what kind of transformation would be the ultimate outcome. For instance, formation of strong alliances or the emergence of a particular standard in the form of *dominant design* (Anderson and Tushman, 1990) may facilitate higher coordinated response among incumbent actors, or it may result in some form of consensus among actors towards particular choices of technology in the form of ‘parallel’ dominant designs. In any case, higher coordinated action among incumbents would then result in *purposive transition* instead. Table 17 illustrates these two scenarios as follows:

Table 17. Potential transformations through engaging in the emerging sector (Berkhout et al., 2004)

Transition Contexts		Coordination <i>(deliberate actions by incumbent actors)</i>	
		Low	Hi
Locus of resources <i>(means of change)</i>	Internal	Reorientation of trajectories	Endogenous renewal
	External	Emergent transformation	Purposive transition

The table shows two possible types of transformations. The main difference between the two scenarios is the level of coordination (i.e. intended response) by the incumbent actors. The similarity is that both scenarios are based on external locus of resources. It may even take the form of a hybrid transformation (combination of two transformation paths), and some incumbents may be forced to exit and give space to new entrants.

But here lies an important point: The concept of 'regime' is mostly perceived as a coherent entity in the existing literature and when it comes to regime response to external forces, individual differences among incumbents make some of those theorizations irrelevant. In this case, a classic reading of transition literature suggests that the adaptive capacity of incumbent actors plays a crucial role for internalizing resources to survive.

However, due to the individual differences among incumbent actors, this would not necessarily be a determining factor for all actors involved. For instance, those actors who may choose isolated learning by adopting a fit-and-conform strategy do not necessarily have to bother about the required changes in the established sectors in favor of the niche criteria; because they can simply mimic the same performance criteria of conventional diesel buses with the quick fix battery-intensive solutions. Specialized bus manufacturers that have outsourced their powertrain technology can easily switch to any alternative propulsion system available in the market. Therefore, unlike the previous study, the heterogenous nature of actors in this study does not provide the ground for generalization of the existing theories. Moreover, empirical findings from this study showed that some incumbent actors are actively present in both spheres simultaneously (i.e. niche and regime) and they work side by side other actors (incumbents and new entrants) in the development of the emerging niche. This is again contrary to the normative perspective in transition theories.

Another important aspect is the role of incumbents from multiple established sectors which the current literature has not properly addressed in relation to niches. As it was shown in Paper-III and Paper-IV, incumbents from various established sectors (particularly from energy and power systems) are not only engaged in the development of niche technological innovations, but they often find it compatible with their technological capabilities to expand the current business into electromobility. Therefore, contrary to the normative perspective in transition literature, incumbents do not necessarily resist, but in contrast may even support promising niches that can develop into new sectors. They do so by facilitating the aggregation process through internalizing knowledge and experiences gained from niche experiments (*knowledge accumulation*) and then disseminating those knowledge and experiences to other niche projects (*knowledge sharing*). As shown in the findings from Paper-III, the two mechanisms are complimentary and mutually reinforcing for niche-aggregation.

Moreover, as shown in Paper-IV, the aggregation process for the emerging sector may then follow two different learning scenarios: 1) isolated learning where the process of *knowledge development* is primarily focused on building internal system learning in the emerging sector; 2) integrative learning, where the cross-boundary nature of *knowledge integration* process goes beyond the emerging sector and stipulates structural changes to the established sectors. This in turn facilitates niche empowerment by changing the established norms and practices in favor of the niche criteria known as the stretch-and-transform strategy (Smith and Raven, 2012).

In response to *Sub.RQ.2* on how incumbents can act to facilitate transformations through engagement in emerging sectors, the answer can be summarized as follows: as learning agents, incumbents can facilitate niche aggregation through both *intra-* and *inter-*organizational learning processes. Moreover, because of the access to established markets, incumbents can help to

overcome the problem of niche isolation and facilitate global-niche formation. Thanks to their established foothold, incumbents can facilitate translation of local niche lessons into global cognitive rules. But more importantly, using their legitimacy and the power to influence the established norms in the market, they are able to challenge established rules and introduce more radical innovations by pursuing stretch-and-transform strategies for niche empowerment. And finally, in the case of emerging niches in the backdrop of multiple regimes, incumbents can act as integrators among various established sectors.

CHAPTER 6.

CONCLUSIONS

This final chapter summarizes findings from the research and in doing so aims to answer the main research question. This is also done in light of the research purpose to contribute to a more comprehensive theorization of the role of incumbents in transition theories. The chapter consists of the following sections:

- 6.1) Role of incumbents in sectoral transformations: corresponding to the main research questions and the research purpose
- 6.2) Study implications
- 6.3) Ideas for further research

6.1 Incumbents in sectoral transformations

Incumbent actors and their potential role in transforming industrial sectors are largely neglected in transition theories. They are often black-boxed as a homogenous group of actors with a pre-defined role as the guardians of existing structures who are stuck with old technologies and sunk investments (Geels, 2002, 2005b). However, processes that engage multiple actors are essential for sustainability transitions, and single-sided views based on pre-defined roles do not offer an inclusive approach in formulating multi-actor processes. (Grin et al., 2010; Rotmans & Loorbach, 2010).

This thesis aims to contribute to a more comprehensive theorization on the role of incumbent actors by asking ‘how can incumbents act to facilitate sectoral transformations towards environmental sustainability?’ as the main research question. In this final chapter of this thesis, the answer to the main research question can now be summarized as follows:

The findings of this thesis have shown that incumbent actors are diverse and that there are heterogeneities in their actions, capabilities and technological choices. They sometimes appear as a coherent entity through established industry networks and act in highly coordinated fashion as shown in STUDY-I, but they can also act diversely and demonstrate rather heterogenous characteristics as it was shown in STUDY-II.

