



**CHALMERS**  
UNIVERSITY OF TECHNOLOGY



## **Two related niches and interactions between them:**

A case study on charging infrastructure for electric and autonomous electric trucks

Master's thesis in Master Programme Management and Economics of Innovation

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## Abstract

The road haulage industry is today facing three kinds of pressures that are driving change in the industry: climate change, the need for cost improvements, and driver shortages. These are pushing the industry towards electrification as well as a higher degree of automation which are representing two ongoing transitions. One element of interest in the ongoing transitions is the charging infrastructure, which is argued to be one of the most crucial barriers to a large-scale adoption of electric trucks. Further, the coexistence of electric and autonomous electric trucks and their respective charging solutions (manual and non-manual) brings up the question of how these two different solutions could impact each other.

This thesis is investigating how one of two related niches, i.e. charging for manual electric trucks (MET charging) and charging for autonomous electric trucks (AET charging), is developing through investment and learning effects and influencing the other niche. The research was designed as a case study with an abductive approach. The study includes two parts, a techno-economic perspective, and a wider system perspective. Together with a case company, a scenario model was developed for the techno-economic perspective and external interviews with various actors in the industry were conducted for the system perspective. Three dimensions: technology, knowledge and know-how and societal constituted an analytical framework for the study.

Findings show investment and learning effects as well as interactions in the form of both positive and negative externalities within all three dimensions. The most prominent positive externalities are seen in the knowledge and know-how dimension, e.g. investment in training and skills within battery management and schedule optimization. The study shows that the type of externality depends on what perspective one has and contributes to previous literature by showing that different types of externalities can be present *within* the same dimension, at the same time. Hence, the study shed light on transition dynamics by picturing the complexity of niche-niche interactions. Further, the study shows tendencies of that interactions could change over time as the less mature niche develops.

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Regarding implications for firms with both MET and AET operations, they should aim at leveraging positive externalities and minimizing negative externalities. This study suggests a strategy with an increased focus on flexibility when building charging infrastructure in order to prepare for the future. Another strategy for leveraging location-specific positive externalities, such as grid capacity, and simultaneously reducing sunk costs is to add AET chargers next to the MET chargers instead of replacing the MET chargers.

**Keywords:** Investment and learning effects, Self-reinforcing mechanisms, Niche-to-niche interactions, Socio-technical transitions, Positive externalities, Negative externalities, Charging, Electric trucks, Autonomous electric trucks.



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Olivia Forsselius & Clara Ottosson,  
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# Terminology

Below is the list of terminology that have been used throughout this thesis listed in alphabetical order:

**Autonomous Electric Truck (AET)** : An autonomous electric truck is a vehicle powered by batteries designed to transport cargo. Unlike manual electric trucks (METs), an AET lacks a driver cabin and instead drives based on algorithms or a remote human operator. There is hence no driver who can charge the plug-in charger to the vehicle. The trailer is the part of the truck where the goods are located.

**AET charging** : Defined as a niche with the aim to charge the AETs. The niche consists of a network of charging stations and relevant actors including the necessary hardware, software, and groundwork associated with the charging station.

**Agency** : A Swedish government agency.

**Carrier** : A company that employs drivers and transports goods for other companies.

**Charging station** : A location where you can charge en route, i.e. along the way between a departure and a destination site. These can be either private or public.

**Delivery window** : A set time frame of when goods can be picked up or delivered, i.e. the opening hours of the hubs. Naturally, a short delivery window requires more trucks when the transport demand is high as several trucks need to drive simultaneously. In contrast, a long delivery window allows higher utilization of the truck as a truck has time to drive back and forth and hence deliver the whole transport demand by itself.

**En route charging** : Charging done on the way, i.e. between two hubs. Typically needed when the distance is shorter than the truck range.

**Fast charger** : Here defined as a charger with a power capacity of  $> 150$  kW.

**Hub** : Referred to as a destination or departure site. A hub can be a warehouse, a distribution center, a terminal, or a customer site, where goods are either loaded or unloaded. Hubs are always private.

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**Logistic loss** : Defined as an inefficiency that would not have existed if the transport had been conducted with a diesel truck. It often originates from the need to stop for charging without doing another necessary activity simultaneously, i.e., non-opportunity charging, which is time that otherwise could have been spent on driving. The concept of logistic loss is broader than the concept of non-opportunity charging, as it could also include e.g., the time it takes before charging starts.

**Manual Electric Truck (MET)** : An electric truck is a vehicle powered by batteries designed to transport cargo. The truck is driven by a driver who sits in the cabin. The trailer is the part of the truck where the goods are located.

**MET charging** : Defined as a niche with the aim to charge the METs. The niche consists of a network of charging stations, including the necessary hardware, software, and groundwork associated with the charging station. It also includes other elements and actors, such as the truck drivers that can plug the charger into the truck.

**Non-opportunity charging** : All charging that is conducted without any other simultaneous activity.

**OEM** : Original equipment manufacturer of chargers or trucks.

**Opportunity charging** : To charge the truck simultaneously as the truck is required to stand still for another activity, e.g., at driver rest or when the truck needs to be loaded.

**Shipper** : A company that owns the goods that are being transported, and often the warehouses that are the end destination of the transport. Some shippers also own their own carrier company, which means that not all transport is outsourced.

**Slow charger** : Here defined as a charger with a power capacity of  $\leq 150$  kW.

**Tonne-kilometer (tonne-km)** : A tonne-kilometer is a measurement of freight and is received by multiplying the total number of tonnes transported by the number of kilometers the goods are transported. For instance, 20 tonnes that are transported over a distance of 10 kilometers amounts to 200 tonne-km. Similarly, 10 tonnes that are transported 20 kilometers also results in 200 tonne-km.

**Trailer swap** : An activity where a tractor swaps trailers with another tractor. This way, a truck does not need to stand still at a hub when the trailer is loaded, and can instead arrive at the hub to pick up a preloaded trailer.

**Transport route** : A distance that a truck transports goods along, i.e. a distance between hub A to hub B.



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# 1

## Introduction

This chapter aims to present an empirical as well as theoretical background to why this thesis was conducted and includes a clarification of essential concepts and a presentation of the research gap this thesis aims to address. The chapter ends with a description of the thesis's purpose.

### 1.1 Background

The road haulage industry, i.e. the business of transporting goods by road in large trucks, is currently exposed to three kinds of pressures that are driving change in the industry. Climate change initiatives are pushing the industry towards electrification and driver shortage and a need for cost improvements are driving the industry toward higher levels of automation. Regarding climate change, the industry is dominated by fossil fuels and in 2021, total emissions from medium- and heavy freight trucks amounted to 1.8 G tonnes (IEA, 2022). The industry is thus facing major challenges in reducing emissions where various climate actions and regulations put pressure on the current regime. For instance, several governments have agreed on tightened CO<sub>2</sub> emission targets (IEA, 2022) and according to the Swedish Government, the electrification of the transport system is crucial to reach the climate targets (Regeringen, 2022 a). Policy measures are also seen in several countries. For example, 15 countries recently agreed upon the ambition that all new truck sales would be electric in 2040 (IEA, 2022), and Sweden has developed a national strategy for electrification, which indicates that there are high expectations on electric trucks (Regeringen, 2022 a). As a response to the large landscape pressures, both private and public actors have invested in the electrification of the road haulage industry. Many of the largest heavy-duty vehicle original equipment manufacturers (OEMs) have made commitments to zero-emission vehicles (IEA, 2022). Yet in 2021, only 0.3% of new truck sales concerned electric trucks (IEA, 2022).

Further, the low margins characterizing the road-haulage industry (Dagens infrastruktur, 2021) create a need to redesign and find cost improvements for an electric transformation to be economically feasible. Moreover, driver shortages are a global structural problem (IRU Intelligence Briefing, 2022) which is pointed out as the leading issue in the road haulage industry in the United States (Statista, 2022 a). IRU Intelligence Briefing (2022) surveyed 19 countries in their *Driver Shortage Global Report 2022* and found that over 2.1 million truck driver jobs were unfulfilled in 2021. These shortages are expected to escalate (IRU Intelligence Briefing, 2022),

and only in the United States, driver shortages are forecasted to reach 162,000 by 2030 from the estimated 80,500 drivers needed in 2021 (Statista, 2022 b). The expected increase originates from problems with attracting young people in combination with the high proportion of older drivers approaching retirement (IRU Intelligence Briefing, 2022). Besides the electric transition, the industry is therefore facing higher degrees of automation driven by driver shortages and the high savings in primarily labor costs that automation would imply (McKinsey & Company, 2018).

As a response to these pressures, several autonomous truck startups have emerged (New York Times, 2022) and the first autonomous truck entered a public road in 2019 (Forbes, 2022). Industry incumbents have also recognized the potential of the transition and have initiated collaborations with startups to test and develop the technology (Dagens Industri, 2021). Although most pilots still include a test driver behind the wheel (New York Times, 2022; Dagens Industri, 2021), countries like the US and Sweden have granted permissions for autonomous electric trucks to drive on public roads without a driver cabin, where safety drivers can intervene remotely (Dagens industri, 2022). However, pilot studies have shown that the technology is not yet ready to realize its potential (New York Times, 2022).

The current electrification and automatization of the road haulage industry can be argued to be what in theory are described as two ongoing transitions. A transition is defined by Geels (2005) as a shift from one socio-technical system to another, involving changes in the various elements that constitute the socio-technical system. Hence, a transition does not only involve the replacement of the mere trucks but also other elements needed to fulfill the transport function, for example, road and fuel infrastructure, regulations, and user practices (Geels, 2005). For instance, the transition to autonomous trucks will imply profound changes in industry structure, operations, and profits (McKinsey & Company, 2018).

One particular element of interest is the replacement of fuel infrastructure with charging infrastructure. According to the *Road Freight Zero report* made by McKinsey & Company and World Economic Forum in 2021, one of the most crucial barriers to the large-scale adoption of electric trucks is the lack of charging infrastructure. Although there have been major improvements in the market formation for public charging stations for electric passenger cars, the corresponding public infrastructure for trucks is considerably less developed (Volvo Trucks, 2021). The situation is described as the classic chicken and egg dilemma, where actors refrain from investing in electric trucks when there is no available infrastructure, at the same time as there is a reluctance to make high investments in charging systems before enough trucks are on the road (McKinsey & World Economic Forum, 2021). The relevance of the problems associated with the build-up of charging infrastructure is emphasized by the Swedish Government's initiative to do an action plan for building electric charging infrastructure (Regeringen, 2022 b). Further, while the societal benefits of a green transport network are clear, it is not yet obvious whether the investments will be made by public or private actors. As seen in the build-up of charging infrastructure for private passenger cars, private actors could play a crucial

role if they find the investments economically viable.

For private actors, it is argued that the high investments emphasize the need for strong business cases to be economically justifiable (McKinsey & World Economic Forum, 2021). For chargers, the most important factor to reach a high return on investments is to have high utilization (Lindholmen Science Park, 2020). While trucks are mobile and thereby a flexible asset that could be redistributed to achieve an optimal business case, charging investments are more long-term and concentrated in fixed locations. Hence, the reluctance towards making the high investments required emphasizes the need to design a charging system that can assure a high degree of utilization and therefore a high return on investments, especially for private actors. This means that the investments made today should not only match the requirements of today's industry but also fit a future system that includes both electric and autonomous electric trucks.

The charging system built for manual electric trucks (METs) needs to match the requirements of METs. For such charging, the driver is a key element that can plug the charger into the vehicle. Similarly, the charging system built for autonomous electric trucks (AETs) needs to be adapted to AETs, which do not have a driver that can charge the truck. Charging thus requires either a non-manual solution or personnel at the charging station that can connect the charger to the vehicle. Today, no standard non-manual charging solution has been identified (Interview 1). Instead, a wide variety of solutions exist, including inductive wireless solutions and conductive solutions complemented with a robotic arm (Gladstein Neandross & Associates, 2019) as well as battery swapping where the trucks are not charged but given a new battery (interview 1). Further, while the first Swedish public charging station for electric trucks opened in 2021 (Göteborgs Energi, 2021), there are still no public charging stations for autonomous trucks. Since both METs and AETs are expected to co-exist in the foreseeable future (McKinsey & Company, 2018), both paths must be developed and supported to avoid lock-in.

The coexistence of two types of charging solutions, as a consequence of the coexistence of the two truck types, sheds light on the possibility that the two charging solutions could impact each other. Especially, since investments currently appear to primarily be made in charging for METs, it is relevant to see how these investments will play out for future chargers for AETs. On one hand, the electric transition is expected to facilitate the autonomous electric transition (Interview 1), hence implying a positive interaction, but it is not yet known if and how investments in the electric transition will generate learnings that can be used in the autonomous transitions. On the other hand, when an initial decision has been made to develop or adopt a charging system for METs, the more attractive becomes the decision to continue to develop or adopt such a charging system, which might harm charging solutions for AETs. Hence, if manual chargers repeatedly are chosen it might also decrease the attractiveness of developing the non-manual charging systems that are required for AETs. This way, the development and diffusion of chargers for METs could result in a lock-in that can hinder the development of charging solutions for AETs.

From a theoretical point of view, this thesis conceptualizes *charging for manual electric trucks (MET charging)* and *charging for electric autonomous trucks (AET charging)* as two emerging niche innovations (Geels et al., 2017 a; Geels et al., 2017 b) and studies them from a socio-technical, multi-level perspective (MLP) (Geels, 2005) to get a deeper understanding of the ongoing transitions. According to Geels (2002), niche innovations tend to be low-performing, inconvenient, and costly. This description corresponds well to both MET and AET charging as they are both immature (Gladstein Neandross & Associates, 2019) and cannot compete with the existing, highly efficient network of fuel stations. Although the two charging systems are related due to a partly shared technology base, they are in this report treated as separate niches because of their different requirements and technologies.

To support two niches that are related in terms of shared artifacts, there is a need to understand what is driving one niche and how that affects the other. This is not only interesting from an industry perspective, but also from a theoretical point of view since interaction between niches is a relatively untapped topic in current literature. The focus in the current literature on MLP is on interactions between the three different analytical levels and not much on interactions between niches. The gap in the literature regarding inter-niche interactions was highlighted already in 2008 by Markard & Truffer, who argued that the MLP gives little explanation to the dynamics between different niches. Bakker, van Lente & Engels (2012) elaborated that the MLP has been less explicit in explaining what happens when several options challenge the regime at the same time. Further, Verbong, Geels & Raven (2008) argue that “multi-niche analysis” can be valuable for understanding the transition processes, as their study showed that negative learning processes within one niche often led to a positive impact on another niche and, conversely that positive learning processes of one niche impacted another niche negatively.

Although the literature on technology interaction tends to focus on competition (Bakker et al., 2012), some literature sheds light on positive interactions as well (e.g., Sandén & Hillman, 2011; Nykvist & Whitmarsh, 2008; Onufrey & Bergek, 2015; Markard & Truffer, 2008; Pistorius & Utterback, 1997). This phenomenon has also been touched upon by Geels (2005) who discussed hybridization, meaning the use of two technologies simultaneously, and saw that one technology could increase the development of the other. Bergek & Onufrey (2015) concluded that several technologies can compete in the same market, while also experiencing positive influences from each other, for instance, due to potential synergies in terms of shared resources. Already in 1997, Pistorius & Utterback argued for the multi-mode interaction between technologies, saying that one technology could affect another technology’s growth rate not only negatively, but also positively. Viewing a technology as a niche, this implies that the development of one niche might influence the other niche positively. Similarly, Markard & Truffer (2008) highlighted positive interactions by arguing that MLP neglected the complementary effects of developments in different niches and the emergence of niche-transcending institutions. Hence, the literature not only suggests that niche interactions are important

to understand transitions, but also that the interactions could have other forms than traditional competition. However, what appears to be lacking in the literature is how two related niches influence each other in the context of ongoing transitions.

### 1.2 Purpose

The purpose of this research is to investigate how one of two related niches, that have not yet broken through the existing regime is developing and influencing the other niche. More specifically, the purpose is to investigate how MET charging is developing and influencing AET charging.

### 1.3 Delimitations

This study is limited to investigating interactions between two pre-defined niches, which implies that interactions from other contextual niches and regimes are not included in the study. Most notably, the study excludes factors in the socio-technical system needed for the development and diffusion of electric and autonomous electric trucks as such, which obviously are closely connected to the development and diffusion of MET and AET charging. For instance, several factors are currently slowing down and/or inhibiting the development and diffusion of autonomous electric trucks, e.g., lack of relevant legislation for autonomous driving or immaturity of the technology (McKinsey & Company, 2018), and such factors need to be in place for the niche AET charging to take off.

# 2

## Theoretical framework

This chapter presents relevant literature on transitions and interactions in the context of niches. The Multi-Level Perspective (MLP) and how that relates to the empirical case is presented followed by interactions in the MLP. Then, literature on niche development and niche-niche interactions is presented. The chapter ends with introducing three dimensions that build up the analytical framework that will be used in the study.

### 2.1 Transitions and the Multi-Level Perspective

Socio-technical systems fulfill a societal function and involve the technical system, actor network, and rules (Geels, 2004). Transitions are described by Geels (2005) as a shift from one socio-technical system to another and involve changes in several of the different elements of the system. Hence, a transition is not limited to technological changes but often includes re-configurations of e.g., markets, user practices, norms, and values (Turnheim & Nykvist, 2019; Foxon et al., 2010; Geels 2005). This is also highlighted by Nykvist & Whitmarsh (2008) who argued that neither technological solutions nor policy alone could enable a transition of the passenger transport sector by referring to unsuccessful attempts that have resulted in backlashes when technological solutions are introduced without support from producers and consumers.

Such transitions can be described and understood through the Multi-Level Perspective (MLP), which combines insights from different kinds of literature and includes three analytical levels to grasp the complexity of technological changes: the socio-technical regime, landscape, and niche (Geels, 2005). Through these levels, MLP combines technology and society. These three levels are described more in detail below.