Moreover, the relationship between incumbents and new entrants is not always adversarial as it is often suggested in the existing literature, but can take many different forms of interaction and exchange. The implication is that the classic dichotomy of regime vs niche actors is not always valid and perhaps requires further scrutiny.

Furthermore, the results show that incumbents can play different roles simultaneously such as acting at regime and niche levels at the same time. In such role, incumbents act as translators who can facilitate local-global structuration processes by turning local niche lessons and experiences into generally applicable rules. Incumbents can act as learning agents enabling transfer of knowledge and experience across time and space. By accumulating knowledge and experiences gained from local niche experiments, incumbents act as knowledge repositories who can transfer those local experiences and learning elsewhere and overcome the problem of niche isolation. They can also facilitate the emergence of new sectors by integrating knowledge and technologies from various established sectors.

The role of incumbents in relation to learning processes is an important theoretical contribution that can be elaborated further here. These learning processes can be classified as following:

- ❖ Firstly, learning processes can be carried out at different levels: at the level of organization (i.e. organization activities), or at the level of innovation system (i.e. organizational field);
- ❖ Secondly, those learning processes may take an inward, or outward direction.

The outcome of such classification results in four different types of learning processes that can be summarized in a 2x2 matrix (see Table 18).

Table 18. Classification of learning processes and incumbents' unique areas of competence

The above matrix illustrates a classification of different learning processes according to *organization-* or *innovation system-* level (vertical dimension), versus the *inward-* or *outward-* direction (horizontal dimension). The distinction between different types of learning processes have been already pointed out in previous chapters (see Section 4.2), but what is important to highlight in this final chapter is the role of incumbents in relation to different learning processes.

The role of incumbents is particularly pronounced where they have unique capabilities in terms of maintaining knowledge and experiences in their internal organizational routines (i.e. *knowledge accumulation*), and in terms of integrating knowledge and technological capabilities from other established sectors (i.e. *knowledge integration*). This is not to undermine incumbents' capabilities in other learning process areas such as knowledge development or knowledge sharing. Indeed, incumbents do contribute in those areas as well, for instance, by investing in research-and-development and hence contributing to the *knowledge development* function in innovation systems, or by sharing knowledge and experiences with other organizations through *knowledge sharing*. But what can be considered as the unique competence areas that incumbents can exclusively contribute to is *knowledge accumulation*, which requires established internal organizational routines, and *knowledge integration*, which requires a comprehensive understanding of established systems. These are the unique areas of competence by means of which incumbents can contribute and they are highlighted with an oval shape in Table 18.

6.2 Study implications

The implications of this thesis promote fundamental changes in perceptions about incumbent actors and their role in sustainability transition theories.

Incumbents possess considerable amount of R&D resources, technological know-how, and knowledge of customers, sales, distribution channels and service, but more importantly they have unique organizational capabilities as well as knowledge and experience in dealing with complexities of established systems. These resources could be used for protecting the status quo as the classic literature suggests, or they can be deployed to facilitate industry transformations as the results of this study have shown.

As academic scholar, policy maker, government agency, politician, analyst, activist, or simply as an engaged citizen, we need to discuss about actors and their potential roles in our societies. We may need to examine how we envision multi-actor participation in processes of transformative change. It is in the nature of social sciences that theorizations about actors and their expected behavior influence collective perceptions and the consequent provisioning of policies, rules, and strategies that eventually affect actors' behaviors in the society.

Transition scholars may need to ponder more deeply if they want to perceive incumbents merely as the guardians of existing regimes and keep them away from the debate on transformational change, or choose to acknowledge their existence and perhaps try to think about how to engage them into the process of change. The active role of incumbents can be taken into account for envisioning sustainability transitions in established industries and even in facilitating the emergence of new sectors. The adaptive capacity of incumbents in adopting novelty from niche initiatives is another important aspect to consider from a managerial perspective.

We know from past experiences that in many large established companies, there are a lot of small projects and new technology experiments that end up in trash-bins or get stuck somewhere in between units and never spin off. Numerous examples of 'skunk-works' at different companies have shown that the great potentials of many of those projects are never realized and the knowledge and experiences created in those 'niche projects' remain isolated. An important lesson from this thesis is that linking local project experiences to a global-niche level where similar activities and experiments are taking place facilitates niche aggregation and accelerates market introduction of innovations. This is an important, yet very difficult task for engineers who spend most of their time in labs or isolated research facilities and thus the great potential of their work is rarely transferred to the outside world. This is perhaps an important area of improvement where incumbent firms need to pay more attention if transformation of established sectors and the long-term survival of those firms are concerned.

6.3 Ideas for future research

From single-system to multi-systems

Current transition theories have a tendency to focus on single system transitions, while in reality large sociotechnical systems are entangled in multiple dimensions and there are multi-system dynamics that need to be comprehended in relation to each other. Hence, one of the areas where further research can contribute is to understand transitions in the context of multiple regime interactions. Development of niches against the backdrop of multiple regimes is a very important area, which is largely neglected in transition studies. The library search during the writing of this thesis showed that there have been some previous attempts that could be considered as the starting point for further research in this fieldⁱ.

Having said that, interactions between incumbent actors from various established regimes and their role in relation to emerging niches has not received enough attention in the existing literature. Perhaps this thesis could be a starting point for further research in this topic. Particularly, Section 4.1 (Paper-IV), which explains the role of incumbents from various established sectors and how they engage in the development of electromobility as an emerging sector in Europe could be an empirical example of such research topic in the future.