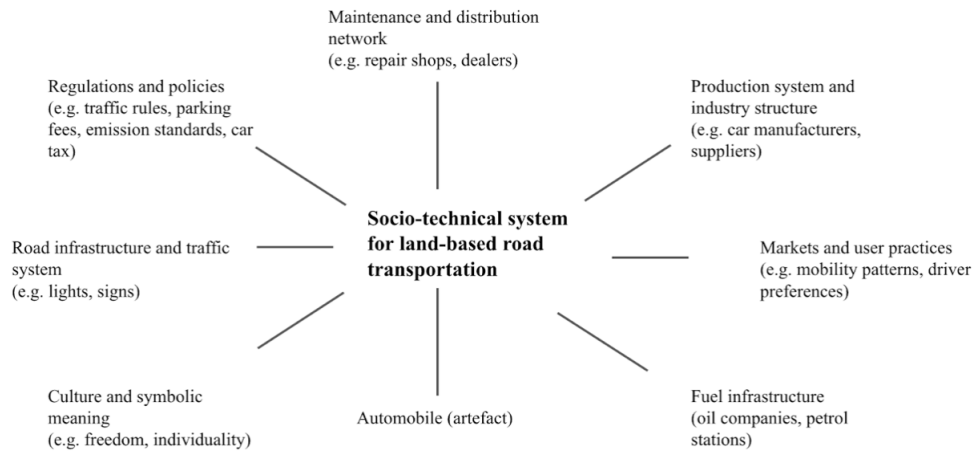
On the meso, or regime, level there is the socio-technical system which consists of the technical system, actors who develop and maintain the system, and rules. The system has evolved over decades and is preserved, defended, and incrementally improved by incumbent actors (Geels et al., 2017 b), such as policymakers, users, and organizations (Geels, 2005). The actions of incumbent actors are directed by deeply entrenched rules, which are referred to as regimes (Geels et al., 2017 b; Geels, 2005). While the definition of the regime refers to rules and institutions, the regime exists, as mentioned, on the same level as the socio-technical system and is often

used almost synonymous with the socio-technical system. Regimes are described as dynamically stable states where incremental changes lead to path dependencies (Geels, 2005). This implies that the regime is stabilized through lock-in mechanisms, for example, sunk investments and institutional commitments (Geels et al, 2017 a). Schreyögg, Sydow & Holtmann (2011) describes path dependency in three phases: preformation, formation, and lock-in where the latter occurs when a dominant pattern becomes fixed and flexibility is lost.

The macro level is the external landscape described by Geels et al (2017 a) as slow-changing trends such as environmental challenges and demographics. The landscape could, however, be exposed to shocks, such as economic crises, oil prices, and wars. When the landscape changes, the regime can encounter stress and is typically slower to adapt to these changes compared to niches (Nykvist & Whitmarsh, 2008). Landscape changes can, therefore, destabilize the current system and make it possible for niche innovations to break through (Geels et al. 2017 a).

Niches represent the micro level and operate at the periphery of the mainstream meso level regime (Nykvist & Whitmarsh, 2008). In the literature, there are essentially two ways to look at niches, where niches are either seen as protective spaces that protect radical innovations from the market pressures of the existing regime or seen as radical innovations themselves. Geels (2005) and Raven et al. (2012) define a niche as a protective place where radical innovations are developed. These places, or niches, are crucial since they provide space for learning activities (Geels, 2005) and enable the development of new routines, standards, and norms that differ from the prevailing system (Raven et al., 2012). Sandén & Hillman (2011) takes a slightly different approach describing the niche concept as more or less synonymous with technologies. This view of niches is shared by Geels et al. (2017 a) who use the concept of niche innovations to describe new technologies, business scenario models, or behaviors that differ radically from the mainstream system, which is the definition that will be used in this study as it appears most useful to the chosen empirical case. Niche innovations and market niches are then viewed as two separate, but related, concepts, where niche innovations are emerging social or technical innovations that differ radically from the prevailing socio-technical system, and market niches refer to the places where these innovations are protected (Geels et al. 2017 b), for example, particular applications or segments such as the military (Geels et al. 2017 b).

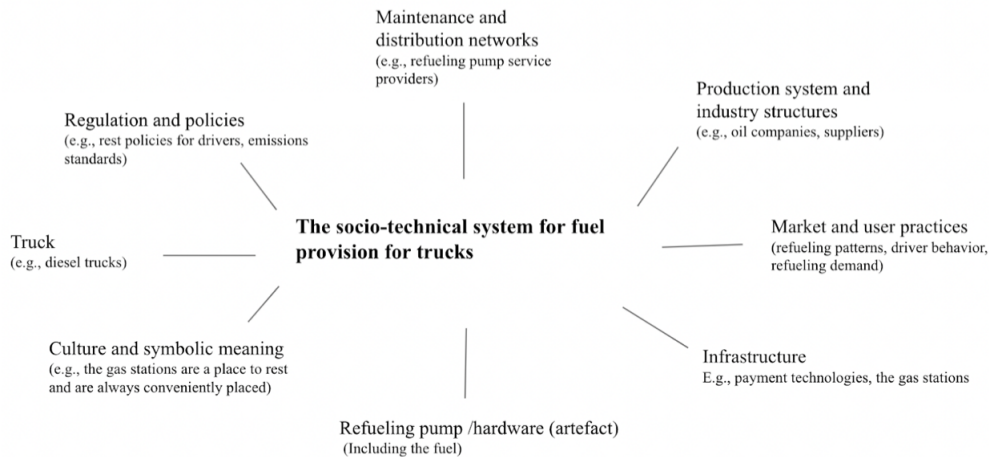
If we apply this perspective to our empirical case, the socio-technical system for land-based road transportation is illustrated in Figure 2.1, showing the different elements such as regulation, infrastructure, and actors building up the socio-technical system. Climate change initiatives that are driving the industry towards lower emissions are in this study viewed as landscape pressures that destabilize the regime and trigger a transition of the prevailing regime. A transition in land-based road transportation would imply that several of these elements were replaced by elements from a new socio-technical system (Figure 2.1). The automobile could for instance be replaced by electric trucks, and the fuel infrastructure could be replaced by charging infrastructures and related energy providers.



**Figure 2.1:** An example of a socio-technical system (Geels, 2005).

This study focuses on a subset of the socio-technical system for land-based road transportation, i.e. the supply or provision of fuel or energy to trucks. This smaller socio-technical system is illustrated in Figure 2.2 and represents the regime of this study. In short, the regime is characterized by trucks with diesel engines and the technical components of the regime constitute the refueling hardware, the fuel per se, the truck that requires refueling, and the physical location of refueling stations. Regime actors include oil companies who supply fuel stations with diesel, drivers who perform the refueling activity, and transport buyers who create the demand for fuel. Lastly, the regime rules are characterized by behavioral patterns of not having to plan when refueling needs to be done since the network of refueling stations is well developed, the refueling times are short and the truck ranges are long.

As mentioned, while diesel trucks and their respective fueling stations dominate the road haulage industry, later developments have shown that both METs and AETs have emerged and created the need for new ways of providing the energy needed for the new truck types. In the context of this study, this has resulted in two new emerging niche innovations. These are defined as *charging for manual electric trucks (MET charging)* and *charging for autonomous electric trucks (AET charging)*.

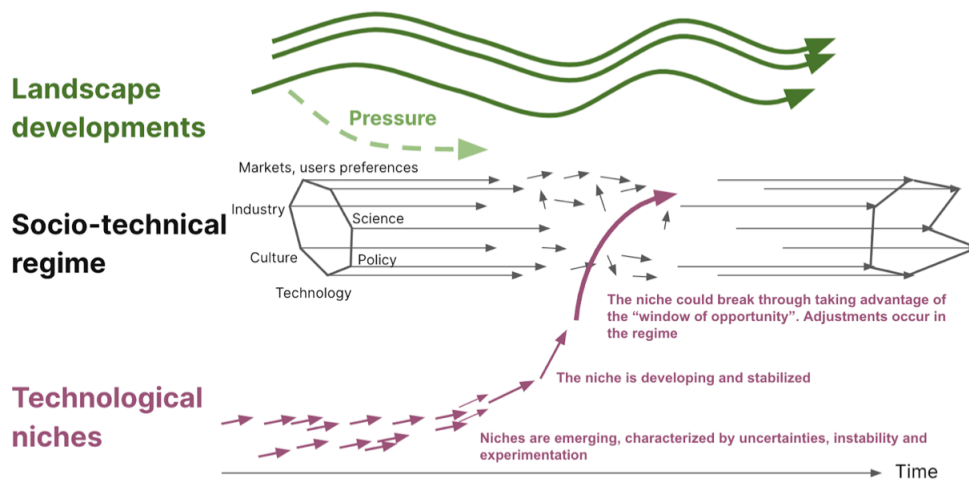


**Figure 2.2:** The socio-technical system of truck refueling in this study

Although some elements that constitute the wider socio-technical system of land-based road transportation are excluded in this study, such as the traffic light system and traffic rules, this system and the smaller socio-technical system illustrated in Figure 2.2 are in no sense independent. Instead, a transition of the smaller subset is driven by the transition of the larger socio-technical system of land-based road transportation. The selected niches in this study are defined by the type of truck technology they are related to, i.e. to charge a MET or an AET. Hence, the development of the selected niches is dependent on the developments and diffusions of METs and AETs.

## 2.2 Interactions

A key point in the multi-level perspective is that the success of an innovation is dependent on the development of all three levels and the dynamic interactions between them (Geels, 2005). The relation between the three levels in the MLP is described by Geels (2005) as a “nested hierarchy” meaning that niches are enclosed by the regime which in turn is enclosed within the landscape. When a dominant design is reached and the niche is more developed it could break through if it is able to take advantage of the “window of opportunity” emerging when the current regime is put under pressure (Geels, 2005). The pressure can result from internal problems in the regime or shifts in the landscape. When niches have matured and challenged the regime, there could be struggles between the niche innovation and the existing regime, for instance in the form of economic competition between the regime and niche technology (Geels et al. 2017 b). Geels (2005) argues that a transition happens if the niche replaces the current regime, which is referred to as technological substitution (see Figure 2.3). This form of transition is a time-consuming process associated with major changes in the socio-technical regime and therefore happens gradually (Geels, 2005).



**Figure 2.3:** Multi-Level Perspective (Geels, 2005).

However, this description of the interactions between the three levels represents a traditional view and is in no sense comprehensive. There are examples of varying amplitudes of landscape pressures (Geels et al., 2016) as well as examples of symbiotic relationships between the niche and the regime, where regime actors make use of niche innovations (Nykqvist & Whitmarsh, 2008). There are also several forms of interactions *within* the levels. Raven & Verbong (2009) investigated regime-regime interactions in terms of competition, symbiosis, integration, and spill-over. The authors explain the different interaction modes as relations between rules, actors, and technologies that could change over time. Opposite to competition, symbiosis is defined by Raven & Verbong (2009) as when two regimes both benefit from cooperation which can result in them being mutually dependent. Further, integration is described as when regimes that have been separated merge and become one. Partial integration is also possible, for instance when two regimes merge in terms of production but remain separated in terms of distribution and use (Raven & Verbong, 2009). Lastly, spillover is explained as the transfer of knowledge or rules from one regime to the other. Raven & Verbong (2009) argue that these different interaction modes can occur at the same time or sequentially. Moreover, the degree of interaction can change, for instance that competition can intensify over time.

There are also interactions within the micro level, i.e. niche-niche interactions. Even if these interactions are less articulated in literature, or even neglected by the MLP as it traditionally assumes that there is only one niche that challenges the regime, Geels & Schot (2007) highlight that there are transitions where several niches co-exist. In the example brought up by Geels & Schot (2007), several niches interact in form of competition for some time before one niche becomes dominant and creates a new regime, but as we will see in the following section, other forms of niche-niche interactions are possible.

## 2.3 Niche-niche interactions

To understand niche-niche interactions, one must first understand how niches are developed. This section, therefore, starts by describing niche development before presenting niche-niche interactions.

### 2.3.1 Niche development

Literature on Strategic Niche Management (SNM) describes the dynamics of niche-development trajectories as interactions between three processes: articulation of expectations, learning, and the building of social networks (Geels & Raven, 2006). This study focuses on niche development in terms of learning processes.

Initially, niche innovations are characterized by uncertainty, fragility, instability, and experimentation (Geels et al. 2017 b). There is no dominant design and several design options are cultivated and many of them are likely to fail (Geels et al. 2017 b). However, Geels et al. (2017 a) explain that despite the difference from the dominant system, niche innovations can still gain a foothold in certain geographical spaces or market niches, or in a wider space as a consequence of targeted policy support. For instance, a phase-out policy can accelerate a transition by creating space for niche innovations which enhances their diffusion (Geels et al. 2017 a). Protected market niches can hence be created by policies and stimulate technological learning and improvements, entry of new firms, and the growth of new industries (Geels et al, 2017 a). Niche innovations can then diffuse in the form of niche-accumulation (Geels & Schot, 2007; Levinthal, 1998) or bridging markets (Andersson & Jacobsson, 2000), in which an innovation enters increasingly bigger markets. For a niche in the current system to break through, it has to first develop and improve as a result of learning processes (Geels, 2005). Geels et al. (2016) explain how a niche is developing with internal drivers such as R&D, resulting in price and performance improvements. Scale and learning economies, complementary technologies, network externalities, support from political actors in the form of subsidies and supportive regulations, and cultural enthusiasm are other examples of internal drivers (Geels et al. 2017 b).

Such internal drivers can be related to the self-reinforcing mechanisms described by Onufrey & Bergek (2015), that make a certain product or technology increasingly attractive. These are dynamic processes that lead to the repetition of an earlier chosen path and eventually make the path self-sustaining, which could lead to lock-in (Schreyögg, Sydow & Holtmann, 2011; Onufrey & Bergek 2015). The concept of self-reinforcing mechanisms is, thus, almost synonymous with the term positive feedback, which is the increased likelihood for continued adoption or development of a technology (Onufrey & Bergek, 2015). Thus, actors within the chosen path, such as policymakers and engineers are more prone to continue along the chosen path that has been developed (Bakker et al., 2012).

Investment and learning effects is one of the four types of self-reinforcing mechanisms

described in the literature (Onufrey & Bergek, 2015). As non-transferrable resources and knowledge related to a certain alternative are accumulated, such accumulation increases the attractiveness for continued adoption or development (Dobusch & Schüßler, 2013). On a company level, investment and learning effects can for instance take the form of sunk investments in R&D (Dobusch & Schüßler, 2013). High upfront or sunk costs that are paid early on in technology development will make actors more inclined to proceed with the selected technology or product (Onufrey & Bergek, 2015). Technology development also experiences related learning-by-doing effects, which encourages companies to continue the development of that specific technology (Onufrey & Bergek, 2015). Examples of such learning-by-doing are learnings retrieved from manufacturing a technology, e.g., the identification of new bottlenecks and the development of technology-related skills and routines (Onufrey & Bergek, 2015). Hence, these effects make companies more prone to focus on exploitation and new opportunities close to their existing technology base rather than exploring other alternatives (Onufrey & Bergek, 2015).

Similar investment and learning effects can also be seen in terms of technology adoption (Onufrey & Bergek, 2015). Economies of scale and experience refer to the process when increased diffusion of a technology or product prompt learning effects and result in cost reductions and performance improvements, which in turn increases the incentives for users to adopt the technology (Onufrey & Bergek, 2015).

Investments and learning effects are especially relevant when the technology is complicated, as adoption then requires investments in training (Onufrey & Bergek, 2015). As users have to invest in training and competence-building when they adopt a new technology they can exploit these investments further (Arthur, 1996). Users also learn over time how the technology works. They thereby get used to it and are likely to stay loyal when new versions are introduced (Dobusch & Schüßler, 2013). Related to this study, the high investments in charging infrastructure mentioned in the background suggest that investment and learning effects are likely to be seen on both the development and the adoption side. As there are several complicated charging technologies available, such effects could regard technology development of charger hardware as well as investments in training for drivers in how to charge electric trucks.

### **2.3.2 Types of niche interactions**

Investments and learning effects can result in several forms of niche-niche interactions. First, there is a risk that positive feedback created from investments and learning effects for one technology has a mirroring effect that decreases the relative attractiveness for another technology. Such mirror effects are described as negative externalities (Vergne & Durand, 2010) and are hence a form of negative interaction. Negative externalities can for instance occur when an emerging technology does not fit into a system developed by another technology (Sandén & Hillman, 2011). Second, Onufrey & Bergek (2015) found evidence that positive feedback could also have a mirror effect of a positive character, i.e. a positive externality. This finding

helped to explain how various paths could coexist during a more sustained period, compared to the shorter periods that constitute the era of ferment described by Andersson & Tuschman (1990), and experience non-competitive interaction even in a context of path dependency (Onufrey & Bergek, 2015). Hence, the prevalence of positive externalities helps explain how lock-in can be avoided (Onufrey & Bergek, 2015), and suggests that niches not only compete but could positively influence one another.

However interactions between two technologies do not necessarily only have one direction (Sandén & Hillman, 2011). Hence, the interaction is not limited to one technology affecting another, as the second technology can also affect the first one. The niche-niche competition described by Geels & Schot (2007) in which several niches compete for attention and resources until one ultimate niche outcompetes the others suggests that the niches exert negative externalities on each other. This aligns with the conventional scenario model of Andersson & Tuschman (1990) where an era of ferment is characterized by uncertainty and competition between alternatives before ultimately one single dominant design is selected and flexibility is lost. Opposite to competition, two niches may exert positive externalities on each other, which is described as symbioses by Sandén & Hillman (2011) and as co-evolution by Nykvist & Whitmarsh (2008). They can for instance take place when two substitutes are used in combination to increase performance or when two technologies in conjunction create a new market and share the burden of change (Sandén & Hillman, 2011). According to Sandén & Hillman (2011), four additional modes of interactions could take place between technologies: neutralism, parasitism, commensalism, and amensalism. The six modes of interaction are listed in Table 2.1.