ⁱ The following list of references can be used as a starting point for those who are interested in conducting research on multi-regime interactions or the emergence of niches in the backdrop of multiple established systems:

- Raven, R.P.J.M., 2005. Strategic niche management for biomass: a comparative study on the experimental introduction of bioenergy technologies in the Netherlands and Denmark. Technische Universiteit Eindhoven (PhD Thesis), Link for download: <http://alexandria.tue.nl/extra2/200511821.pdf> (see: P.264; P.269)
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- Markard, J., Hoffmann, V.H., 2016. Analysis of complementarities: Framework and examples from the energy transition. *Technological Forecasting and Social Change* 111, 63–75. <https://doi.org/10.1016/j.techfore.2016.06.008>
- Steen, M., Weaver, T., 2017. Incumbents’ diversification and cross-sectoral energy industry dynamics. *Research Policy* 46, 1071–1086. <https://doi.org/10.1016/j.respol.2017.04.001>

New perspectives on the multilevel perspective

The MLP has made significant contributions in theorizing societal transitions and to improve our understanding of multi-level dynamics in large sociotechnical systems. However, there is still room for further improvements in this field, as there are several areas that could benefit from a fresh perspective on the multilevel perspective.

For instance, there have been numerous empirical and theoretical studies related to the concepts of niche and regime, but the concept of landscape and its innerworkings still remain quite broad and abstract in the literature. More clarification of the concept and its empirical analysis would be helpful in gaining a better understanding of this concept. It is important that we do not neglect the determining role of landscape dynamics in maintaining continuous pressure on the regime level as a crucial precondition for sustainability transitions. However, it is still difficult to clearly point out what transition scholars identify as landscape forces and what they do not (i.e. what is in, and what is out) in their analysis. An interesting study may consider parallel developments in various sociotechnical systems that put pressure on a particular regime. Then, an important question would arise as to where multiple regime interactions and their implications on that particular regime should be placed. Are the parallel regime dynamics still part of regime-level analysis, or should they be considered as landscape forces? Hence, the concept of landscape is still vague, and that could again be related to the problem of single-system perspective, which is not capable of analyzing parallel developments in other sociotechnical systems. This relates to yet another important aspect of improvement in this field: the problem of research design.

The original reading of the MLP defines transitions as a result of interactions across multiple levels, but current studies suffer from a decoupling between niche, regime, and landscape levels. This is understandable because studying all three levels at once is not an easy task, but perhaps there could be some ways to address this problem through improvements in research design. Future studies may be crafted in a way to allow multiple levels of structuration to be reflected in the study scope. Moreover, there is a high tendency for ex-post analysis of past transitions, which is sometimes difficult to relate to the challenges of contemporary transitions. This is also an important aspect that could be integrated in future research design. As an example, the research design in this thesis included two independent, yet related research studies: Study-I included an ex-post analysis aiming to understand historical underpinnings of the existing regime, which then provided the foundation for the next study. Then, in the contemporary analysis of Study-II, basic understandings about the structural configuration of the existing regime (gained from the previous study) helped to navigate through the complexities of actor-network constellations at the niche level. Without having the knowledge gained from Study-I, it might have been extremely difficult to understand the complexities of incumbents and newcomers being both involved in niche activities in Study-II. This highlights the importance of integrating multiple levels as well as contemporary and ex-post analysis in the research design. Other important aspects could entail the integration of the geographic dimension into the research design, and scrutinizing on the spatial aspects of landscape pressures and understanding of its regional dynamics in various empirical fields.

Taking back organizations into transition studies

Another important aspect, which is widely absent in the current transition literature, is organizational theory. Particularly, the multilevel perspective is mostly silent when it comes to organization level analysis. This is very unfortunate because organizations and their internal routines are at the heart of innovation and economic change, as we have learned from the classic literature such as Nelson and Winter (1982) as one of the foundations of transition theories. Organizations exist in different forms, and they play a crucial role in every important activity in human societies. Without an informed view of organizations and their internal routines, the MLP will not be able to go far into the analysis of transitions.

An interesting area of study may involve incumbents' internal organizational routines and how they devise strategies in response to external dynamics at the niche, regime or landscape levels. The attempt to understand the inner-workings of incumbent organizations related to learning processes in this thesis could be used as a starting point. The distinction between knowledge-sharing (inter-organizational) and knowledge-accumulation (intra-organizational) as well as knowledge-development (inward) versus knowledge-integration (outward) have been highlighted in this thesis. Moreover, the unique areas of competence where incumbents can contribute with their organizational capabilities (as pointed in Section 6.1) can further enhance understanding about the role of incumbents in transition theories. Further scrutiny of these concepts in relation to MLP studies can potentially enrich transition theories in the future.

And finally, one may follow up on what is being said in this thesis today, and probably in the next few years some may try to check out what has happened to the emerging electric bus sector in Europe through retrospective (ex-post) analysis.

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APPENDIX

1. List of interviews

Table 1. List of interviews for Study–I

Interviewee	Position/Organization	Topic/Subject	Venue	Date
Edward Jobsson	Environmental Director VOLVO BUS	Hybrid electric buses / Euro VI	SHC PhD network Chalmers	8 May 2012
Kaith Hardy	Center for Transportation Research, Argonne National Labs, USA & Senior advisor on vehicle technologies to US Department of Energy	EU/US environmental politics & regulation	SHC PhD network Chalmers	8 May 2012
Ulf Ceder	Senior Manager Research Support Office SCANIA	Hybrid electric buses / CO2 reduction	SHC PhD network Chalmers	8 May 2012
Jonas Hofstedt	Senior Vice President & Member of the Board SCANIA	Emissions control/ EUVI	Scania Södertälje	23 May 2012
Niklas Gustavsson	Senior Vice President for Public & Environment VOLVO	Environmental regulation	Volvo HQ Göteborg	28 June 2012
Bengt Thompson	Senior Environment Advisor SCANIA	EU standard / Emissions technologies	HVTT/IRU conference Stockholm	16-19 Sep 2012
Erik Dahlberg	R&D / Environment SCANIA	Euro VI standard	HVTT/IRU conference Stockholm	17 Sep 2012
Jörgen Meyer	Marketing MERCEDES	Euro VI and Hybrid electric	IAA 64 th Hanover	24 Sep 2012
MS. Lopez	Marketing MAN	Euro VI and emissions control	IAA 64 th Hanover	25 Sep 2012
Sales rep.	IVECO	Euro VI	IAA 64 th Hanover	26 Sep 2012
Sales rep.	DAF	Euro VI	IAA 64 th Hanover	26 Sep 2012
Tech. rep	Eberspächer	Euro VI / SCR	IAA 64 th Hanover	24 Sep 2012
Tech. rep	Emitec	Euro VI/DPF	IAA 64 th Hanover	24 Sep 2012
Leif Johansson	Former CEO of AB VOLVO	Hybrid Electric Heavy Vehicles	Private office Göteborg	03 March 2014