**Table 2.1:** Modes of interactions between two different technologies, (Sandén & Hillman, 2011).

<b>Mode of interaction</b>	<b>Technology 1</b>	<b>Technology 2</b>	<b>General nature of interaction</b>
Competition	-	-	Technology 1 and 2 inhibit each other
Symbiosis	+	+	Technology 1 and 2 benefit each other
Neutralism	0	0	Technology 1 and 2 do not affect each other
Parasitism	-	+	Technology 2 is benefited and 1 is inhibited
Commensalism	0	+	Technology 1 is benefited and 1 not affected
Amensalism	0	-	Technology 2 is inhibited and 1 not affected

According to Sandén & Hillman (2011), these interactions emanate from overlaps between two niches, i.e. when technologies share elements in different parts of the value chain. When shared resources and markets are limited, two technologies often interact in the form of competition (Sandén & Hillman, 2011). Instead, neutralism often occurs if these shared elements exist in an abundant supply or if a shared resource is a non-excludable good (Sandén & Hillman, 2011). However, Bergek & Onufrey (2015) suggested that shared resources could also enable positive external-

ities, due to the advantages of potential synergies. One niche could for instance be positively influenced by the other if it can utilize a resource that is developed by the other niche (Sandén & Hillman, 2011). If a such resource is excludable, the resource-receiving niche will benefit at the expense of the resource-developing niche (parasitism), while the developing niche is not affected if the resource is a non-excludable good, e.g., non-patented knowledge (commensalism) (Sandén & Hillman, 2011).

Both more mature niches and less mature niches can develop resources that can benefit the other niche (Sandén & Hillman, 2011), but it appears to be more common that new niche innovations benefit from a resource or market space that has been developed by a more mature niche innovation. This could be explained by the concept of *bridging technologies* (Bergek et al., 2015; Andersson & Jacobsson, 2000; Sandén & Hillman, 2011). Bergek et al. (2015) investigated how technological improvements and developments in one technological innovation system (TIS) influence the success of another TIS, and argued that an immature TIS was greatly influenced by developments in the surrounding, more mature, TISs while the surrounding TISs only appeared to be affected by the emerging TIS to a limited extent. Viewing TISs as niches, a more mature niche can act as a bridging technology that paves the way for a less mature niche (Bergek et al., 2015), for instance in the sense that the diffusion of the more mature niche can prepare an industry for the characteristics that are common of the two niches (Andersson & Jacobsson, 2000). Less mature technologies could, for instance, benefit from learning related to production, installations, public awareness, and institutions that are not specific to the bridging technology (Andersson & Jacobsson, 2000). The bridging technology could also create a market space that is parasitized by a less mature niche. The bridging technology then parasitizes on an established technology or regime, while the less mature technology parasitizes on the bridging technology. This way, the less mature niche can bypass a structural regime lock-in and diffuse even in a situation where it is in fierce competition with an established regime (Sandén & Hillman, 2011).

The dominant interaction mode between two niches has a propensity to change over time, and such shifts in dominant interaction modes is often related to the niches themselves maturing over time (Sandén & Hillman, 2011). The shift in interaction mode was also highlighted by Bergek et al. (2015) who examined the interactions between a focal technological innovation system (TIS) and other contextual TISs and concluded that the shift originated from the focal TIS growing and maturing. As mentioned, they argued that a focal TIS would be immensely dependent on developments in more mature TISs, but that the dependency is expected to become more equal later on when the focal TIS matures and can have a larger impact on the contextual TISs (Bergek et al., 2015).

According to Sandén & Hillman (2011), two emerging technologies could also show different basic interaction modes in different dimensions at the same time. That means that an investment and learning effect within one niche can influence the other niche positively in one way, but negatively in another. This helps to explain the

concept of bridging technologies, in which two emerging technologies show different interactions simultaneously, as the technologies compete while they at the same time assist each other (symbiosis) or one helping the other (parasitism or commensalism) to develop at the expense of an established technology (Sandén & Hillman, 2011). To understand how a niche is affected by another niche, it is thus not enough to merely identify if the mirroring externality is positive or negative. Instead, one must investigate in what way a niche is affected positively or negatively, and if there are several simultaneous interactions. The following subsection will therefore highlight three dimensions in which externalities can be investigated.

### **2.3.3 Interactions in different dimensions**

The aim of this study will be realized by investigating investment and learning effects and niche interactions within three identified dimensions. The dimensions are defined by the researchers and argued to be connected to investments and learning effects in the context of MET and AET charging. The following subsection highlights and motivates these dimensions in which two niches can overlap. Further, the dimensions will be used as an analytical framework in the study to analyze investment and learning effects as well as niche interactions between MET charging and AET charging.

#### **2.3.3.1 Technology dimension**

In the context of this study, the technology dimension is chosen as it relates to investments in different hardware technologies and physical infrastructure that are required in the niche. Further, learning effects in the technology dimension relate to improvements in these technologies. Geels et al (2017 b) explain that common learning effects within the techno-economic dimension relate to price and performance improvements as a result of R&D but also technological developments as a consequence of for example learning by doing and scale economies.

According to Sandén & Hillman (2011), two technologies understood as niches overlap in what they describe as the material dimension if physical artifacts are shared e.g. if two fuels are produced at the same production plant. Hence, there is an interaction if MET charging and AET charging share the same or parts of the same physical infrastructure. Further, negative externalities could for example be shown if technology developments in manual chargers affect the development of non-manual solutions negatively.

#### **2.3.3.2 Knowledge and know-how dimension**

Since MET and AET charging still are under development and actors are in a learning process we argue that knowledge and know-how is a relevant dimension to consider. For instance, developing skills and routines are mentioned by Onufrey & Bergeek (2015) in the context of investment and learning effects which we argue is related to knowledge and know-how. Turnheim & Nykvist (2019) further state that operational issues often are overlooked but still crucial in transition processes.

Regarding charging, operational issues could for instance consider uncertainties on when and how to charge. Hence, increased knowledge concerning operational issues is therefore argued to be of interest for niche development and to accelerate the transition.

Further, the knowledge and know-how dimension includes investment in training for actors and various actions for competence-building, which is in line with Onufrey & Bergek (2015) describing investments and learning effects. Interactions, positive and negative, are in the knowledge and know-how dimension related to whether developed skills and training for MET charging could be reused for AET charging or not.

### 2.3.3.3 Societal dimension

The third dimension is defined as the societal dimension as we argue that it is crucial to include norms, behaviors, and regulations when investigating niche development of MET charging. For instance, changed norms and attitudes towards electric operations could be argued to create positive feedback loops and increased adoption of MET charging. This is in line with Geels (2005) who argues that a transition is not limited to technological changes since it also often includes re-configurations in markets and user practices.

Further, Geels et al. (2017 b) argue for the importance of social, cultural, and political aspects by referring to internal niche drivers. For instance, niche performance can be increased by actors that support niche innovations with subsidies and supportive regulations, i.e positive feedback. Further, positive or negative interactions in the societal dimension depend on if norms and behaviors related to MET charging will be relevant for AET charging or reduce its attractiveness. Regarding regulation, there is a positive externality if regulation for MET charging also benefits AET charging and a negative externality if AET is not favored. For example, Lin & Sovancool (2020) describe how two niches benefitted from the same regulation and hence showed a symbiotic interaction.

## 2.4 Research questions and redefined purpose

Based on these theoretical considerations described above, we can now refine the purpose to investigate how one of two related niches, that have not yet broken through the existing regime, is influencing the other as a result of investment and learning effects in the technology, knowledge and know-how and societal dimensions. Due to the immaturity of AET charging, the study focuses on investment and learning effects within MET charging and how it affects AET charging. To fulfill the purpose of the thesis, the following research questions were formulated:

1. What types of investment and learning effects are present for MET charging?
2. What are the mirroring externalities of those effects for AET charging?

## 2. Theoretical framework

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The study will include both an operational analysis of the techno-economic perspective and an analysis of the wider system perspective.

# 3

## Methods

This chapter describes the chosen research methods in relation to the aim and research questions of the study. In particular, the research design is described followed by data collection, a critical discussion about the methodology, and ethical considerations.

### 3.1 Research design

The study aimed to investigate how one of two related niches, that have not yet broken through the existing regime, was influencing the other as a result of investment and learning effects. To answer the research questions about what types of investment and learning effects are present for MET charging and what mirroring externalities there are for AET charging, a case study on charging for electric trucks was used. As mentioned, MET charging is a subset of a wider socio-technical system and could be viewed as a defined system, hence suitable for a case study, which is concerned with a detailed and intensive analysis of a specific case and focuses on a bounded situation or system which distinguishes a case study from other research methods (Bell, Bryman & Harley, 2019). Further, a case study is appropriate for a study when the aim is to generate deep knowledge and a holistic understanding of a specific subject (Bell et al. 2019) which was argued to be in line with the aim of this study.

This particular case is suitable for describing related niches since it is clear that the two selected niches are related because they fulfill the same function, i.e. provide the energy needed for trucks to deliver goods, and share resources, e.g., energy. Moreover, it is clear that the niches in this particular case are niches and do not belong to the current regime, as they are characterized by experimentation and have limited market diffusion. In line with Geels et al. (2017 b), niche development is therefore crucial and as MET charging has existed for a while there are probably investment and learning effects within the niche. As mentioned in the background, both truck types are expected to co-exist in the foreseeable future, but MET charging is at this present time more mature than AET charging. Their expected co-existence, relatedness, and different stages of maturity form an interesting situation where it is of interest to understand how these two niches will interact. Therefore, this particular case was appropriate for explaining possible niche interactions.

Regarding the research strategy, an abductive approach was dominantly used. Ab-

ductive reasoning is argued to complement and overcome limitations with the traditional inductive and deductive research strategies (Bell et al. 2019). In an inductive approach, a theory is the outcome of research while in a deductive approach the theory is used to build up hypotheses to be tested (Bell et al., 2019). Dubois & Gadde (2002) present what they call systematic combining, which is grounded in abductive reasoning. The authors describe systematic combining as a process where theoretical concepts, empirical data, and case analysis evolve at the same time and that researchers go back and forth between these parts. This way, researchers widen their perspectives both regarding theoretical concepts and empirical issues. With regards to this study, MET charging and AET charging and their interactions are relatively untapped topics in the current literature which suggests such an abductive approach is appropriate.

The study consisted of two parts: a techno-economic perspective and a system perspective. The techno-economic perspective intended to answer the research questions by focusing on an individual actor and a single transport route, while the system perspective intended to answer the research questions by including a broad set of actors. While the techno-economic perspective mostly concerned investments and learning effects within the technology dimension, the system perspective included a more comprehensive, but less detailed, discussion of all selected dimensions.

Table 3.1 shows an overview of the different phases of the study. The first phase aimed to get a general understanding of both the industry and the case company as well as identify requirements for MET and AET charging. Results from the first phase were input variables for a scenario model where one current and two future scenarios including both METs and AETs were developed. The following phase of the study aimed to get external actors' perspectives on charging for METs and AETs related to the dimension defined in the analytical framework. The scenario model was then iterated in the fourth phase with more system requirements and data points, for instance by improving the functionality of variables that had appeared to be critical during the external interviews. The fifth phase combined findings from all previous phases in a comprehensive analysis of both the techno-economic and the system perspective. In addition, the findings from the scenario model and the external interviews were reiterated through two internal workshops with the case company.

**Table 3.1:** Overview of the different phases in the study.

<b>Phase</b>	<b>Aim</b>	<b>Partial analysis</b>
1. Mapping	<ul style="list-style-type: none"> <li>• Get a general understanding of the industry and the case company</li> <li>• Identify requirements for charging for METs and AETs</li> </ul>	System perspective + Techno-economic perspective
2. Development of scenario model	<ul style="list-style-type: none"> <li>• Build the scenario model</li> </ul>	Techno-economic perspective
3. Conducting external interviews	<ul style="list-style-type: none"> <li>• Get various actors' perspectives on charging for METs and AETs related to defined dimensions</li> </ul>	System perspective
4. Iteration of scenario model	<ul style="list-style-type: none"> <li>• Improve the scenario model</li> <li>• Include additional requirements for the different scenarios</li> </ul>	Techno-economic perspective
5. Analysis	<ul style="list-style-type: none"> <li>• Data retrieved from interviews and the results retrieved from the model were analyzed</li> </ul>	System perspective + Techno-economic perspective
6. Triangulation through workshops	<ul style="list-style-type: none"> <li>• Triangulate findings from scenario model and external interviews through two workshops with the case company</li> <li>• Gain a deeper understanding of how investments affect AET charging</li> </ul>	System perspective + Techno-economic perspective

## 3.2 Data collection

This study used mostly primary data in the form of interviews and workshops but also secondary data in terms of internal reports from the case company. As described in Table 3.2, the techno-economic perspective and the system perspective had different data collection methods, which together built up the analysis of the study. As mentioned, the techno-economic perspective mostly regarded investments and learning effects within the technology dimension while the system perspective investigated all selected dimensions. The following section presents the respective data collection methods more in detail.

**Table 3.2:** The two parts of the study and their respective aims and data collection methods.

<b>Partial analysis</b>	<b>Data collection method</b>	<b>Aim</b>	<b>Dimensions in focus</b>
Techno-economic perspective	Initial interviews External interviews Scenario model Internal workshops	Highlight issues of investments and sunk costs	Technology dimension
System perspective	External interviews Internal workshops	Generate insights about RQs from a diverse set of actors	Technology dimension Knowledge and know-how dimension Societal dimension

### 3.2.1 Techno-economic perspective

The following subsection presents the data collection methods used to gain insights about the research questions from a techno-economic perspective. The primary method used was the scenario model, and different data collection methods were used to build up the scenario model. Moreover, the subsection also includes arguments for the relevance of including a techno-economic perspective in the study.

#### 3.2.1.1 Initial interviews and workshop built up the scenario model

Initial interviews were conducted with people from different delivery areas at the case company to build up the scenarios and get input variables to the scenario model, summarized in Table 3.3. These interviews were explorative and helped the researchers to understand the different requirements the two types of trucks would put on their respective charging systems. The initial interviews were complemented with secondary data in the form of internal documents from the case company. In addition, a workshop with the supervisor at the case company was held to develop the scenarios that would work as input variables in the scenario model, summarized in Table 3.4. The scenarios that emerged from the initial interviews and the workshop are presented in the results.

**Table 3.3:** Summary of initial interviews with the case company.

<b>Reference</b>	<b>Role of participant</b>	<b>Team / Department</b>	<b>Time</b>	<b>Recorded</b>
Interview 1	Product Manager	Autonomous Freight	30 min	Yes
Interview 2	Charging Analyst	Charging	30 min	No
Interview 3	Charging Analyst	Charging	30 min	No
Interview 4	Ph.D. Candidate	Mission Electric Freight	45 min	Yes
Interview 5	Charging Analyst	Charging	30 min	No

**Table 3.4:** Summary of scenario model workshop

<b>Workshop</b>	<b>Reference</b>	<b>Role of participant:</b>	<b>Team / Department</b>
Workshop 1	WS participant 1	Operations Analyst and supervisor at the case company	Solution Development

### 3.2.1.2 Scenario model

As mentioned in the background, while public charging stations exist for METs, there is not yet any public charging station for AETs, which means that there is no empirical evidence of sunk costs related to replacing MET chargers with AET chargers. To respond to the immaturity of AET charging, the researchers developed a techno-economic scenario model of what a hypothetical decision to replace a MET charging system with an AET charging system would imply. The implications of replacing MET charging with AET charging were illustrated by comparing two different scenarios of how charging infrastructure could be installed on a selected transport route. The scenario model was representing a single case, bound to one transport route, of how niche-niche interaction could take place between MET charging and AET charging. Hence, the scenario model was developed in order to generate findings about the techno-economic perspective, e.g. in terms of comparing sunk costs from investments in MET charging.

There are various possible ways to optimize such scenarios, e.g. placing chargers in a way that perfectly matches the driver break or placing charging stations that maximize the distance that is conducted by AETs. In this study, scenarios were optimized based on minimizing charging hardware investments since the high investments in charging infrastructure are highlighted as a barrier towards adoption. It is plausible that the results would have been different if the scenarios had been optimized based on the other conditions. Since there are various ways to build up and optimize such scenarios, the chosen scenarios did not aim to represent all possible transport routes but rather highlight several charging issues that can be encountered when AETs are introduced. Moreover, the techno-economic scenario model included several assumptions, e.g., the assumption that AET charging was conducted with inductive chargers. As mentioned, several other technologies were plausible for AET charging. For instance, battery swapping would have implied different assumptions and requirements that would change the scenario model results.

As mentioned previously, high initial investments create incentives to continue along a chosen path (Onufrey & Bergek, 2015). This means that investments concern individual decisions of a firm or individual and as mentioned in the background, the road haulage industry is characterized by low margins which make actors prone to make decisions based on cost-optimization. The scenario model was aiming to highlight the impact of investments for an individual actor by quantifying the size of sunk costs as well as other logistic consequences initial investments in MET charging would imply for AET charging. Moreover, the scenario model helped to quantify

what technological improvements within for example chargers would imply for a single transport route, hence illustrated learning effects within the technological dimension. Additionally, the scenario model also helped to illustrate what the introduction of AET charging would imply in the societal dimension by identifying certain requirements and bottlenecks in the logistic setup.

#### 3.2.2 System perspective

The system perspective included various actors to get multiple perspectives on investment and learning effects for MET charging and broaden the analysis in the three dimensions technology, knowledge and know-how and societal. Therefore, external interviews with various actors in the industry were conducted. The interviewees were chosen because they in one way or another had been part of the development of MET charging and therefore were considered relevant to the research questions of the study.

Semi-structured interviews were conducted with people outside the case company to obtain an understanding of the system perspective. During a semi-structured interview, the interviewer possesses an interview guide constituted by a list of questions or topics that should be covered in the interview, but the interviewer is not restricted to following these questions exactly (Bell et al. 2019). For instance, the interviewer could add follow-up questions if something of interest came up during the interview, or change the order of the questions depending on what appears natural in that specific context (Bell et al. 2019). The interview questions in the study were divided into the three identified dimensions in the analytical framework and adapted depending on who was interviewed. In total, 15 external interviews were conducted with various actors presented in Table 3.5. To get multiple perspectives in the analysis of the dimensions, the interviewees represented a wide variety of actors ranging from shippers to agencies as seen in Table 3.5. However, all interviewees represented Swedish companies or agencies and while some of them had an international perspective, the findings retrieved from these respondents are mostly limited to the Swedish context.

All interviews were conducted online through video conference calls and most of them were recorded to be able to go back and re-listen. During the interviews, one researcher was responsible for asking questions and the other one took notes. Afterward, the researchers coded all interviews on their own by mapping results in the three dimensions: the technology dimension, the knowledge and know-how dimension, and the societal dimension. Then, the researchers went through the coding together and compiled the results by grouping them by themes within the dimensions in the analytical framework. If there were some parts of the coding that did not match, the researchers went back to the recording to re-listen and agreed upon the interpretation.