Table 2. List of interviews for Study–II

Organization	Respondent	Topic	Venue	Date
ABB	eMobility sales manager	eBus fast charging solutions	Linköping university	Jun 2017
Bozankaya Bus & Bahnsysteme	Development Manager (Stephan Rudolph)	Full electric buses	UITP 2015	June, 2015
BYD	Country Manager Europe Deputy Sales Director EU/Nordic	Full electric/ Double decker	UITP BusWorld	June, 2015 Oct, 2015
DAF	Exhibitor	Advanced diesel	UITP BusWorld	June, 2015 Oct, 2015
Daimler	EvoBus Marketing Information department	CNG, electric, Fuel-cell	UITP BusWorld	June, 2015 Oct, 2015
EBUSCO	COO	Full electric	UITP 2015	June, 2015
EKOVA	Production Technologist	Full electric	BusWorld	Oct, 2015
FIAT/IVECO	Exhibitor	Advanced diesel/CNG	UITP BusWorld	June, 2015 Oct, 2015
Gépé bus	Electric Vehicles OEM Product Director	Full electric	UITP 2015	June, 2015
Golden Dragon	Exhibitor	Diesel	BusWorld	Oct, 2015
Hamburger Hochbahn	Member of the board	Hybrid, Full electric, Fuel-cell	Hamburg	Sep-Oct, 2015
Hybricon	CFO/Sales/Production/Technicians	Full electric	Umeå	
HySolutions	Managing Director	Hybrid, Full electric, Fuel-cell	Hamburg	Oct, 2015
INDCAR	Sales Area Manager	Diesel	BusWorld	Oct, 2015
IRIZAR	Sales director	Full electric	UITP 2015	June, 2015
ISUZU	Export Specialist	Diesel, CNG	BusWorld	Oct, 2015
KARSAN	Sales agent	Diesel, CNG	UITP 2015	June, 2015
King Long	Exhibitor	Parallel hybrid, Power-split hybrid	BusWorld	Oct, 2015
Linkker	Sales Director Nordic	Full electric	Nordic Bus Initiative	Sep, 2015
MAN	Tim Schuler, Natascha Giannopolus	Diesel, CNG, Electric	BusWorld	Oct, 2015
Opbrid	Founder and CEO	Charging system standardization for electric buses	Skype	17, April, 2017
OTOKAR	Sales agent	Diesel, CNG, Hybrid, Electric	UITP 2015	June, 2015

SCANIA	Project Sales Manager (Christian Persson)	CNG, Electric	UITP	June, 2015
SCANIA	Product Manager-BRT (Rutger Hörndahl)	Energy-saving: drivers training + hybridization	BusWorld	Oct, 2015
Solaris	Senior Area Manager Vice Director Public Relations Sale Manager for Sweden	Electric, Hybrid	IAA 2014 UITP BusWorld	Sep. 2014 June, 2015 Oct, 2015
TEMSA	MD German, Sales Italy/ Spain Marketing & PR Germany	Diesel, Full electric	UITP 2015	June, 2015
Umeå Municipality	Public Transport Manager	Full electric	Umeå kommun	Feb, 2016
VanHool	Communicating manager	Diesel, Hybrid, Full electric	UITP BusWorld	June, 2015 Oct, 2015
VDL	Sales Operations Commercial Project Manager	Series hybrid, Electric	UITP BusWorld	June, 2015 Oct, 2015
Vattenfall	Head of the e-mobility program (R&D)	Electric buses as an emerging sector in Europe	Linköping university	20, March, 2017
Vattenfall	Business Strategist in Power Technology (R&D)	Charging systems, standardization and power supply for electric city buses in Europe	Telephone interview	20, Jan, 2017
Volvo	Former CEO Public Affairs Manager Project representative	Hybrid, Full Electric	Gothenburg Hamburg ElectriCity	Sep. 2012 Sep. 2015 May 2015
ZeeEUS/UITP	EU Projects Manager	Hybrid, Full electric	UITP Online interview	June, 2015 Nov, 2015
Ziehl-Abegg	Exhibitor/ Technician	Full electric	BusWorld	Oct, 2015

2. Interview guides

This appendix contains several examples of interview guides containing open-ended questions used for empirical data collection by the means of interview in this research. Some of these questions have been specially designed for interview session with a particular person due, for instance when meeting the former CEO of Volvo Group (*sample 3*), while others have been generally formed to target wider range of respondents with similar characteristics in a crowd or special events such as conferences or automotive exhibitions (*sample 1*). This appendix provides several examples of these interview guides in different occasion.

Sample 1:

General interview guide related to emissions regulation and development of emission treatment technologies in heavy duty vehicles. This general guideline was used as a template for conducting spontaneous interviews (not pre-planned) with the attendants of the conference.

Subject: Environmental innovation in heavy vehicles sector	
Venue: International Symposium Heavy Vehicle Transport Technology Stockholm (250 attendants)	Date: 16-19 Sept, 2012 Time: 9AM-9PM full day conference and dinner
Participants: Benny Borghei	
<div>BACKGROUND</div> <div>Emissions regulations and its impact on OEMs strategies for R&D and innovation</div> <p>The environmental regulation in the automotive industry affects the way companies formulate their R&D strategies and the direction of their innovation activities. With respect to the regulatory body, the European Commission is considered as the main source of legislation at the European level with its Motor Vehicle Emissions Group’s (MVEG) versions of EU-x regulations as the primary set of requirements for vehicle manufacturers. Nevertheless, local or national regulations, environmental standards and regional regulations are important aspects that automotive companies need to appropriately respond to and adjust their strategies accordingly.</p> <div>OEMs and their active role in the development of environmental regulations</div> <p>On the other hand, companies are part of the regulatory process by contributing to the development of technical knowledge, by pulling resources and expertise together, and by advancement of technological capabilities to reduce emissions and environmental impacts, as well as influencing market and customers, diffusion of public knowledge and information about environmental concerns and new technical solutions to overcome environmental impacts.</p>	

...continued

Hence, automotive companies play an important role in the development of new emissions control by their active participation in this process; through diffusion of information, their impact on the market, as well as technical and political engagement in this regulatory process is important.

Environmental innovation as a collective process

Other actors such as universities, local regulatory bodies, national, regional and international associations and affiliations as well as governmental and non-governmental organizations (NGOs) play an important role in shaping and advancing such a collective process. The aim of this interview is to discuss different aspects of this regulatory process and in particular to understand the role of heavy vehicle manufacturers and their suppliers as the major players in this sector.

The first part of this interview concerns the impact of environmental regulations on the internal strategies of automotive companies and how they respond to it and adjust themselves to new regulations. The second part of the interview is to find out more about the role of automotive companies in the development of environmental regulations and how they are involved in this process.

INTERVIEW QUESTIONS

1. Introduction

Would you please provide a brief description of your position and your organization?

Would you please provide a little bit background of yourself, experience and your career in this organization?

2. Development of Emissions Control Regulations

The extent of emissions reduction achievements in Europe during the past two decades is remarkable. How do you describe such great achievement in terms of emissions reduction, and what were the underlying causes?

From a historical point of view, how do you explain the process in which the emissions control regulations evolved throughout the time?

Having this historical background with regards to technological development in mind, how do you see the future? How about CO₂ emission? What would be the next steps?

...continued

From your point of view, would firms be able to follow the pace with existing technologies, e.g. ICE? How do you see the alternative technologies to affect the legitimacy of the current technologies as well as the emissions requirements in the long run?

How do you describe your organization's role in the development of new emissions regulations? Is your organization connected to any regulatory body/procedure: At the local level /At the EU level /outside EU?

How it goes along in relation to other organizations and affiliations in this regulatory process:

- ACEA (The European Automobile Manufacturers' Association)
- Universities / Research centers / Centers of Excellence
- Test centers, standard institutions at the national and international levels, regional national
- Local and regulatory bodies, etc.

3. Implications of the Emissions Control Regulations

What important milestones or major breakthroughs do you see with regards to the technical capabilities which have been developed in the heavy vehicles sector in response to these regulations (technological advancements in response to regulations)

Regarding the EU-VI requirements and its tight margins on NO_x and PMs, how the development costs of related technologies can be justified for customers especially with regards to the fact that customers are not willing to pay extra charges for technologies which are not directly connected to their daily business (e.g. fuel efficiency)

What are the effects of new emissions regulations at your organization:

- How legal requirements are translated into technical specifications
- What parts of the organizations are mainly involved/affected by these regulations?
- And how it affects different parts of your organization?
- How it affects existing technological capabilities?
- How it affects R&D strategies and the direction of innovation activities

What is/would be the role of regulation on the development of new technologies

- For instance, referring to EGR, SCR, Hybrid or other alternative technologies
- What is the justification to develop EGR/SCR and what would be the future of this technology?
- What were the lessons learned from EGR?
- Are there implications on partnering with suppliers and development of new capabilities as well?
- If yes, how do you describe the new emissions control regulations to affect your organization's relationship with its partners, competitors, and other affiliations?

...continued

4. Further proceeding

Would it be possible to contact you again in the future for further questions?

Would it be possible to introduce us to people at your organization who are involved in:

- R&D strategy
- Emissions Regulatory bodies representatives
- Public affairs/Government negotiations
- EU/EC-representatives
- R&D partnering
- White papers, etc.

Sample 2:

Special interview guide designed for the interview session with Senior Vice President for Public and Environmental Affairs at Volvo Group on the issues related to emissions standards and technology strategies by the automotive companies in response to the increasing stringencies. The session was recorded in voice (with permission from the interviewee) and both attendants also took notes during the interview. After the session, the interview notes have been discussed and pre-analysis of the findings have been exchanged.