**Table 3.5:** Summary of conducted external interviews.

Reference	Type of company	Role of the respondent	Time	Recorded
Interview 6	Agency	Senior Expert	1 h	Yes
Interview 7	Agency	Senior Advisor	1 h	Yes
Interview 8	Agency	Chief Strategist	1 h	Yes
Interview 9	Agency	Senior Advisor	1 h	Yes
Interview 10	Agency	Expert	1 h	Yes
Interview 11	Research institute	Unit Manager	1 h	Yes
Interview 12	Interest organization	Expert	1 h	Yes
Interview 13	Science park	Project Manager	1 h	Yes
Interview 14	Shipper and carrier	Transport Developer	1 h	Yes
Interview 15	Shipper and carrier	Transport Manager	45 min	Yes
Interview 16	Carrier and transport company	Business Area Manager	1 h	Yes
Interview 17	Carrier	CEO	1 h	Yes
Interview 18	Carrier	CEO	1 h	Yes
Interview 19	Carrier	Customer Manager	1 h	Yes
Interview 20	Charger	Manager	1h	Yes

### 3.2.3 Integration of techno-economic perspective and system perspective

In line with systematic combining described by Dubois & Gadde (2002), empirical data and case analysis, as well as theoretical concepts, evolve at the same time. The integration of a techno-economic perspective and a system perspective was therefore argued to result in a holistic approach to answering the research questions of the study. Further, to triangulate the study, internal workshops were held based on selected results from the scenario model and external interviews.

After compiling results from the scenario model and external interviews, two internal workshops were held at the case company to get their perspectives on the results. As the results from the scenario model and the external interviews had been ambiguous in terms of investments in the technology dimension, investments were chosen as the focus subject for the workshops. The purpose was to get a deeper understanding of to what extent investments in charging infrastructure in terms of placement and hardware could be reused in an autonomous future, or if investments

that were made for MET charging would result in large sunk costs. As the case company is engaged with MET charging while simultaneously having the ambition to diversify into AET charging, the case company was believed to bring relevant perspectives to the discussion. The discussion points in the workshop were based on the results from the scenario model as well as some selected results from the external interviews. The selection of discussion points was examined together with the supervisor at the case company. Findings that were considered more provoking and uncertain were prioritized. This way, the results from the scenario model and external interviews were triangulated with the results from the workshop. The primary discussion points are listed in Appendix B.

The participants were from different departments at the case company, presented in Table 3.6. The workshops were 45 minutes each and held online. To gather the participants' thoughts in a structured way, the online-tool Miro was used where participants could write down their ideas.

**Table 3.6:** Summary of workshops 2 and 3 from the case company.

<b>Workshop</b>	<b>Reference</b>	<b>Role of participant:</b>	<b>Team / Department</b>
Workshop 2	WS participant 2	Vice President Product	Software
Workshop 2	WS participant 3	Vice President Product	Charging
Workshop 2	WS participant 4	Project Manager	Operations
Workshop 2	WS participant 5	Project Manager	Project Deployment
Workshop 2	WS participant 6	Charging Installation Lead	Charging
Workshop 3	WS participant 7	Customer Operations Director	Operations
Workshop 3	WS participant 8	Project Manager	Project Deployment
Workshop 3	WS participant 9	Charging Analyst	Charging

### 3.3 Methodology discussion

To evaluate the quality of a study, Mason (1996) argues that reliability, validity, and generalizability could be used for qualitative research. Further, the three concepts are related. For instance, even though reliability and validity are distinguished, they are related since validity is presuming reliability (Bell et al. 2019). Also, the authors argue that validity and generalizability are connected because generalizability refers to external validity. The following section is discussing the quality of this study and is divided into reliability, validity, and generalizability.

### 3.3.1 Reliability

Reliability refers to how consistent a concept is and whether one could trust the results of a study (Bell et al. 2019). To ensure that one could trust the results, other researchers should be able to replicate the study. The researchers aimed in this chapter to describe in detail how the research was carried out to allow others to follow the process. Further, in order to ensure the inter-rater reliability of the study, coding was used as an analysis method since it enabled the researchers to code separately and then go through the coding together and agree on interpretations. Also, coding enables other researchers to review the study which implies transparency and increased reliability. A limitation of the coding method is however whether there have been misinterpretations in the interviews. For example, if the interviewee misunderstood the question or if the researchers misunderstood the answer leading to wrong interpretations (Bell et al. 2019). Misinterpretations were partially mitigated by letting the supervisors iterate the interview questions and thereby reducing possible misinterpretations originating from unclear questions. As the supervisor at the case company has experience of the industry, this also assured that questions were asked in a way that would be understood by industry actors.

A weakness regarding the replicability of the study is anonymity, i.e it is not possible to replicate the study since the case company and all interviewees are anonymous. Moreover, some of the assumptions in the scenario model were confidential which contributes to reducing replicability. Also, since AET charging is immature, the results from the interviews and the scenario model are based on current assumptions and requirements of AETs. Hence, these requirements and assumptions are to some extent speculative as they could change in the future if AETs develop. The actual impact of MET charging on AET charging can, therefore, not be identified until AETs are more mature. As uncertainty decreases while the niches mature, it could therefore be of interest to investigate how the actual interaction played out.

### 3.3.2 Validity

Validity refers to whether the study investigated what was intended to be investigated (Bell et al. 2019). Regarding the scenario model, assumptions regarding the different scenarios were verified during the initial interviews as well as by the supervisor at the case company. However, as the scenario model was built on many assumptions about the future and included several simplifications, it could be questioned. At the same time, the assumptions that have been made to calculate investments and the efficiency of the different scenarios were not argued to be anything more than assumptions and the aim of the scenario model was not to generate an exact value of the efficiency, but rather to highlight the possible difference in efficiencies between different scenarios depending on the investments that were made. By building the different scenarios based on the same assumptions, some sorts of insights could still be gained about the different relative performances of the scenarios.

The interview questions were formulated based on each dimension and therefore related to the theoretical framework, see Appendix A. Further, validity was strength-

ened as the interview questions were discussed and iterated with both the supervisor at the case company and the supervisor at Chalmers. This way, it was ensured that the interview questions were to answer the research questions and that they were formulated concisely. Further, as described before, two internal workshops were conducted after compiling results from the interviews and scenario model. The theme of the workshops was investments in terms of placement and hardware since that had been ambiguous results from interviews and the scenario model. This way, another source of data was used to complete what was missing. In literature, the use of more than one method or source of data is referred to as triangulation which is strengthening the validity of a study (Bell et al. 2019).

#### 3.3.3 Generalizability

Generalizability is related to what Bell et al. (2019) refer to as external validity, i.e the degree to which findings in a study can be generalized to other contexts. Researchers often discuss case studies in terms of external validity, since it appears puzzling how a single case can be representative yielding findings that can be applied more generally to other cases, which is seen as a problem for qualitative research (Bell et al. 2019). This study did not aim to make generalizations about the specific case, but rather make theoretical implications about niche-niche interactions. This is in line with Flyvbjerg (2006) who argues that the purpose of qualitative research is not to make empirical generalizations about entire populations, but instead that the findings from qualitative research should be used to make theoretical generalizations.

Regarding the scenario model, generalizability was ensured by carefully choosing the case (Flyvbjerg, 2006). By selecting a case that is “most likely” to prove a hypothesis, one could draw conclusions in line with the argumentation “*If it is not valid for this case, then it is not valid for any (or only a few) cases*” (Flyvbjerg, 2006). The selected transport route in this study was assumed to show high sunk costs from MET charging. Hence, if the result from the scenario model would not show sunk costs one could argue that if sunk costs did not exist even in a case where they were likely to be present, then sunk costs would probably not exist for any, or only a few, other transport routes.

Concerning the external interviews, small samples are argued to be a problem regarding generalizability for qualitative research (Bell et al. 2019). This study included 15 external interviews and to increase generalizability, more interviews with different actors could have been conducted. However, due to time constraints that were not possible in this study. Further, generalizability could also be discussed regarding how the interviewees were chosen. The researchers first sampled a small group of participants that were relevant to the research. These participants were then asked to suggest others with relevant experience to the study, who in turn were asked to suggest others. This sampling technique is referred to as snowball sampling and is criticized due to its low probability of being representative of the population, hence reducing the generalizability (Bell et al. 2019). However, as argued by Flyvbjerg (2006), a representative case or a random sample may not be the appropriate strat-

egy when the aim is to attain the greatest possible proportion of information on a given phenomenon. Instead, one should choose the case that reveals more information and is able to deeply describe insights about the phenomenon. In this study, participants that appeared to have an interest in future developments of AETs and had engaged in MET charging were considered to be more relevant and probable to generate insights about the research question. However, a weakness of the sampling method used in this study was that the researchers could have missed important aspects when omitting actors from the initial sampling which could have had an impact on the results. At the same time, due to the time constraints mentioned above, there was not much choice but to choose a few actors.

Further, the thesis studies charging in the road haulage industry within a Swedish context which implies that the results of the study might have been different if the study had been conducted elsewhere and hence could impact the generalizability. For instance, countries differ in terms of MET adoption, AET adoption, regulations, grid capacity, and land availability which indicate that countries could differ in terms of what investment and learning effects are present within MET charging. Moreover, these differences could also imply that the resulting mirroring externality from these effects could vary between countries.

#### **3.3.4 Overall methodology assessment**

In summary, when we have looked at the various quality measures of the study we could conclude that there are some limitations with the study. One of the most critical ones is argued to be the anonymity of the study since it affects the replicability of the study. Also, the fact that the study only included Swedish interviewees was seen as a limitation as it narrows the generalizability. However, what was strengthening the study were the various perspectives included in the study: the developed scenario model, 15 external interviews, and workshops with the case company. In addition, interviewees and workshop participants were carefully chosen which contributed to obtaining a deep understanding of the research topic.

#### **3.3.5 Ethical considerations**

Bell et al. (2019) stress the importance of ethical considerations when conducting research and avoiding any type of harm. This applies to the result of the study as well as chosen methods and people involved in the research. When conducting interviews, interviewees were asked if they were comfortable with the researchers recording the interview and personal information was excluded from the final report. In addition, all recordings were deleted when the study was completed, according to the guidelines regarding GDPR. Further, the interviewees were informed about the aim of the study before the interview and told to only answer questions they felt comfortable with. Concerning confidentiality for both the case company and the external actors, the report was written anonymously.

# 4

## Scenario model results

The following chapter presents the results from the scenario model. The scenario model depicts a transport route, i.e. a specific route that trucks are transporting goods upon, and three scenarios of how chargers can be installed on that route: one scenario that represents how a charging system can be built up in 2022 and operated by METs, and two future scenarios that represent how transport can be conducted in the future with a mixed fleet of METs and AETs. Further, the scenarios in the scenario model are depicting fictitious cases of how charging can be installed, and do in no sense argue that these are the only ways one can operate the transport route. The chapter starts by presenting the selected transport route followed by an outline of the most basic assumptions. Additional assumptions are listed in Appendix C. Several assumptions have been made regarding the logistic setup which are not outlined in Appendix C due to confidentiality reasons. However, we argue that understanding these assumptions is not crucial as the importance for further discussion in the thesis instead lies in the outcome of the scenario model. Lastly, the scenarios will be presented and compared in terms of charger hardware cost and efficiency.

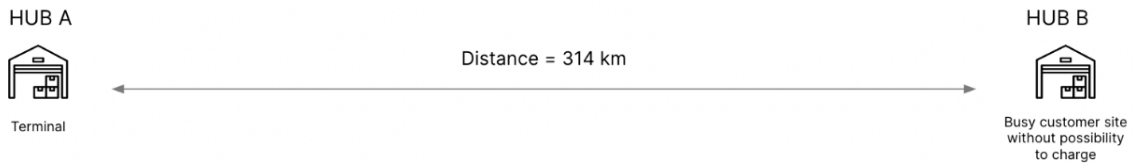
### 4.1 Selected transport route

The transport route that was selected for the scenario model is a long-haul route, which in this thesis refers to a distance that requires en route charging since the distance is longer than the range of an electric truck in 2022. In order to determine the exact distance, we used the distance of a real-world route with a high transport demand with goods being transported back and forth on a one-way distance of 314 km. As this route is currently driven by diesel trucks, there are no charging stations in the real-world scenario. The charging locations in the scenarios are, therefore, depicting a fictitious case where there are METs.

The choice of a long-haul route is based on two considerations. First, these distances currently appear to be the least suitable in practice for METs, but are nevertheless necessary for a transition of the current diesel and fueling regime. Many routes that are electrified today are shorter distances that do not require expensive investments in a complex charging system. Instead, the MET can conduct a short delivery and then return to its home site to charge overnight with a slow charger. For longer distances, i.e. where the one-way distance is longer than the vehicle range, the vehicle needs to stop en route to charge as it otherwise would not be able to make it to the

destination. Second, the long-haul routes are more suitable for automation as they are the least popular routes among drivers, and therefore are particularly subjected to driver shortages, and also include a higher proportion of highways (McKinsey & Company, 2018).

The transport route of 314 km is, thus, a route between two hubs (see Figure 4.1). The transport route has deliveries in both directions, i.e., goods need to be transported from a larger logistics terminal (Hub A) to a customer warehouse (Hub B), but goods also need to be transported from the customer warehouse (Hub B) to the terminal (Hub A). Most of the distance is conducted on a highway, but Hub B is situated in a more complex city environment, where charging is not possible. All scenarios illustrate different ways that charging stations can be installed for the goods to be delivered.



**Figure 4.1:** The selected transport route in the scenario model is a long-haul back-and-forth between Hub A and Hub B

The decision to let most of the distance take place on a highway originates from the assumption that AETs are closer in time to conduct transport on highways than other routes such as city routes (McKinsey & Company, 2018). In the report *Distraction or disruption? Autonomous trucks gain ground in US logistics* by McKinsey & Company (2018), it is assumed that local drivers will take over the control of the vehicle when the truck leaves the highways. This shift is illustrated in the selected transport route by letting the last part of the distance depict a more complex city environment that is assumed to require a driver at least in the near future. This way, the transport route also illustrates the coexistence of METs and AETs that was mentioned in the background. The impossibility to charge at Hub B reflects the difficulty that the case company sometimes experiences at customer sites (Interview 3; WS participant 1).

## 4.2 Assumptions

All assumptions in the scenario model were made together with the case company as a result of initial interviews and the scenario model workshop. As the scenario model depicts two future scenarios, several assumptions about future technological developments were made. The most crucial ones are listed in subsection 4.2.1. Assumptions related to charger hardware cost and efficiency are described in subsection 4.2.2.

### 4.2.1 Assumptions about technological developments

To illustrate that the niches differ in terms of maturity, the scenario model assumes that AETs would not be able to operate on the roads in 2022 but to drive on highways in the future scenarios. It is also assumed that the future will imply longer truck ranges due to improvements in battery developments. The scenario model also assumes that AETs and METs will have the same ranges. Further, it is assumed that the AETs will be charged with non-manual inductive chargers since there is no driver that can plug a manual charger into the AETs, while METs will continue to be charged by manual conductive chargers. The main differences between the current and future time frame are summarized in Table 4.1.

**Table 4.1:** Assumptions about current and future transport system.

<b>Time frame</b>	<b>Type of tractor</b>	<b>Range</b>	<b>Type of Charger</b>
Current (year 2022)	AETs cannot operate on highways. The distance is only operated by METs.	120 km	Manual conductive chargers are installed
Future (no specific year)	AETs and METs coexist. The AET is not mature enough to drive in city environments, which means that the last part of the distance must be conducted by a MET.	350 km	Manual conductive chargers are installed for METs and AETs are charged with non-manual inductive chargers.

### 4.2.2 Underlying assumptions for charger hardware cost and efficiency

The scenario model compares the scenarios in terms of charger hardware cost and efficiency. These metrics are the result of the different set-ups and assumptions that follow each scenario. However, some general assumptions and factors influence these metrics in all scenarios.

In short, charging hardware cost is calculated based on an indicative cost per charger outlet multiplied by the number of necessary charger outlets in each scenario. The indicative cost per charger outlet and the number of chargers required are, in turn, determined by several assumptions listed in Table 4.2.

Efficiency is measured in terms of the total weight of the transported goods multiplied by the total distance driven. Some factors that could impact the efficiency are listed in Table 4.3. These factors could, in principle, be modified in the scenario model, but standard values were set to compare the scenarios. A more comprehensive description of the assumptions is listed in Appendix C.

**Table 4.2:** Factors that determine the charger hardware cost.

Factor	Motivation
# Charger outlets per charging station	To decrease the complexity of timing issues that would occur if several trucks shared a charger outlet, it was decided to assume one charger outlet per truck per charging station. This assumption is rather conservative as several trucks could share a charger if they do not need to charge simultaneously and use the same charger type.
Non-manual or manual charger	The cost per charger outlet depends on what type of charger it is. It is assumed that non-manual chargers are more expensive than manual chargers.
Fast or slow chargers	It is assumed that the faster chargers installed in the future are more expensive than the slower chargers installed in the current scenario.

**Table 4.3:** Factors that determine transport efficiency.

Factor	Motivation	Standard value
Delivery window	The longer delivery windows, the more goods can be transported and the longer distances can be driven during a day.	8 hours
# Trucks per scenario	The more trucks that operate the flow, the more goods can be transported and the longer distances can be driven during a day.	12 trucks (transport demand is spread evenly across the installed trucks)
Charger power	The faster chargers, the faster the charging time. If there is no other reason for the truck to stand still (e.g., mandatory driver break), this means that the round-trip time is shortened which implies that the trucks have time for more round-trips within the set delivery window. This way, charger power can influence the number of goods that can be transported and the distance that can be driven during a day.	Current scenario: 150 kW  Future scenarios: 500 kW for both manual and non-manual chargers

### 4.3 Scenarios

As mentioned, the scenario model aims to highlight externalities that originate from investment and learning effects from METs by comparing two future scenarios that include AETs. In the first future scenario, MET charging infrastructure has already been installed on the route. This implies that the future scenario (Scenario 1b) cannot be explained without explaining the current scenario (Scenario 1a). In the second future scenario (Scenario 2), the route has not been electrified earlier and thus represents a scenario where AETs immediately replace diesel trucks and fueling stations without METs as a ‘middle step’. Hence, Scenario 2 is standalone and detached from other scenarios. In Scenario 1a, charging infrastructure is optimized with the current conditions in mind, while Scenario 2 is optimized based on future conditions and AETs. However, as mentioned in Chapter 3 the transport route can be optimized in several different ways, depending on future conditions, and

Scenario 2 illustrates one way this can be done. The scenarios will be presented in the following order: Scenario 1a, Scenario 1b, and Scenario 2.