Subject: Emission regulation and technology strategies of OEMs Interviewee: Senior Vice President for Public and Environmental Affairs at Volvo Group	
Participants: Benny Borghei, Thomas Magnusson Venue: Volvo Group, Göteborg-Sweden	Date: Wed., 28, June, 2012 Time: 9:00-11:00 AM
<p style="text-align: center;">BACKGROUND</p> <p>Environmental regulation and its impact on technology strategies of companies</p> <p>The environmental regulation in the automotive industry affects the way companies formulate their R&D strategies and the direction of their innovation activities. With respect to the regulatory body, the European Commission is considered as the main source of legislation at European level with its Motor Vehicle Emissions Group's (MVEG) versions of EU-x regulations as the primary set of requirements for vehicle manufacturers. Nevertheless, local and national emission regulations and environmental standards are important aspects that automotive companies need to appropriately respond to and adjust their strategies accordingly.</p> <p>Automotive companies and their active role in the development of environmental regulations</p> <p>On the other hand, companies are part of the regulatory process by contributing to the development of technical knowledge, by pulling resources and expertise together, and by advancement of technological capabilities to reduce emissions and environmental impacts, as well as influencing the market and customers, diffusion of information and new technical solutions to overcome environmental pollutions. Hence, automotive companies play an important role in the development of new emissions control by their active participation in this process; through knowledge and technological development, their impact on the market, as well as political engagement in this regulatory process.</p> <p>Interview Agenda</p> <p>The first part of this interview concerns the impact of environmental regulations on the internal strategies of automotive companies and how they respond to it and adjust themselves to new regulations. The second part of the interview is to find out more about the role of automotive companies in the development of environmental regulations and how they are involved in process.</p>	

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INTERVIEW QUESTIONS

1. Introduction

Would you please provide a brief description of your job as the Senior Vice President for Public & Environmental Affairs at Volvo Group

Would you please provide us some background about your career experience at Volvo

2. Euro emissions regulation and its impact on the automotive companies

How would you describe the environmental regulations to affect your company's business with regards to its internal strategies, organizational aspects as well as R&D and technological competence?

Which parts of the organizations are mostly affected by these regulations?

How it affects existing technological capabilities at Volvo

Does it also have implications on the development of new capabilities at Volvo?

Are there implications on partnering with suppliers and development of new capabilities as well?

If yes, how do you describe the new emissions control regulations to affect Volvo's relationship with its partners, competitors, and other affiliations?

3. Development of Emissions Control Regulations

The extent of emissions reduction during the past two decades is remarkable. How do you describe such achievement in terms of emissions reduction, and what were the underlying causes?

As the senior vice president for Public and Environmental affairs at Volvo, how do you describe the process of development of environmental regulations?

- How do you describe the role of automotive companies in this process?
- How about their suppliers? Do they have a strong voice in this process?
- How about industry associations and collaborations among automotive companies?
- How do you see the future? What would be the next steps, from you point of view
- How do you see the alternative technologies to affect the legitimacy of the current technologies as well as the emissions requirements in the long run?

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- How do you describe the role of Volvo in the development of new emissions regulations
 - At the EU level
 - Outside EU
 - How it goes along in relation to partnering with other vehicle manufacturers:
 - For instance with ACEA (The European Automobile Manufacturers' Association)
 - May anyone have a single voice when it comes to negotiations with the regulatory bodies, or is it always preferred to get along with others through affiliations or associations?
- What's the role of consulting firms and universities in this process?
- What's the role of other actors such as test centers, standard institutions at the national and international levels, regional and national regulatory bodies, etc.

Further proceeding:

Would it be possible to contact you again in the future for further questions?

Would it be possible to introduce us to people at your organization who are involved in:

- R&D strategy
- Emissions Regulatory bodies representatives
- EU/EC-representatives
- Affiliations and R&D partnering
- White papers from Volvo

Sample 3:

Special interview guide designed for the interview session with former CEO of Volvo Group on the issues related to emissions standards and technology strategies by the automotive companies in response to the increasing stringencies. In addition to interview notes, the audio was also recorded with permission from the interviewee and then findings were shortly discussed where we sat together with my supervisor (Thomas Magnusson) and co-supervisor (Christian Berggren) in a nearby café in central Gothenburg.

INTERVIEW GUIDE	
Subject: Emission regulation and emission reduction technologies HDVs	Venue: Göteborg (private office)
Interviewee: Former CEO of Volvo Group	Date: 3 March, 2014
Participants: Christian Berggren, Thomas Magnusson, Benny Borghei	Time: 15:30-16:30 Location: Göteborg
<p>Emissions regulation</p> <ul style="list-style-type: none"> • What differences do you see in the development of emissions regulations across the triad (EU/US/JP)? • The EuroVI standard has been recently implemented since the beginning of 2014. Having considered the level of stringency in terms of NOx/PMs in the current regulations for HDVs, do you see any potential further developments after the Euro VI? Also in US and Japan? • When it comes to CO2 emission, do you think that market forces (i.e. fuel consumption) would be enough as it has been so far to reduce fuel consumption in the HDVs sector? What is the industry's standpoint on this issue across the triad? What would be the challenges in developing CO2 emission? • Would there be a harmonization of CO2 emission regulations across the triad or globally? Does everyone agree on a global or at least cross-triad harmonization? <ul style="list-style-type: none"> ○ If yes, what would be the potential challenges of regulating CO2 across the triad? ○ If globally (i.e. Worldwide Harmonized Heavy Duty Emissions Certification Procedure) what would be challenges in there? <p>Emissions reduction technologies</p> <ul style="list-style-type: none"> • When it comes to electrification, Hybridization may seem to be a bridging technological solution for a future transition towards full electric mobility. However, the complexities and other difficulties may actually make it more difficult to develop hybrid technologies rather than fully adapting the electric paradigm. 	

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- So what made Volvo to make such decision and make such big commitment in investing into HEVs?
- Why not other industry players did so? Didn't they see the potential or didn't they have the capacity?
- Was there any specific characteristic in Volvo's domestic environment (i.e. the **institutional settings in Sweden**) which facilitated or at least motivated such decision?

Organizational aspets:

- Having made a critical decision to put investment in a new area of technology in which future turn over was gloomy, what was the motivation internally in favor of that?
- What were the challenges in justifying it internally?
- What are the most distinguished challenges you identify in developing new technological solutions (such as electric hybrid) for the company which didn't supposedly have enough background or technological competence to deal with?

Sample 4:

Special interview guide designed for the interview session with the Head of E-Mobility R&D program at Vattenfall on the issues related to electrification in public transportation and the role of established sectors in the development of electric city buses as an emerging industrial sector in Europe. The interview was conducted as part of the Vinnova project on environmentally enhanced city buses followed by lunch meeting and the project with other stakeholders in the project on the same day.

Subject: Electrification in public transport	
Interviewee: Head of E-Mobility R&D -Vattenfall	Date: 20 Mar, 2017
Participants: Benny Borghei, Thomas Magnusson	Time: 11:30-12:00 Venue: LiU
<p style="text-align: center;"><u>Background</u></p> <p>Concerning recent developments in terms of electrification in public transport, established industrial sectors are now converging to give birth to a new industrial sector in Europe i.e. electric city buses. This convergence mainly includes automotive sector on the one hand, and the energy sector and its related actors such as electric power companies, power distribution and grid owners as well as electrical equipment manufacturers on the other hand. There are also other actors involved in this process such as public transport authorities, city planning and municipal authorities, bus operators, as well as policy makers at different levels of governance.</p> <p>Considering Your role, as a representative from the energy sector, first I would like to get to know about your understanding of the situation and if this picture corresponds to the reality out there. Secondly, I would like to have your insights about the main actors and driving forces within the energy sector in facilitating further development and diffusion of electric buses in Sweden/Nordic/Europe (i.e. what are the driving forces for electrification and how those forces interact). And third, what are the challenges or impediments for collaboration among actors from different industrial settings with diverse technological backgrounds? These can be summarized as the following questions:</p> <p style="text-align: center;"><u>QUESTIONS</u></p> <ul style="list-style-type: none"> • Do you see a convergence between automotive and energy sectors to give birth to electric buses as a new industrial sector in Europe? If yes, how do you describe the dynamics of this converging process? • What are the main actors/driving forces from the energy sector? And what is their role in facilitating further development and diffusion of e-buses in Sweden/Nordic/Europe? 	

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- What are the challenges or impediments for collaboration among actors from different industrial settings? i.e. from automotive industry and from energy sector with different mind-sets and technological backgrounds and technological competence to deal with?

3. Focus group meetings

The focus group meetings involved a wide range of representatives from the established sectors who shared their experiences or concerns with regards to public transport, electric buses and energy. The group met eight times during a period of 2.5 years (early 2016 – mid-2018) each meeting lasted for 3 hours. We also organized a scenario workshop involving more than 20 representatives from 11 different organizations (see the last row). The meetings notes have been documented and shared among the project participants after the meetings. The project participants' experiences as well as our ongoing studies of the emerging European electric bus sector served as inputs to the discussions for the meetings. Below, each meeting is specified with date and the topics that have been discussed during each session:

<i>Date</i>	<i>Topics of the meeting</i>
2 Feb. 2016	Project start-up, presentation of participants and their expectations
2 May 2016	Lessons from a field visit to a city that had implemented electric buses, different electric bus charging systems, introduction to simulation tool
29 Sep. 2016	The internationally operating electric utility's experiences in the ZeEUS-project, preparations for electric bus system simulation
20 Dec. 2016	Lessons from study of European pioneering cities in electric buses, preliminary results from the electric bus system simulation
20 Mar. 2017	Final results from the electric bus system simulation and discussion of implications
1 Jun. 2017	The Swedish government's strategic plans for fossil free transport, criteria for selection of fuels/energy for public transport buses, the truck and bus manufacturer's strategies for alternative fuels/energy in different vehicles
5 Dec. 2017	Governmental support for electric buses (invited speaker), the Swedish Bus and Coach Federation's view on alternative fuels/energy (invited speaker), ideas for extended scenario-workshop
27 Feb. 2018	Overview of electric bus initiatives in Europe, competing future visions for public transport, preparations for extended scenario-workshop
2 May 2018	Extended workshop with participants from 11 organizations discussing different scenarios for electric bus implementation

4. Field empirical data

Table 3. Field visits during Study-I

Venue / Event	Topic	Date
Automotive World – Megatrends Brussels	Heavy Vehicles Sustainability & Future advancements	12-13 Nov, 2013
Field visit Scania (R&D / Test Center) Södertälje	Advanced technologies test & development	1, Nov, 2012
HVTT, 2012 International Symposium on Heavy Vehicle Transportation Technology, Stockholm	Road transport and commercial vehicles	18-19 Sep. 2012
ACEA annual Policy meeting 2012 Brussels	European HDVs policy & market	Dec 2012
Virtual summits by AW (online)	Engine technologies, Road, fuels, alternative propulsion systems	Different occasions 2012-2014
ACEA annual policy meeting 2014 Brussels (online meeting)	European HDVs policy & market	Dec, 2014
EU premises in Brussels European Parliament / European Commission	European regulatory system	Dec, 2014
FFI: vägen fortsätter framåt National policy meeting (Stockholm Waterfront)	Advanced & green engine technologies	20, Nov, 2012
FFI/SHC: Elektriska Fordon i Fokus Chalmers	Electric engine advancement	3 Sep, 2013
IAA international motor show for commercial vehicles - Hanover, Germany	HDVs, Euro VI Emissions treatment Advanced technologies	Sep, 2012

Table 4. Operationalization of SSI framework in STUDY-I

These sources included field visits and attending industry events policy summits, expert panels and debate sessions combined with library resources and secondary sources of data as specified below:

Empirical entities		Data types (including primary and secondary sources)			
Actors	OEMs	annual reports	interviews	field visits	public announcements
	Suppliers	field visits	firms publications	online sources	
Network	OEMs	public announcements	annual conference 2012 (Brussels)	field visits	
	Suppliers	CLEPA	online sources	interviews	
Institutions	EU institutions	field visit (Brussels)	official EU publications	online sources	Library resources ⁱ
	Euro Standard	interviews	firms' annual reports	official EU publications	online sources
	US	Library sources on US environmental politics ⁱⁱ	(Osenga, 1998) report on EPA/EMA	United States Congressional reports on EPA	EPA official website: www.epa.gov
	Japan	Library sources on environmental policies, Japan ⁱⁱⁱ	Japan's delegate at European Commission	online sources	Japan's ministry of environment
Technologies	ICE	interviews	field visits	dieselnets.com	OEMs online
	Powertrain	tech. demonstrations	OEMs online		
	Body & Chassis	IAA	annual reports	HVTT2012	online sources
	Complete vehicle	HVTT 2012	VTI	Gerpisa	
	Fleet system	IAA	SHC	Megatrends	
	Alternative technologies	FFI	SHC	consulting reports	white papers

ⁱ See for example: (Borrás and Jacobsson, 2004; Börzel and Cichowski, 2003; Buhr, 2012; Delmas and Toffel, 2004; Heritier, 2003; Hey et al., 2007; Jacobsson et al., 2004; Köhler et al., 2013; Kuhlmann and Edler, 2003)

ⁱⁱ See for example: (Acton et al., 1992; Delmas, 2002; Gerard and Lave, 2005; Gordon, 1986; Kagan, 2000; Ng, 2006; Nivola, 1986; Riddesperger, 1988; Touchton, 1981; Vogel, 1986)

ⁱⁱⁱ See for example: (Iguchi and Hillman, 2012; Kagan, 2000; Naturvårdsverket, 2005; Mikler, 2009, 2005; Pohl and Yarime, 2012; Boulton et al., 1992; Massini et al., 2002)

Table 5. Field visits during Study–II

Venue / Event	Topic	Date
IAA Internationale Automobil Ausstellung (Commercial Vehicles), Hanover, Germany	Hanover, Germany	25-27 Sep, 2014
UITP world congress and exhibition	Milan, Italy	Jun, 2015
Nordic Electric Bus Initiative (NEBI) coordinated by Nordic Energy (Nordic council of ministers)	Gothenburg, Sweden	Sep, 2015
BusWorld bi-annual international conference and exhibition	Kortrijk, Belgium	Oct, 2015
Nordic Electric Bus Initiative II (NEBI-II)	Helsinki, Finland	May, 2016
Transport forum	Linköping, Sweden	Jan, 2016

Field visits to electric bus projects	Location	Date
Hamburger Hochbahn and innovation Line #109	Hamburg, Germany	Sep, 2015
ElectriCity project Line #55 / Line #60	Gothenburg, Sweden	Jun/Sep 2015
Umeå airport shuttle electric bus	Umeå, Sweden	Feb, 2016
Umeå Line #9 charging station	Umeå, Sweden	Feb, 2016
Helsinki Line #11	Helsinki, Finland	May 2016
VTT test and simulation laboratories for e-buses	Otaniemi, Finland	May 2016
ZeEUS main demonstration site Line #73	Stockholm, Sweden	May 2016

5. PhD Courses and research training activities

The research education (*forskarutbildning*) in Sweden consists of advanced courses and research training activities for PhD students. The amount of courses may vary between 60-120 ECTS* depending on the field of studies, department policies or specific requirements of the PhD student. Below, is the list of PhD courses and training activities as they appeared in the doctoral portal and Ladok registration system corresponding to the total amount of 90 ECTS stipulated by the Department of Management and Engineering at Linköping university.

Table 6. Courses and research training activities supporting PhD studies

Course / Training activity	ECTS	Ladok registration
Institutional Theory (<i>Uppsala University –Sweden</i>)	7.5	2012-05-24
Qualitative Research Methods	7.5	2012-08-24
The Dynamics of Knowledge Integration	6.0	2012-09-18
Innovation and Entrepreneurship, advanced topics I	7.5	2012-12-04
Basic Management of Research Projects	1.5	2012-12-15
Development Program for PhD Students: From Student to PhD Student	0.5	2013-05-20
Scientific Methods and Research Practice, Part 1 Scientific Methods	4.5	2013-06-24
NVivo Essentials and Analysis	1.5	2013-06-28
Writing a thesis cover paper in Innovation, Entrepreneurship and Industrial Management/Organization	1.5	2013-08-28
Learning and Knowledge - Basic Course in Higher Education Pedagogy	6.0	2013-08-29
Scientific Methods and Research Practice, Part 2 Research Practice	1.5	2014-05-20
Development Program: Module 2	0.5	2014-05-30
PhD Academy on Sustainability and Technology (<i>ETH –Switzerland</i>)	4.5	2014-06-07
Classics in Innovation and Entrepreneurship	8.0	2014-07-03
Writing a thesis cover paper in Innovation, Entrepreneurship and Industrial Management / Organization, Part 2	1.5	2015-02-19
Theories of Sustainable Transitions (<i>Aalborg University –Copenhagen campus</i>)	5.0	2015-05-31
Measuring & Modeling Dynamics in Innovation Systems (<i>Utrecht University –NL</i>)	3.0	2015-08-21
Infrastructures as a contested terrain	6.0	2016-06-15
Niches in Transition Arenas: Critical Perspectives (<i>Lund University –Sweden</i>)	3.0	2016-11-07
Career Planning for Doctoral Students	0.0	2017-01-26
Academic Writing in English	7.5	2017-10-30
International Business Environment Analysis and Strategic Management – Project (<i>Transferred credit from Handelshögskolan, University of Gothenburg –Sweden</i>)	5.5	2009-01-27
Total:	90.0	ECTS*

*ECTS: European Credit Transfer and Accumulation System

Appended Papers

The papers associated with this thesis have been removed for copyright reasons. For more details about these see:

<http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-150955>