### 4.3.1 Scenario 1a: Current scenario

Scenario 1a illustrates how the route could be electrified in 2022, and what a feasible operational set-up could look like then. In Scenario 1a, the long-haul is populated by METs with a range of 120 km, which implies that the maximum range between charging stations is 120 km (Figure 4.2). This results in the three en route charging stations and one charging station at Hub A, where the truck can charge while the driver loads the vehicle with goods. Figure 4.2 illustrates where the charging stations are located and the chargers required to conduct the transport routes based on the assumptions listed in Table 4.1 and assumptions regarding the logistic set-up. The trucks are operated in a manner so that the full transport demand is spread evenly across the trucks, and the charging sessions are planned as optimized as possible given technical prerequisites in vehicles and chargers.

Compared to when the distance is driven with a diesel truck, this scenario implies longer operational time as the trucks must stop to charge at the charging stations. For instance, when a truck that has been driving from Hub A reaches charging station 1, it has to stop to charge for 1 hour and 45 min (with the current charger power), which implies that 45 minutes of the charging time can be completed while the driver has the mandatory driver's rest, but the additional charging time that is required could be considered a logistic loss, i.e. an inefficiency that would not have existed if the transport had been conducted with a diesel truck. However, there are several ways in which the logistic losses can be minimized, e.g., with faster chargers or that a trailer can be dropped and be picked up by another truck.

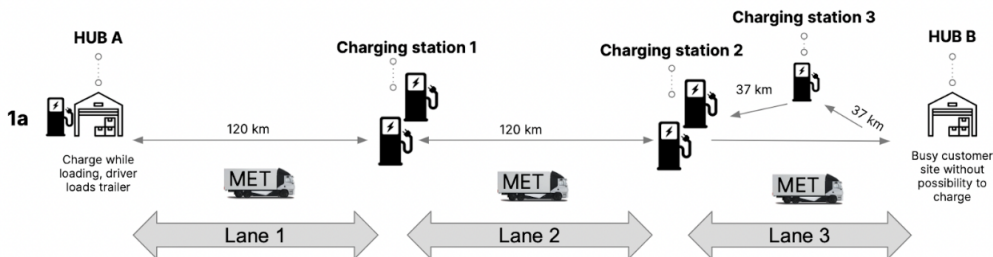


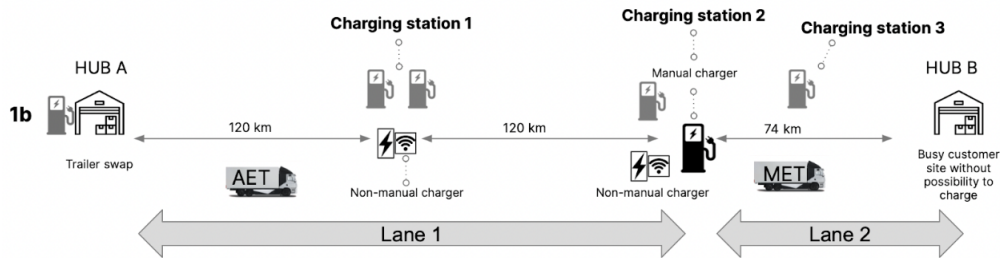
Figure 4.2: Illustration of Scenario 1a.

### 4.3.2 Scenario 1b: Future scenario

Scenario 1b depicts how the charging system built in Scenario 1a can be adjusted to meet the requirements of AETs. Hence, in this scenario, there is a mixed fleet with AETs and METs where some manual chargers have been replaced with non-manual chargers (see Figure 4.3). This is based on assumptions presented in Table 4.1 as well as assumptions regarding the specific logistic set-up. While a MET still operates the last part of the distance, one AET replaces two METs and Lane 1 and Lane

2 in Scenario 1a are now merged into one longer lane (see Figure 4.3). As AETs in this scenario drive the part of the distance that starts from Hub A, no driver can load and unload the truck at Hub A. Therefore, warehouse personnel is assumed to preload a trailer that can be mounted on the AET when it arrives at the HUB A, i.e. trailer swapping.

The changed conditions make some of the already installed chargers obsolete (represented by gray charging stations in Figure 4.3). For instance, the manual conductive chargers installed at charging station 1 have to be replaced with new non-manual chargers, as no METs drive past the station anymore. While some of the manual conductive chargers at charging station 2 can still be used by the METs, some of these chargers have to be replaced with non-manual chargers as the AETs have to be charged at charging station 2 as well. Hence, both charger types are installed at this charging station. The replaced charging hardware can be considered sunk investments from Scenario 1a. Similarly, the manual chargers installed at Hub A are also included as sunk investments from Scenario 1a, as no MET start or stops at Hub A. However, there is no need to invest in a new non-manual charger at Hub A since the ranges are longer and the AET is trailer swapping and therefore not spending much time at Hub A. Moreover, the extended ranges also rendered charging station 3 obsolete. The costs of these obsolete charging stations are included as sunk investments from Scenario 1a.

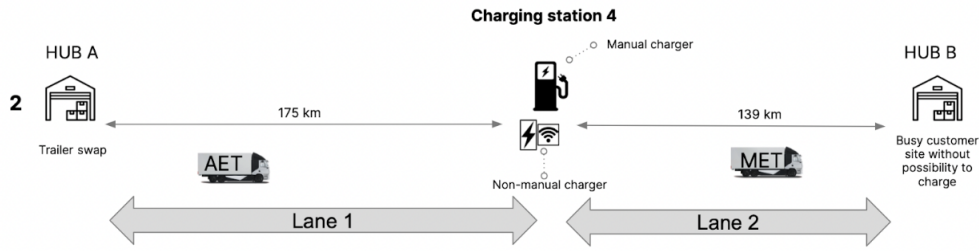


**Figure 4.3:** Illustration of Scenario 1b.

### 4.3.3 Scenario 2: Future scenario

Scenario 2 illustrates a scenario where the long-haul route had not been electrified earlier, which meant that no prior charging infrastructure exists. This means that chargers could be installed and optimized based on future conditions, without any legacy of old decisions.

As mentioned before, the placements of chargers were chosen to minimize the charger hardware costs, i.e. to install as few chargers as possible. This scenario therefore only has one charging station, which includes both manual conductive chargers and non-manual inductive chargers. The charging station is placed so that the AET can drive as long as possible before it has to stop to charge (Figure 4.4). Similar to Scenario 1b, this Scenario also requires the warehouse personnel to load and unload the goods at Hub A.



**Figure 4.4:** Illustration of Scenario 2.

## 4.4 Comparing the scenarios

The scenarios were compared in terms of charger hardware investment costs and efficiency. The charging investment cost depends on how many charger outlets are needed as a consequence of the different logistic set-ups described in the scenarios as well as if the chargers are manual or non-manual. A detailed description of these assumptions, i.e. the number of charger outlets per location and indicative charger hardware costs, are summarized in Appendix C.

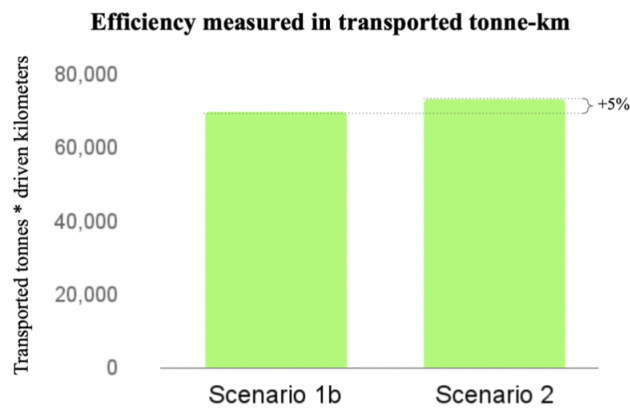
The comparison between Scenario 1b and Scenario 2, i.e. the two scenarios in which METs and AETs co-exists, shows that rebuilding an already installed charging infrastructure for METs to fit AETs (Scenario 1b), is less beneficial than directly building up charging infrastructure for AETs and longer ranges (Scenario 2). More precisely, the results show that:

1. Scenario 2 is 5% more efficient than Scenario 1b. This means that more goods can be transported in the same amount of time and with the same number of trucks (Figure 4.5).
2. Scenario 2 requires 54% lower total charger hardware installation costs than Scenario 1b (Figure 4.6) and Scenario 2 is 56% cheaper than Scenario 1b in terms of charger hardware cost per transported tonnes km (Figure 4.7).

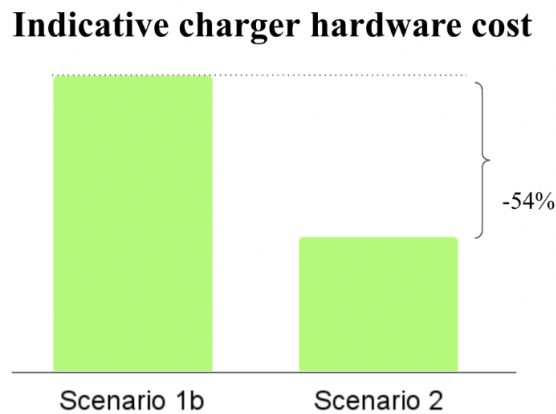
As seen in 1), the scenarios differ in efficiency which means that the two scenarios differ in the number of goods they deliver. Further, in 2), both total charger hardware installation costs per scenario and per transported kilometer are calculated. The first metric does not take into account that the scenarios differ in terms of the number of goods that are delivered while the latter metric is comparing the charging hardware costs of the different scenarios when the same amount of goods are transported.

## 4. Scenario model results

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**Figure 4.5:** Comparison between Scenario 1b and Scenario 2 concerning efficiency, i.e tonnes of transported goods\* km driven per day.<sup>1</sup>



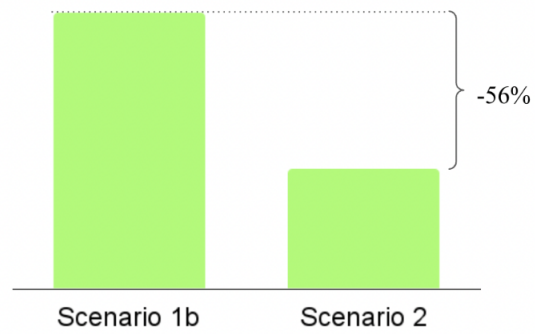
**Figure 4.6:** Comparison between Scenario 1b and Scenario 2 concerning indicative charging hardware cost per scenario.<sup>2</sup>

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<sup>1</sup>Assuming 8-hour delivery windows and chargers of 500 kW.

<sup>2</sup>Indicative charging cost per charger outlet as well as the number of outlets required per scenario are listed in Appendix C. All used chargers are assumed to have a power capacity of 500 kW, while the unused chargers are assumed to have a power capacity of 150 kW.

**Indicative charger hardware cost per transported tonne-km**



**Figure 4.7:** Comparison between 1b and Scenario 2 concerning indicative charging hardware cost per transported tonne-km.<sup>3</sup>

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<sup>3</sup>Assuming 8-hour delivery windows. All used chargers are assumed to have a power capacity of 500 kW, while the unused chargers are assumed to have a power capacity of 150 kW.

# 5

## Investment and learning effects and their externalities

The following chapter synthesizes the results from the scenario model, the external interviews, and the workshops using the analytical framework. The results are therefore structured as follows: technology dimension, knowledge and know-how dimension, and societal dimension. Within each dimension, investment and learning effects within MET charging and their respective influence on AET charging are described.

### 5.1 Technology dimension

The following section presents the technology dimension and is divided into two parts. First, investments in MET charging and how it affects AET charging are presented followed by learning effects and the influence on AET charging.

#### 5.1.1 Investments in MET charging and how it affects AET charging

Regarding investments in the technology dimension, the study highlights two main themes: investments in charging *hardware* and investments in specific charging station *placements* with related investments in grid capacity and groundwork investments. This subsection presents how these two types of investments are expected to lead to positive feedbacks within MET charging and the resulting mirroring externalities on AET charging. The study shows that externalities are dependent on whether the investments are considered sunk costs or not and that the view on sunk costs depends on whether a techno-economic or a system perspective is used.

##### 5.1.1.1 Hardware

The results from external interviews showed a repeated adoption pattern, which could have appeared for several different reasons. For instance, one reason was investments in training, which are required for efficient use of the hardware (Interview 17; Interview 15). When actors start to learn about a new technology and how it works, they are more likely to continue with the same technology and less prone to buy an alternative as the investments in training then would be sunk costs. Another reason for the repeated adoption pattern was that it appeared as invest-

ments in slow chargers made actors more prone to make investments in expensive fast MET chargers after they had invested in slow MET chargers, as the use of slow MET chargers highlighted the benefit of faster chargers. For instance, one of the shippers had invested in slow overnight chargers (22 kW) and had plans to invest in faster chargers at their terminals (Interview 14). The respondent described that they initially would start with a few chargers and then successfully increase the number. Similarly, another shipper described how they had first installed slow chargers of 40 kW, but were now planning to invest in faster chargers at one of their transport routes to decrease charging time (Interview 15). As indicated above, fast chargers shorten the charging session and therefore allow higher utilization of the trucks. The high investment costs associated with the adoption of fast chargers were also a potential reason for continued adoption. Although many of the respondents had not yet invested in fast chargers, it became clear that actors wanted a high utilization of the chargers, which indicates that once actors invest in fast chargers, they will want to further exploit the investments in hardware that they have already made (Interview 14). This was also illustrated by the scenario model, which highlighted that the investments made in Scenario 1a would imply high sunk costs if they were replaced. The repeated adoption pattern indicates that there could be positive feedback. However, we could not determine the positive feedback loop back to charger developers and it is therefore unknown if the adoption of MET chargers could lead to further development of fast chargers. Furthermore, some respondents highlighted that investments in charging hardware will not always result in repeated adoption patterns, as grid capacity could inhibit investments in additional chargers at a location (Interview 14; Interview 18).

Although the above examples show that investments in charging hardware can result in repeated adoption patterns, the most important factor for further adoption, and hence positive feedback, appears to be the number of METs. The more METs, the more MET chargers, but the result also showed that the investments in one MET did not necessarily motivate investments in MET charging. For instance, one of the shippers described one of their transport routes where they used a public charger and argued that even if public charging implied high operational costs, investment in a private charger was not motivated at the site as long as they only had one MET. However, this example also highlights that the investment in the MET was facilitated by another actor's investment in a public MET charging station.

Regarding externalities, both the scenario model results and the interviews imply that investments in MET charging could result in sunk costs and, hence, a negative externality on AET charging. The scenario model shows high sunk costs for Scenario 1b, while no sunk costs were present in Scenario 2. One reason for the sunk costs is the assumption that AETs require another hardware type. Out of the manual chargers installed in Scenario 1a, 75% of them became obsolete when AET charging replaced MET charging (see Appendix C). The assumption in the scenario model that manual chargers will be sunk costs is confirmed by the external interviews as there was a general agreement among the respondents that today's standard with conductive manual chargers will not be used for charging AETs since there is a need

for a non-manual solution. This was highlighted by an agency who argued “*We will not go back 50 years in time where there was personnel who fueled the vehicle for you at a fueling station*” (Interview 6). Several of the respondents argued that high sunk costs can not be neglected. Carriers are already financially pressured by the high truck costs and the overall low margins in the road haulage industry (Interview 19), and those who make large investments in MET charging will want to use the chargers until they are fully depreciated and not invest in non-manual chargers before that (Interview 14).

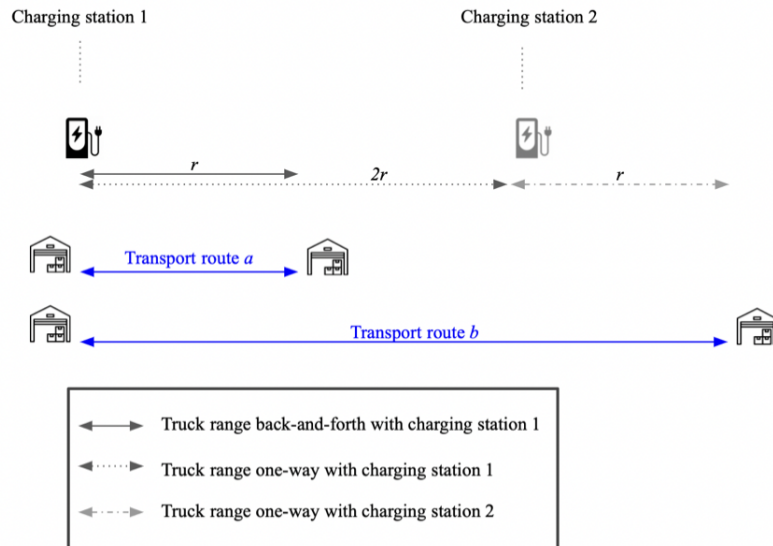
However, other respondents argued that investments in MET charging would not result in sunk costs, as MET charging will not be installed on every transport route at once and the hardware will be replaced organically. One of the respondents stated that “*We are investing in a system that grows organically, not with full capacity at once*” (Interview 6). With this system perspective, AET charging might not experience a negative externality from previous MET charging investments since investments in AET charging will start on other transport routes. For instance, a shipper explained that when AETs are introduced to their terminals they would introduce the new vehicle and charging hardware at other loading docs than the ones on which they have already built MET charging infrastructure. There was a general consensus among the workshop participants during workshops 1 and 2 that the risk of getting locked in is currently small since the transport demand is high and the need for charging stations is probably higher than what is available in the near future. Hence, it is unlikely that all MET chargers will be installed on all routes, which makes it possible to install AET chargers on other routes than the routes that already have MET chargers installed.

Moreover, the timing of a broad AET introduction is unknown and the MET chargers eventually need to be replaced. As described by a workshop participant: “*Technology has its lifetime which means we will have to replace charging stations in the future and maybe that will be at the same time when we see possibilities of driving the AET on highways*” (WS participant 9). Respondents also argued that “*While we of course need to build for the future, we also need to build for the demand we have today*” (WS participant 9; Interview 11). This implies that manual chargers will be the focus in the short term and the focus could later shift to non-manual chargers when AETs are introduced. Respondents also added that AETs probably could be charged manually in the short term even though it is suboptimal and not a long-term solution, which means that if AETs mature before the end of the lifetime of MET chargers they do not need to be replaced immediately. Hence, MET chargers will most likely be used until it is time to replace them.

#### **5.1.1.2 Placement**

The results from the external interviews showed that investments in charging station locations resulted in positive feedback loops that inclined actors to further adopt MET charging on nearby locations. For instance, one of the carriers explained how they had recently opened a charging station and was already planning on building additional charging stations within the same region (Interview 18). Another carrier,

who has been operating METs since 2020, explained how the lack of public charging had initially been severe, but that the public charging station network recently has evolved (Interview 19). This has expanded the possible market for METs as more complex flows now could be electrified. With this logic, an investment in one charging station enables the introduction of METs to the region, and as soon as METs are present in the region, these trucks could diversify into additional transport routes which motivates investments in additional charging stations. An illustrative example can be found in Figure 5.1, where *Transport route b* requires investments in two charging stations, but *Transport route a* only requires investment in one charging station. Due to the high investments required, an actor may hesitate to electrify Transport route b. However, as soon as investments have been made for Transport route a, the actor can use charging station 1 for Transport route b as well and hence only need to invest in one additional charging station.



**Figure 5.1:** Illustrative example of possible feedback loops as a consequence of an investment in one charging station

When it comes to externalities for AET charging, two perspectives could be identified among the respondents regarding whether the placement of charging stations will be reused for AETs, i.e. a positive externality, or if they would be incorrectly placed for AETs and thereby result in sunk costs, i.e. a negative externality. There was a general agreement among the respondents that much of the investments made in a charging station, for example, grid connections and some parts of the larger underground cables, could be reused by AETs, even if the particular charger component had to be replaced (Interview 20; Interview 14; Interview 18, Interview 8). One of the shippers stated that “*More than half of the investment is grid cost, which could be reused*” (Interview 15). Participants from the workshops argued that a flexible hardware design as well as modularity will facilitate the transition to non-manual chargers required for AETs (WS participant 2; WS participant 3). One of the participants stated that “*A modular system allows us to replace the main body*

*of the charger. The main parts of the charging infrastructure regard power purchase agreements and energy sources”* (WS participant 2).

However, in order to obtain these positive externalities from investments in MET charging, the placement has to be relevant for AET charging. In this regard, some respondents argued that AETs will be able to use the same charging stations as METs, despite their differences, hence a positive externality. One agency highlighted that even if AETs imply new charging behaviors, these behaviors might not necessarily imply new locations for charging (Interview 6). One of the factors that were brought up in both external interviews and workshops was that strategically good locations are argued to be where there is transport demand, which meant that charger stations that are built where there is a transport demand will continue to be relevant locations also in the future when AETs are more diffused. One respondent argued: *“The same places will probably be used for AETs since the stations are already strategically at good locations”* (Interview 13). Examples of such locations were mentioned as close to highways, near ports and train depots as well as at entry and exit points to cities. Today’s gas stations were also mentioned as suitable locations by external interview respondents: *“Fueling stations are located strategically close to highways where a lot of goods are passing by. They are therefore likely to be used for METs as well”* (Interview 13).

Another reason why the same charging locations might be used for AETs is regarding grid availability. One of the respondents stated that *“The location of chargers will be a trade-off between the power availability and transport demand”* (Interview 12). The issue of receiving the capacity that is required was mentioned as the biggest challenge for both MET and AET charging (Interview 13). A carrier stated that *“It would have been time efficient if we charged at the terminal at our biggest customer, since we are standing there to load for 1.5 hours anyway, but we could not install the chargers there due to the limited grid capacity”* (Interview 18). Local differences in grid availability have, thus, made actors look for new locations. For instance, some actors are planning charging stations at old disused factories, instead of locations where the competition for grid capacity is more intense (Interview 13). Hence, investments in MET charging at locations with sufficiently available grid capacity will be relevant for AET charging as it requires similar grid availability, i.e. a positive externality. Correspondingly, land availability is an issue for both MET and AET charging. In contrast to fuel stations, MET and AET charging requires more space as the charging sessions are longer than refueling sessions, which might make some locations more or less suitable for charging (Interview 13). Hence, charging stations that are adjusted for METs will also fit AETs, i.e. a positive externality.

In contrast, other respondents pointed out several differences between AETs and METs and argued that optimal placements for MET charging would not be optimal for AET charging, which would mean that even grid connections and other location-specific investments as described above will be sunk costs, i.e. a negative externality. For instance, several respondents emphasized that the increased flexibility that AETs imply could have an impact on the charging location. In contrast

to METs, AETs are more flexible in where to stop for charging (Interview 11; Interview 13). While drivers often require nearby service facilities such as restaurants, an AET charging station could be located in more rural areas (Interview 13). As stated by one of the shippers “*An AET is more flexible and can stop whenever it wants, and the stop does not need to align with the driver’s rest.*” (Interview 14). Hence, several respondents suggested that charging locations would be sunk costs due to the different charging behaviors that AETs imply.

Another example of sunk costs that was highlighted by a workshop participant as well as shown in the scenario model was that charging while loading and unloading might not be the optimal location for AET charging. The scenario model shows that even though charging while loading at Hub A is reasonable when the distance is driven with METs as the driver loads the truck (Scenario 1a), the charging station at Hub A is not needed when the route is operated by AETs (Scenario 1b). That is because AETs require that unloading and loading are performed by warehouse personnel which implies that instead of stopping for a longer time to load the trailers, they can instead be swapped to increase efficiency. This implies that if MET chargers are placed at terminals, which is suggested by external interview respondents, these investments could result in a negative externality for AET charging.

Hence, the techno-economic perspective shows that if MET charging stations are suboptimal for AET operations, actors must contrast the sunk costs to the potential savings in efficiency that the build-up of new, optimal charging stations would imply. Alternatively, they could choose to charge AETs at suboptimal locations.

However, other workshop participants applied a system perspective and argued that even if charging stations become suboptimal for one actor, they would not necessarily imply sunk costs for the overall system as they might be optimal for another actor. As long as the charging stations are located close to roads where a lot of goods pass by, it is likely that another actor can find the location optimal even if it has become suboptimal for the actor that the charging station was originally built for (WS participant 7; WS participant 8; WS participant 9).

### **5.1.2 Learning effects for MET charging and how it affects AET charging**

In this subsection, examples of how MET-related technologies have been improved, resulting in a repeated choice of adoption and/or development are presented. Two themes related to technology development were identified in the study: *technological development of MET chargers* and *technological development of batteries* which are connected and imply positive feedback for MET charging. The resulting mirroring externalities of these feedback loops for AET charging are described.

### 5.1.2.1 Technological development of MET chargers

Technology development in chargers was brought up during the external interviews as chargers are becoming cheaper and faster. According to an interest organization, the price of chargers has declined as the volumes have risen (Interview 12), which indicates that the charger developers have experienced economies of experience and hence imply positive feedback. However, one of the biggest barriers to adoption is the high investment cost which was highlighted by carriers and one of them stated “*We chose to not buy powerful chargers due to the high investment cost. While a 40 kW charger costs 150 000 SEK, a 300 kW charger costs 2 million SEK*” (Interview 15). This indicates that even if chargers have become cheaper, the niche is still relatively early in its development and charger developers have not reached the desired levels of price/performance ratios that attract the mass market.

A key metric for increased charger performance is the ability of chargers to deliver higher power, which allows for faster charging sessions (Interview 12). Recent years have shown substantial development in this metric and most fast chargers have a power capacity of 175 kW or above, indicating positive feedback for MET chargers (Interview 9). According to an agency, charger developers have learned that higher capacity is needed for trucks and a new standard has been developed that is expected to deliver 1000 kW before 2025 (Interview 9). The results show that actors who get the opportunity to adopt fast MET chargers are more likely to continue to adopt MET charging. For instance, shippers and carriers agreed on the benefits of faster chargers for MET charging since it implies fewer logistic losses. There is a general agreement among the respondents that to achieve better performance of the charging system and a cost-effective logistic set-up, the logistic losses that non-opportunity charging implies need to be minimized and trucks should charge when the vehicle stands still (Interview 9; Interview 6; Interview 12; Interview 19; Interview 20; Interview 14). One of the carriers explained that non-opportunity charging sessions could be the result of slow chargers and described that faster chargers were one of the reasons why they were now resuming one of their previously tested transport routes (Interview 19). The transport route had previously included six hours of charging time, but the new charging station with faster chargers would shorten the charging time by 3 hours. This implies that using fast chargers results in better performance, which makes the carrier more prone to continue to adopt, i.e a positive feedback. The carrier stated: “*Six hours of charging is very inefficient, and the driver is left with not much to do*” (Interview 19).

The benefits of fast chargers were also shown in the scenario model, as faster chargers resulted in less or no non-opportunity charging. For example, with a 150 kW charger, the charging times exceeded driver breaks in all scenarios. When fast chargers with 500 kW were used instead, non-opportunity charging for the MET lane in Scenario 1b was completely removed, as the truck was able to complete the required charging during the driver break (see Appendix D). Fast chargers hence increase the utilization of trucks as less or no time is required for only standing still and charging. It also results in better performance for the entire system and lowered costs since the same amount of goods can be transported in less time, and, consequently, at a

lower cost. Hence, the results indicate that improvements in charging technology, i.e. faster chargers, increase the adoption of MET charging, but the results could not determine the feedback loop back to the charging developers. However, the improvements in chargers suggest that developers are experiencing learning-by-doing as a consequence of their initial choice to develop slow chargers and knowledge about customer demand.

Technology development for MET charging does not have to mean technology development for AET charging since the two truck types may be charged by completely different technologies. Even if a non-manual technology could reuse the advancements made in manual chargers, it is not known if faster chargers are beneficial for AETs. There is no general agreement among the respondents and the scenario model about the relevance of fast chargers for AETs. From one standpoint, the consequence of logistic losses is smaller for AET charging as these sessions are exempted from labor costs (Interview 13). From another standpoint, AET vehicle costs are higher and there is no driver break that motivates the truck to stand still (Interview 13). This is also shown in the scenario model where all AET charging is non-opportunity charging which suggests that while the benefit of faster MET charging has an upper limit, i.e. there is no need to have shorter charging sessions than the driver break, AET charging could benefit from even faster chargers than METs (see Appendix D). Hence, the mirroring externality of these feedback loops is unknown. Nevertheless, what could be said from the scenario model is that the transport routes that include both METs and AETs are more efficient when manual chargers are faster as the overall system is performing better.

### 5.1.2.2 Technological development of batteries

Although technological improvements of batteries are related to truck development and could be argued as being out of the scope of this study, battery development was recurrently mentioned by the respondents as crucial for MET adoption and therefore also for MET charging adoption. For instance, one of the shippers explained how they define which flows are suitable for electrification by investigating what flows have a distance that works with the battery range. That implies that better batteries lead to increased adoption of METs and MET charging, creating a positive feedback loop.

Both workshop participants and respondents from external interviews highlighted that battery improvements lead to extended ranges. For example, a battery with 1000 kW will be bigger and have a longer range than one with 300 kW. A battery with higher capacity implies longer charging sessions which further incentivizes the development of fast chargers (Interview 3). Faster chargers are more expensive than slow chargers, which means that bigger batteries demand more expensive chargers (Interview 3). However, the scenario model illustrates how increased ranges as a result of battery development can decrease charger investment costs, as fewer charging stations are needed to transport goods between Hub A and Hub B. For instance, when ranges became longer in Scenario 1b, charging station 3 was not needed. Moreover, Scenario 2 illustrates that only one charging station was needed

to cover the charging demand. As charger investment costs are one of the major barriers to MET charging adoption, reduced investment costs in charging stations could increase adoption, i.e. resulting in a positive feedback.

Other than increased battery size, i.e. higher power capacity, workshop participants mentioned that batteries could also improve in terms of efficiency. Improved battery efficiency implies lowered energy consumption of the battery, which means that the battery lasts longer without increasing in size. With increased ranges, trucks do not need to charge as often as before and, consequently, fewer chargers are needed and the charging investment cost can be reduced. In contrast to increased bigger batteries as described above, more efficient batteries do not demand higher charging capacity (WS participant 9). Increased efficiency in batteries would hence imply fewer charging stations but without having to invest in faster and more expensive chargers. Respondents also mentioned that longer ranges increase flexibility on when to charge which makes it possible to optimize charging based on energy prices. This increases the performance of both the MET and AET charging systems as operational costs are reduced when electricity can be purchased for more favorable prices.

Battery development as a consequence of MET adoption implies positive feedback for METs and hence also for MET charging, but also a positive externality on AET charging. The scenario model also shows that even though METs do not need to stop to charge as often as a consequence of battery improvement, they still have to stop for driver breaks. However, this is not relevant for the AETs since there is no driver and the benefits of battery improvements are hence not limited by drive and rest regulations. Respondents also agreed that battery development will benefit AET charging and one respondent argued that “*The development for METs and AETs follow each other, i.e. battery improvements will also be relevant for the future with AETs. However, the design of AETs might be different, and if it is less expensive to charge AETs when there is no driver cost one might use smaller batteries*” (Interview 6). Hence, although it is still unknown what the optimal battery size will be for METs and AETs, improvements in batteries will increase flexibility and benefit both MET and AET charging.

## 5.2 Knowledge and know-how dimension

This section presents the knowledge and know-how dimension and is divided into two parts. First, investments in MET charging and how it affects AET charging are presented followed by learning effects and the influence on AET charging.

### 5.2.1 Investments in MET charging and how it affects AET charging

Investments in the knowledge and know-how dimension will regard *investment in training*. This subsection presents how investments led to positive feedbacks within MET charging as well the resulting mirroring externalities on AET charging.

From the external interviews, it became clear that the industry has learned about electrification and charging through investing in test pilots and participating in knowledge-sharing forums including various actors (Interview 6; Interview 10; Interview 13; Interview 16). The investments in training have resulted in actors being convinced that electric trucks and charging work and hence are becoming more prone to adopt an electric fleet, i.e. positive feedback for MET charging. One of the respondents stated, “*The pilot projects that have run over the recent years have contributed to the learning that electric heavy-duty trucks actually work*” (Interview 13). Similarly, a carrier emphasized the need for education to lower the threshold and stated that “*To be able to electrify, one must understand how it works and what it would mean to invest in an electric truck and charging infrastructure. Do I dare to acquire an electric truck?*” (Interview 16). Respondents also argued that even driver-specific knowledge contributes to the positive attitude toward electric trucks and will have a positive impact on charging for AET since actors develop their knowledge about charging in general. One of the respondents argued that “*We are learning now and taking that with us in the transition to autonomous*” (Interview 17).

Shippers and carriers also emphasized the importance of involving the driver early on in the process and training them to get used to how driving and charging work. One carrier argued that knowledge related to electric driving and charging, both theoretical and practical, should be included in the recurring driver education that every driver in Sweden is obliged to take part in (Interview 17). This type of driver training is however not relevant when going autonomous since AETs have no drivers, and some respondents, therefore, argued that the specific training investments for drivers would be sunk costs, i.e. a negative externality when AETs replace METs.

## **5.2.2 Learning effects for MET charging and how it affects AET charging**

Learning effects that were identified within the knowledge and know-how dimension are related to operational knowledge in the MET charging niche. In this subsection, examples of newly developed skills and routines that improved the performance of the MET charging niche, resulting in a repeated choice of adoption and/or development, are presented. Two themes were identified in the empirical results: *skills within battery management and schedule optimization* and *application routines for charging infrastructure*. The resulting mirroring externalities of these feedback loops are presented.

### **5.2.2.1 Skills within battery management and schedule optimization**

Respondents from external interviews explained how they have developed know-how that has improved their MET operations to work more efficiently and thereby resulted in decisions to continue with METs and related charging activities, i.e. positive feedback. Carriers explained that in contrast to refueling, planning is a critical part of MET charging and concerns mostly battery management. Specifically, carriers have learned how to read the battery to know when to charge and how much

which is seen as positive feedback for MET charging. In addition, learning in battery management was also highlighted as important when dealing with range anxiety. A carrier described “*We were first worried about if we would make the distance before returning home to charge, even if it was stated that the distance was possible in theory. We are now comfortable about how long we can drive*” (Interview 15). Another carrier explained that new skills in how to calculate energy consumption are critical to plan for charging and compared their knowledge today with two years ago by saying “*Two years ago, I hardly knew what a kWh was*” (Interview 18). Knowledge in battery management was argued by the actors to be relevant in a future with AETs to plan for optimal charging since AETs also involve energy and batteries similar to METs.

Another example related to planning for charging that was brought up during external interviews was how industry actors have learned how charging should be scheduled. By the use of opportunity charging, i.e. that charging is done while doing something else, logistic losses could be reduced, and hence efficiency increased. One of the respondents expressed it as “*Finding that we can solve the issue of charging while driver break has improved feasibility for electric trucks*” (Interview 12). This implies that actors are more prone to continue with MET operations, resulting in positive feedback for MET charging. However, since AETs do not have a driver the knowledge about how to plan for charging during driver breaks will not be relevant anymore. One of the agencies stated that “*There will be new charging behaviors and you will optimize charging in a new way when you do not have driver breaks*” (Interview 8). Hence, although general knowledge about how charging should be scheduled to minimize logistic losses is argued to be considered a positive externality, it is emphasized that new knowledge is required to optimize charging for AETs.

#### **5.2.2.2 Application routines for charging infrastructure**

Another perspective on increased efficiency in operations came from agencies who expressed that they now have more routines and experience of applications regarding charging infrastructure, e.g., how to handle permissions to increase grid capacity at a site. One agency respondent stated that “*The industry and agencies have learned how to work with this issue together*” (Interview 8). This creates positive feedback for MET charging. Further, a carrier explained how they now are familiar with the permission process and know what is taking the most time which facilitates their application process (Interview 18). The increased routines in applications for grid permissions will also have a positive impact on AET charging.

### **5.3 Societal dimension**

The following section presents the societal feasibility dimension and is divided into two parts. First, investments in MET charging and how it affects AET charging are presented followed by learning effects and the influence on AET charging.

### 5.3.1 Investments in MET charging and how it affects AET charging

The results from investments in MET charging in the societal dimension regard support in form of *subsidies*. This subsection presents how investments lead to positive feedback within MET charging as well as the potential mirroring externalities on AET charging.

Today there are policies that support investments in MET charging, such as subsidies and supportive regulations both on the national and EU level (Interview 9). Respondents from external interviews highlighted the Swedish initiative *Klimatklivet* which can give investment support to charging projects. Although both manual and non-manual charging solutions are supported with research grants, the initiative only gives investment grants to projects that follow one of the two existing standards for conductive manual chargers which are *Combined Charging System* (CCS) and *Megawatt Charging System* (MCS) (Interview 9). Such financial support can be crucial for actors that are leaping to invest in charging infrastructure. For instance, one carrier explained how they invested in charging infrastructure and received half of the investment cost from *Klimatklivet* and were now prone to invest in more charging infrastructure (Interview 18).

While it is evident that such targeted subsidies facilitate the diffusion of MET chargers, the externality to AET charging is more ambiguous. The carrier that received half of its investment cost from the subsidy explained how they had saved some charging lots for future charging technologies (Interview 18). If the carrier would decide to use these to install non-manual chargers, it would be partly financed by *Klimatklivet* as the subsidy had supported the installation of the charging location (Interview 18), which would imply a positive externality. However, one could also argue that the mirroring externality from the subsidies for manual chargers generally is negative. As these investment subsidies currently only support MET charging, as there is no AET charging standard yet (Interview 9), the subsidies incentivize MET chargers over AETs chargers. However, drawing on the same logic that was used in the technology dimension, as soon as investments have been made in charging locations, MET chargers could easily be replaced by AET chargers at the end of their lifetime. Therefore, the grants could be seen as positive externalities as investments in grid capacity and other location-specific investments can be reused by AETs.

At the EU level, there is a commission amendment proposal (AFIR) saying that there must be a charging station every 60 km on some selected roads before 2025 (Interview 12). If this proposal is accepted, it will force a dense set of charging infrastructure (Interview 12). This type of regulation increases investments in MET charging but since the proposal is not yet implemented, the impact of such regulation is still uncertain. However, based on the results, it is suggested that as soon as actors, both public and private, have invested in charging stations, they are likely to continue to use and further expand the network of charging stations as it would otherwise imply sunk costs, i.e. a positive feedback. Further, although the proposal, in theory,

might support AET charging, the policy is directed to support MET charging, and the mirroring externality from large investments in MET charging is as mentioned ambiguous and dependent on e.g., the timing of AET diffusion and lifetime of MET chargers. Moreover, workshop participants expressed that there is also a risk that such a proposal could result in overcapacity. One respondent argued that in the short term, the demand for charging stations is higher than the supply, but in the long term, there is a need for more deliberate planning to make sure that charging stations are optimized. *“I am not worried that the system would be overbuilt in the short term, but in the long term, the charging system requires smart planning and booking functionalities”*(WS participant 7). According to a charger developer, the public charging stations funded by public actors will result in sunk costs as these stations are only a short-term solution, and argued that such policies risk a lock-in to an inefficient system that will result in power peaks during lunch breaks.

### **5.3.2 Learning effects for MET charging and how it affects AET charging**

Learning effects that were identified within the social dimension are related to norms, behaviors, and attitudes. In this subsection, examples of how norms, behaviors, and attitudes have changed as a consequence of MET charging adoption and/or development, resulting in a repeated choice of adoption and/or development are presented. Three themes were identified that resulted in positive feedback: *changed general attitude towards electric trucks, changed driver attitudes and behaviors and changed customer norms*. The resulting mirroring externalities of these feedback loops are presented.

#### **5.3.2.1 Changed general attitude towards electric trucks**

There are several examples of changed norms, behaviors, and attitudes that have been adjusted as a consequence of MET charging adoption. Perhaps most prominent is the change of overall attitude towards METs, and hence also MET charging, which has evolved over the last few years. One of the agencies highlighted that *“It was only a few years ago that an OEM stated that electric trucks were for transporting crisps, and now they have electric trucks driving timber”* (Interview, 6). Another respondent argued, *“When people see that METs and charging actually work you become more inclined to try it out”* (Interview 6). These changes in attitudes are argued by the respondents to have a positive externality on AET charging, as they are also electric trucks.

#### **5.3.2.2 Changed driver attitudes and behaviors**

Respondents from external interviews highlighted that changes in driver behaviors and attitudes when driving and charging electric trucks have shown positive feedback for MET charging. One of the carriers elaborated on how the attitude among drivers had changed: *“There is a culture clash, the carrier industry is old and the electric transition is disrupting the whole industry. There has been a macho culture in the carrier industry, where drivers push the gas pedal a little extra so that one*

*should hear the truck. The truck was supposed to be idling and it was loud, but here comes a quiet electric truck. However, the new calm and quiet way of driving has been met positively*” (Interview 17). Another carrier stated that *“The old men that only wanted to drive diesel never want to go back as soon as they try out driving an electric truck because the work environment is 10 times better”* (Interview 18). Similar statements were repeated over all carrier interviews (Interview 15; Interview 16; Interview 19), much due to the reduced noise and the decreased stress levels also while charging. As there is no driver in AETs, the changed driver attitude was argued to be irrelevant to AET charging.

One of the carriers explained that changes in driving behavior are critical, and gave an example of one of his drivers who was one hour faster than others because of his driving pattern which resulted in less need for charging. Hence, drivers learn from experience how their driving behaviors should be adapted to increase charging performance, which indicates that there is a positive feedback loop. These behavioral aspects will not affect the AETs since there is no driver in the truck.

### 5.3.2.3 Changed customer norms

Both the scenario model and external interviews highlight the need for extended delivery windows which implies changed behaviors among customers. Compared to diesel trucks, electric trucks are expensive and imply a need for higher utilization and therefore extended delivery windows, i.e more flexible opening hours when carriers can deliver goods (Interview 15; Interview 17). The scenario model shows that to meet the same transport demand as a diesel truck, METs require either extended delivery windows or an increased amount of trucks and hence an increased amount of chargers. Hence, if actors change their delivery windows, fewer electric trucks are required. This implies reduced investment costs and increases the overall performance of the electric system, which makes METs cost comparative to diesel. This way, more actors can afford to adopt METs, which in turn will increase MET charging, hence implying a positive feedback. Moreover, the scenario model also shows that the introduction of AETs is likely to induce the need for even longer delivery windows. The scenario model illustrated that both METs and AETs require extended delivery windows which means that if customers accept more flexible delivery time frames, such a change of norms would have a positive externality also on AET charging. Since investment costs in AETs are even higher than investment costs in MET (McKinsey & Company, 2018), higher utilization and extended delivery windows are even more crucial for AETs. Moreover, as argued by a respondent, as *“AETs allow for higher utilization as they can drive on evenings and nights which would make the roads less crowded”* (Interview 8) they are also more suitable for 24/7 operations.

The external interviews highlighted that these norms are starting to change and are acknowledged by both carriers and customers. One of the carriers elaborated *“METs imply a new way of working and we need to get the transport buyers to understand what it means to drive electric when vehicles are much more expensive. Some of them have the willingness and understanding, while others have the willingness but are still not committing, partly due to the costs ”* (Interview 19). In general, the

industry has tight delivery hours and a carrier explained they are to a large extent controlled by departure and arrival times set by their customers (Interview 17). For instance, one of the shippers explained that 80% of their transports in the Stockholm region are conducted between 07:00-09:00 in the morning. Another shipper expressed how the views on night deliveries have changed during the last years “*In 2015 when we started discussions around night deliveries, the response from our customers was completely different. Some expressed that if we wanted to deliver during the night, we would need to pay our customers. Today, some customers are open for night deliveries while some are still not*” (Interview 15). This shows that some customers have changed their behavior and the respondent continued to explain that when a customer starts with night deliveries they do not want to go back since they save money when having the possibility to optimize scheduling. Further, the understanding and knowledge about the benefits of night deliveries will have a positive impact on AET charging. However, night deliveries need to be adjusted to fit AETs since it today requires that the driver unloads the goods at the customer.

In addition, respondents highlighted several other norm changes that would be beneficial for MET and AET charging adoption, but that had not been changed. For instance, charging differs radically from refueling in terms of where the charging is conducted since METs can be charged by a broader set of actors compared to diesel trucks, e.g., at home or the customer site while loading (Interview 13). One respondent argued that MET charging thus requires longer contracts with customers and facility owners than what is generally the norm in the industry, as investors might otherwise hesitate to invest in chargers at customer warehouses (WS participant 9). However, it is unclear if this is something that is happening in the industry, or if actors are just acknowledging that the norms need to change.

## 5.4 Summarized results

The results in this and the previous chapter show that several investment and learning effects could be identified within MET charging as well as mirroring externalities for AET charging. These investments and learning effects and respective externalities are summarized in Table 5.1.

**Table 5.1:** Summary of identified investments and learning effects within MET charging and respective mirroring externalities on AET charging.

<b>Dimension</b>	<b>Identified investment \&amp; learning effects for MET charging</b>	<b>Resulting externality for AET charging</b>
Technology	Investments and sunk costs in charging hardware	Negative or no externality, depending on what perspective is used
	location-specific investments and sunk costs in charging stations	Negative, positive or no externality, depending on if the placement can be reused and on what perspective is used
	Battery development	Positive externality
	Charger development	Unknown externality due to uncertainty about the transferability of the knowledge as well as what type of technology will be used for AET charging
Knowledge and know-how	Investment in training	Positive externality from general knowledge about charging, but negative externality for the driver-specific investments
	Skills in battery management and schedule optimization	Positive externality
	Application routines for charging infrastructure	Positive externality
Societal dimension	Investments and sunk costs related to subsidies	Negative or positive externalities, depending on perspective
	Changed general attitude towards electric trucks	Positive externality
	Changed customer norms	Positive externality
	Changed driver attitudes and behaviors	Negative or positive externality, depending on perspective

# 6

## Discussion

The purpose of this thesis was to investigate how one of two related niches, that have not yet broken through the existing regime, is developing and influencing the other niche. To fulfill this purpose, this study investigated what learning and investment effects were present within the first niche (MET charging) and if these effects had a mirroring externality on the other niche (AET charging). This chapter aims to further discuss the results from chapters 4 and 5 with consideration to the literature presented in chapter 2. The chapter ends with a discussion regarding wider implications.

### 6.1 Investments and learning effects

The following section discusses investment and learning effects and the mirroring positive feedback. First, positive feedback will be discussed related to the three dimensions. Then, intertwined dimensions are discussed followed by the risk of lock-in effects.

#### 6.1.1 Positive feedbacks within all dimensions

The first research question of the study was what investment and learning effects are present in MET charging. The empirical analysis shows that there are positive feedbacks within all dimensions as a consequence of various investment and learning effects summarized in Table 5.1. This was in line with literature on niche development, as niches are developing from internal learning processes (Geels et al. 2017 b) which leads to the decision to continue to adopt or develop a technology that is reinforced, i.e positive feedback (Onufrey & Bergek 2015).

However, we also saw that some positive feedbacks were more distinct than others. These were for the most part related to the knowledge and know-how dimension, as training and learning in new skills and routines clearly demonstrated positive feedback for MET charging. There were also examples of weak positive feedback. For instance, although the results showed that changed customer norms in terms of prolonged delivery windows would increase the performance of a MET charging system, the actual change of these norms was not yet widely diffused even if some examples of changed delivery windows were highlighted. This suggests the MET charging niche is still relatively early in its niche development and an interesting topic for further investigation would be to take a larger set of actors and investi-

gate if adoption increases when customers become more willing to change delivery windows. Similarly, other norm changes were highlighted by respondents as requirements for wide MET as well as AET charging adoption but could not yet be seen in the industry. It would therefore be interesting for further research if adoption increases when, or if, these norm changes are realized. The appearance of different strengths of positive feedback could be argued to be in line with Schreyögg, Sydow & Holtmann (2011) who describe self-reinforcing processes, i.e. positive feedback, as being dynamic. In addition, as positive feedback is argued to make an alternative increasingly attractive (Onufrey & Bergek, 2015), this suggests that there are various degrees of strengths for the mechanisms.

There were also more ambiguous examples of positive feedback, as we saw patterns of repeated adoption of MET charging but could not fully determine the positive feedback loop. For instance, although we could distinguish a repeated adoption pattern of MET chargers as a consequence of price/performance improvements in the charger hardware technology, it could not be determined that improvements in the MET charging technology originated from increased adoption.

Although other self-reinforcing mechanisms were out of the scope of this study, there was repeated empirical evidence of phenomena that could be explained by the lack of other self-reinforcing mechanisms. For instance, according to the results, the adoption of charging hardware did not always result in further adoption due to limited grid capacity, even if the intended adopter was willing to. Viewing grid capacity as a complementary service to MET chargers, the occasional absence of further adoption could be explained by the absence of complementarity effects, i.e., that technology diffusion depends on the development of complementary services (Sydow et al., 2009). Similarly, the absence of coordination effects was illustrated by the lack of a standard for where the charger should be plugged into METs, as well as the lack of direct network effects when many actors contribute to a dense set of charging stations. That implies that it is likely that more positive feedback could be identified. Hence, a comprehensive study of all self-reinforcing mechanisms is suggested for further research. When including all self-reinforcing mechanisms (Onufrey & Bergek, 2015), one extends the analysis of niche development to also include the building of social networks and expectations, which according to Geels & Raven (2006) are essential to fully understand niche development.

### **6.1.2 Intertwined dimensions**

The results of the study also showed that the three dimensions in the analytical framework are intertwined. For instance, carriers' increased learning in battery management (knowledge and know-how dimension) enabled more efficient investments in charger hardware as carriers learned how to charge with limited logistics losses (technology dimension). Also, policies in terms of subsidies (societal dimension) were related to increased investment in charger hardware (technology dimension). Further, a clear theme that was seen in all dimensions related to positive feedback was that actors are becoming more prone to adopt an electric fleet when they are

convinced that electric trucks and charging work. This regards investment in training as well as learning how the hardware works. Hence, as in previous literature, the results demonstrate the importance of not only technological changes but also re-configurations of norms, user practices, and values (Turnheim & Nykvist, 2019; Foxon et al, 2010; Geels 2005) which implies that all dimensions are crucial for niche development.

Moreover, we saw that the societal dimension could be positively influenced by advancements in the technology dimension of another regime which could be related to a focal TIS (MET charging) being dependent on developments in its contextual TIS (another regime) (Bergek et al. 2015). This was seen in the case of opening hours at hubs. As described by one of the shippers, it was likely that the automation of the warehouses would facilitate the transition to new customer norms, since the customers would then also have higher investment costs, and lower operational costs, which would incentivize higher warehouse utilization and thereby longer opening hours. Further, the same trend in warehouse operations was also likely to impact the technology dimension in the MET charging niche as increased automatization of warehouses could potentially imply increased energy demand, which could further limit the possibility to charge while loading.

### **6.1.3 Risk of lock-in effects**

As presented above, the study showed investment and learning effects within all dimensions. Further, as positive feedback implies further adoption of a chosen path we identified a risk for path dependency and lock-in within MET chargers, which is in line with previous literature (Onufrey & Bergek, 2015; Schreyögg, Sydow & Holtmann, 2011). When looking at the transition from diesel to MET operations, one tendency of lock-ins was seen in the societal dimension regarding the attitudes of drivers. Several respondents argued that once drivers had adopted METs and MET charging, they expressed that they never wanted to go back to diesel operations. This inflexibility suggests that individual drivers are locked-in to the MET charging niche.

However, when examining the shift from METs to AETs, a lock-in was generally not seen for the MET charging niche. This could be explained by the fact that the MET charging niche is still under development, hence showing flexibility rather than fixed patterns in for example placement for charging stations. Moreover, although manual conductive chargers, primarily the CCS standard, appeared to have become the standard design for MET charging, hence suggesting a dominant design, some of the respondents argued that there is still ambiguity regarding what type of hardware METs should be charged with (WS participant 9; Interview 6) as there are test pilots with other technologies (Interview 20; Interview 9). This is in line with the experimentation phase of niche development, when for instance experimental projects regarding new technologies are performed (Geels & Raven 2006) as well as literature regarding dominant design (Andersson & Tuschman, 1990). According to Andersson & Tuschman (1990), an industry is characterized by technological uncer-

tainty and trial-and-error learning during the time before and dominant design is set, and it is not until after that the industry shifts focus from product to process development within the dominant design and flexibility is lost.

Further, one could also discuss whether some lock-in effects would imply bigger risks than others. For instance, the results showed that the risk of getting locked in to a specific placement appeared larger than being locked in to hardware since the hardware has a shorter life span and could be replaced more easily compared to power grids and cables at a particular location. In literature, placement and hardware are described as different “paths” that could result in lock-in if self-reinforcing mechanisms are sustained (Vergne & Durand, 2010).

Moreover, the results highlight the risk of lock-in both for individual actors and for the wider system, which implies that there are different degrees of lock-in depending on what perspective one has. The results show that there could be individual lock-in without a lock-in on the system level. For instance, one individual actor or one specific route could be locked in to MET charging, but on the system level MET charging and AET charging could co-exist. This is in line with Sandén & Hillman (2011) who argue that even if two technologies in principle compete in the same market, they can co-exist when they are separated geographically. However, independent of what perspective one has, the literature shows that it is possible to avoid lock-in through the prevalence of positive externalities which will be discussed more in the following section (Onufrey & Bergek 2015).

## 6.2 Externalities

This section discusses externalities experienced from positive feedback. It begins with a discussion regarding both positive and negative externalities related to the dimensions before it moves on to discuss the positive externalities more in detail. The following subsections highlight the potential negative outcome of positive externalities followed by a discussion around externalities related to what perspective one has. This section ends with describing tendencies of interactions in the other direction.

### 6.2.1 Positive and negative externalities in all dimensions

Our second research question concerned the mirroring externality of positive feedbacks on AET charging in the selected dimensions of the study. The empirical results show that externalities were present within all dimensions. As in the previous literature (Onufrey & Bergek, 2015; Sandén & Hillman, 2011; Andersson & Tuschman, 1990; Geels & Schot, 2007), the empirical results showed that the self-reinforcing mechanisms that make a certain niche increasingly attractive also can have a negative externality that makes an alternative niche less attractive. For instance, while investment grants directed to MET chargers increase the adoption of MET charging, these investments can result in sunk costs that make actors less inclined to adopt

AET charging.

Moreover, as in the previous literature (Onufrey & Bergek, 2015; Sandén & Hillman, 2011), the empirical results showed that positive feedback could also result in a positive externality on another niche. For instance, when norms regarding delivery windows are changing as a consequence of MET charging adoption, which increases the performance of the MET charging system, it results in a positive externality on AET charging, as such norms are also favorable for AET charging performance. In fact, the majority of the externalities shown in the study were positive and could be found in all dimensions (see Table 5.1).

Additionally, the results from the study also confirmed the statement made by Sandén & Hillman (2011) that two emerging technologies could show different basic interaction modes in different dimensions at the same time. For instance, as seen in Table 5.1, while the dominant interaction mode in the knowledge and know-how dimension was characterized by positive externalities, the technology dimension exhibited more negative externalities than the others. This was however expected as sunk costs in literature are described as high initial investments (Onufrey & Bergek, 2015) and as mentioned in the background, high investments in charging hardware are identified as one of the biggest barriers to MET diffusion. Further, when interviewee respondents were asked about sunk costs, they immediately highlighted sunk costs related to charger hardware, which implies that these sunk costs are generally more discussed.

Further, this study extends previous research by Sandén & Hillman (2011) by suggesting that there could be different interaction modes within the *same* dimension at the same time. This pattern was seen in all three dimensions. For instance, some respondents pointed out that investments in driver training result in a negative externality in the form of sunk costs, which would make carriers less inclined to adopt AET charging since they would want to further utilize the investments they had already made. Other respondents argued that investments in driver training result in a positive externality as it contributes to general learning about charging which is valuable for AET charging as well. Hence, the empirical results suggest that opposing interaction modes can take place within the same dimension, and even originate from the same positive feedback.

## 6.2.2 Positive externalities

Some positive externalities appeared to be location-specific, while others were more general. The most prominent location-specific positive externalities concerned the ability to reuse grid upgrades and other location-specific investments made in the technology dimension, which implies that such positive externalities will be absent if AETs are installed at new locations. Similarly, there is also a risk that it applies to the other dimensions. For instance, the advantages of prolonged delivery windows might not be transferred to the AET charging niche if AETs are installed at new locations, as it is not evident that other potential customers will be more

inclined to prolong their delivery windows. As seen in the results, some customers had prolonged their delivery windows, while other customers had not. In contrast, one could argue that prolonged delivery windows are not location-specific in other situations. For instance, if a customer adopts METs on one of its transport routes and prolongs its delivery windows, the same customer could be more inclined to prolong delivery windows on another transport route. Moreover, as mentioned, the prolonged delivery windows appear to align with the overall trend of automatization also in the warehouse industry, as higher degrees of automatization demand increased asset utilization (Interview 14).

As mentioned before, the knowledge and know-how dimension was the dimension that most clearly showed positive feedback and is also the dimension that showed almost exclusively positive externalities. We saw that in general, much knowledge could be reused for AET charging. A reason for that could be that the two niches are related and thereby have many synergies in terms of for example both being electric trucks that have to be charged and including many similar actors. Hence, general knowledge regarding electrification and charging is therefore relevant also for AET charging. This is in line with literature regarding the advantages of potential synergies in terms of shared resources as well as positive developments within one technology resulting in spillovers to another (Onufrey & Bergek, 2015).

However, shared resources do not necessarily have to imply positive externalities, which is highlighted by other literature (Sandén & Hillman, 2011). For instance, Sandén & Hillman (2011) declare that competition often occurs when shared markets or resources are limited, which could explain why many negative externalities prevailed in the technology dimension, as physical assets, available investments money and grid capacity often appeared to be limited and excludable resources. Although there is not an abundant number of transport routes, the road-haulage industry is vast and the empirical evidence repeatedly refers to the immense transport demand, hence suggesting that although the market, in theory, is limited it is not particularly limited in practice which would suggest a non-competitive interaction. Further, many of the shared resources appear to be what the literature (Sandén & Hillman, 2011) refer to as a non-exclusive good, e.g., non-patented knowledge. According to Sandén & Hillman (2011) if two technologies share non-excludable resources they often experience a neutral interaction, but if one technology develops a non-excludable good that can be used by the other technology as well, the two technologies interact in the form of commensalism which is when one technology experience a positive externality and the other one is not affected. This could explain why the knowledge and know-how dimension primarily experienced positive externalities, as most of the knowledge developed in the MET charging niche, e.g., battery management, are non-excludable goods. This way, the empirical evidence is supported by the literature.

Although Onufrey & Bergek (2015) did not study what enables positive externalities to occur, the authors made a suggestion that a possible explanation would be the presence of different market applications that prefer different performance criteria.

The empirical evidence of this study supports this suggestion. First, the niches are per se defined by their different market applications, i.e. that AET charging is directed to the routes that are operated by AETs, while MET charging addresses the routes that are operated by METs. Although both non-manual and manual charging solutions could in theory charge both types of trucks and compete for all transport routes, the two truck types prioritize different characteristics of chargers. While AETs in practice generally require that the charger is non-manual, this criterion is less important for METs which instead favor speed and price. A prerequisite for the existence of the two market applications is that the two broader niches, METs, and AETs, can coexist without out-competing each other. Although this is partly out of the scope of this study, if one views transport routes as different market applications, the results presented in section 4.1 suggest that METs and AETs are likely to coexist in the near future as different types of routes prioritize different performance criteria. For instance, while city distribution is unsuitable for AETs since they require complex decision-making and perception, this is not as equally critical for highways and these routes can instead prioritize the cost criterion.

Second, different market applications could also be seen *within* MET charging, as well as *within* AET charging. As mentioned, the result showed several occurrences where manual conductive charging solutions were considered inappropriate to charge METs. In these situations, it appeared as the qualities of inductive non-manual charging were more prioritized, e.g., when the truck stops were too short to allow the driver to plug in a manual charger, or when there was limited available space. This suggests that different types of charger technologies could coexist even within the MET charging niche. For instance, some METs that operate on shorter distances in dense city environments might favor slower inductive chargers, while METs that operate on long hauls favor fast manual chargers that limit logistics losses. Similarly, although a non-manual charger generally was required for AET charging, the result showed that there were some situations where this criterion was less critical, for instance at stops where there was personnel available. This suggests that actors could contemplate a manual solution if the manual solution outperformed the non-manual solution on other criteria such as charging speed and price.

### **6.2.3 Positive externalities preventing disruptive innovations**

However, positive externalities do not necessarily imply a positive outcome. Onufrey & Bergek (2015) suggested that positive externalities might prevent more disruptive innovations since they had found evidence that some positive externalities were obtained by imitating characteristics of a more mature technology. In the case of AET charging, it is not yet known what non-manual technology will become the dominant design, and as argued by (Andersson & Tuschman, 1990), the dominant design is not necessarily the best available option and is rather the result of other circumstances and chance. Without knowing what technology is better than the other, non-manual conductive chargers are more closely related to MET charging than the more disruptive ones (inductive charging and battery swapping), which might imply a risk that the non-manual conductive one is selected even if another

technology would prove to be better. For instance, a respondent (Interview 3) highlighted that it would be less expensive to replace a manual conductive charger with a non-manual conductive charger than to replace it with an inductive charger. As argued by the literature (Onufrey & Bergek, 2015), this could have a negative effect on the niche as it could inhibit an industry from exploiting the benefits of new technologies.

#### **6.2.4 Type of externality depends on what perspective one has**

The study emphasizes that whether the cross-niche influence is positive or negative depends on the level of analysis. As seen in Table 5.1, positive feedback often came with different types of externalities depending on if a more narrow techno-economic or a wider system perspective is applied. This was especially prominent in the technology dimension for both hardware and placements.

For instance, while it was evident that manual charging hardware would not be used to charge AETs in the long term, there was a disagreement about whether manual chargers would result in sunk costs or not. For a specific route or a specific actor, investments in manual charging hardware would be sunk costs and could hinder the adoption of a non-manual charging technology as the actor was reluctant to lose the already high investments made in charging hardware. One can assume that the reluctance increases if the actor has invested more extensively in MET charging, e.g., by investing in fast chargers, as the sunk costs would then be even higher. As mentioned in the background, high utilization of chargers is a prerequisite to obtaining a good return on investments of chargers, which means that chargers must be used over their lifetime. This perspective was shown in the scenario model, as the scenario model highlighted the big cost difference (see Figure 4.6 and Figure 4.7) between first building up a transport route with MET charging and then replacing the necessary hardware to fit AETs (Scenario 1b) versus building up charging infrastructure for AETs directly (Scenario 2). With this perspective, the high sunk costs imply that actors might hesitate to adopt AET charging on a specific route until the end-of-lifetime of the manual chargers, or hesitate to adopt MET charging in the first place if the actor is planning to install AET chargers in the near time. The techno-economic perspective hence highlights the fact that several individual actors are experiencing high sunk costs and are likely to slow down the AET adoption rate as they want to exploit the investments they have already made. However, this perspective neglects certain aspects.

For example, the system perspective highlights that even if a specific route operated by METs is replaced by AETs, the investments made in charging infrastructure do not necessarily imply sunk costs if the new non-manual chargers are built adjacent to the manual ones and new MET customers are found to use the manual ones. Further, other respondents argued against sunk costs as AETs do not necessarily have to be introduced first on the routes where MET charging hardware has already been. If installation starts on other routes, an actor can adopt MET charging as

well as AET charging, without wasting the investments made in MET charging. The system perspective hence highlights that since METs and AETs are expected to coexist, there is a possibility to avoid sunk costs as long as there is a demand for MET charging. Transitions are argued to happen gradually (Geels, 2005), which implies that the MET charging niche will not replace the existing regime overnight. As suggested by the literature on niche-accumulation (Geels & Schot, 2007; Levinthal, 1998) and bridging markets (Andersson & Jacobsson, 2000), a niche innovation is often introduced to small markets and thereby diffuses to broader markets as the niche develops. The empirical evidence confirms this view as MET charging was initially mostly installed in shorter routes that only required slow charging before it diffused to longer routes. Similarly, AET charging is still limited to private, enclosed areas, but is expected to diffuse to highway routes. Therefore, there will most likely be several transport routes without MET charging in the near future. Hence, the literature (Geels, 2005; Geels & Schot, 2007; Levinthal, 1998; Andersson & Jacobsson, 2000) validates the argument that sunk costs can be avoided by initially introducing AET charging on other routes than the ones where there are already MET chargers and gradually replacing MET chargers when they have reached their end of the lifetime.

Although this broader perspective suggests that sunk costs can be avoided, such assertion does not come without issues e.g., since individual actors sometimes only operate on a few selected routes and do not have the choice to introduce AET charging on other routes than the ones with MET charging, i.e. expand organically. We argue that the inclusion of a techno-economic perspective is crucial since adoption ultimately relates to decisions made by individual actors. We would therefore argue that both perspectives are necessary to fully understand the interaction and in turn also make more deliberate actions to better exploit the positive externalities and minimize the negative externalities. This way, the potential risk of sunk costs is illuminated by the techno-economic perspective, while potential ways to avoid them are illustrated by the use of the system perspective.

### **6.2.5 Interactions in both directions**

This study focused on one-way interactions from MET charging to AET charging as we did not expect to find interactions in the other direction since AET charging is immature. Nevertheless, an interesting observation is that there are tendencies of both negative and positive interactions also in the other direction. Tendencies of negative interactions are seen in the scenario model in Scenario 1b when AETs are replacing METs. This could be related to what in literature is referred to as parasitism when AETs are cannibalizing on MET routes (Sandén & Hillman, 2011) which implies that AETs are taking market share from METs.

However, we mostly saw tendencies of positive interactions in that AETs could further develop the inductive charging technology, which would be a resource that could be exploited by METs. Although inductive non-manual charging has been developed for METs, the current technology is less developed in terms of power capacity

(Interview 20; Interview 11) and expensive (Interview 19; Interview 11) compared to the CCS standard in manual chargers, which indicates that it is more likely that the development of inductive chargers might be driven by AETs than by METs. The results show that MET charging could benefit from inductive non-manual charging, especially if this technology is developed in terms of power capacity and price. There are two reasons for this. First, problems with MET charging could be solved with non-manual charging. Second, non-manual solutions imply higher convenience for MET charging.

Regarding problems with MET charging, carriers and shippers expressed how manual chargers have a high risk of being destroyed at terminals since trucks easily could drive over them. In addition, in city environments distribution locations show tendencies of being more suitable for inductive charging as there is less space for cables required for manual charging. They are also characterized by shorter stops which further favors inductive charging as manual charging is too cumbersome and time demanding and can not be justified with the limited stop time. Furthermore, the volatility of energy prices was also experienced as a problem within the MET charging niche as it complicates how the charging system's performance in terms of price (Interview 17). To address this problem, several respondents discussed the concept of *smart charging*, which would be able to better determine when to charge based on more variables, e.g., deciding to charge when the energy price is low even if charging is not required (Interview 12). According to an interest organization, smart charging of METs would have better performance with a non-manual solution. This suggests that if inductive chargers experience positive feedback as a consequence of economies of experience within AET charging, this could result in a positive externality from AET charging to MET charging.

Additionally, it was suggested that non-manual solutions would be favorable for MET charging even where the typical problems of limited space and time restrictions did not exist, due to their convenience. Especially as the cables for manual charging are cumbersome to handle, it was emphasized that it would be convenient with a non-manual solution. It was also emphasized that a non-manual charging technology even for METs would align with the overall human demand for convenience, as convenient solutions tend to be prioritized in general (Interview 6; Interview 7). This is in line with Sandén & Hillman (2011) who describe how a more mature niche may benefit from a less mature niche when the less mature niche develops a resource that can be exploited by the first niche, i.e. experience a positive externality as a consequence of development within the less mature niche. Here, the resource is the non-manual charging solution developed by the less mature niche AET charging which has a positive impact on MET charging.

Further, if the same type of technology would be used for both MET and AET charging as a result of the positive externalities described above, the two niches could become one. This is related to what in literature is described as an integration that has been discussed in the context of regimes (Raven & Verbong, 2009). Similar to how two initially separated regimes integrate and become more or less one

regime (Raven & Verbong, 2009), this could be argued to be the tendency also with niches. The empirical evidence from this study displays a tendency for a similar niche-niche integration as non-manual solutions could benefit both niches.

However, as many of the reasons why actors suggest non-manual solutions for MET charging relate to identified problems with manual chargers, one could argue that integration becomes less likely when the MET charging niche matures and these problems probably get solved. Further, one of the carriers that had been using MET charging for a longer time period argued that non-manual chargers were unnecessary, as manual chargers worked well (Interview 19). This suggests that inductive charger solutions will be less demanded by METs when the MET charging matures and awakens the question of whether the advantages of non-manual chargers will be able to attract MET operators when, or if, MET charging is more developed. Hence, it is still unclear whether non-manual solutions will be widely used for MET charging even though the empirical evidence shows tendencies for it.

Perhaps most interesting is how non-manual charging solutions will develop *in relation to* MET charging niche development. As suggested above, if self-reinforcing mechanisms are improved within MET charging, it could be more difficult for actors to switch to a non-manual solution. However, as AET charging is also developing, non-manual chargers are likely to improve as well. If non-manual charging matures faster than MET charging develops, integration is more likely. It is therefore of interest to follow the development of both niches in relation to each other to further investigate interactions in both directions. This could be a subject for further research to expand the understanding of interactions.

### **6.3 Externalities - mitigating or exacerbating a lock-in?**

From an empirical perspective, it is of interest to understand if the development and diffusion of MET charging could result in a lock-in that hinders the development of AET charging. As mentioned in subsection 6.1.3, a lock-in state has not yet been reached, as there is still some flexibility regarding charging technologies and relatively weak positive feedback in some dimensions. Due to the early stage of the MET niche, it is difficult to convincingly state whether there will be a lock-in, but several findings highlight that there is a risk for it, especially related to the technology dimension. Two levels of potential lock-in could be found which will be presented in more detail below.

First, there is a risk of getting locked-in to an inferior MET charging system, which will not be optimal even for METs. There are still many uncertainties in how a MET charging system should be optimized, and if rapid investments in the technology dimensions are made before these uncertainties are cleared out, some investments can result in sunk costs. For instance, respondents referred to the risk of overcapacity, e.g., building up a system of fast chargers at non-optimal locations that will not

be needed in the future, which would result in system inefficiency. In addition, the discrepancy related to when trucks should be charged in the future, e.g., if METs should be charging while loading or if trailer swapping should be used, indicates that there is a risk that chargers that are installed at loading docs will become sunk costs. Moreover, the results suggested that it is not yet known what technology, or technologies, that METs should be charged with in the future, as there were signs that different market applications favored different technologies. Hence, the uncertainty in MET charging placements and hardware points to a risk that the investments made might result in a lock-in to an inferior or suboptimal MET charging system. At the same time, the result showed that investments in all dimensions induce positive feedback that results in further adoption and development of MET chargers. This suggests that investments are required, even if some might turn out to be sunk costs, and need to be made even if there are uncertainties. The implications of this tension will be discussed more in section 6.4.

Second, there were also signs of a risk to get lock-in to MET charging in general, at the expense of AET charging, which could be described with the concept of amensalism, in which an emerging niche does not fit into the system that has been developed around the other niche and is structurally locked out (Sandén & Hillman, 2011). The risk of lock-in mainly originates from MET niche development resulting in negative externalities within the technology dimension in the form of sunk costs, as AETs require non-manual hardware and might also be charged at other locations. The result showed that the risk to get locked in depends on the speed of MET niche development in relation to the AET niche development, i.e if MET infrastructure is widely dispersed at the time when AETs are mature, the sunk costs will be higher and the MET charging system might be less adapted to AETs. At the same time, the empirical study also showed contrasting forces in the form of positive externalities. These externalities indicate that niche development of MET charging might not result in a lock-in, as the developments within MET charging appeared to facilitate AET charging development in all studied dimensions. There is hence a tension between the negative externalities, suggesting a lock-in, and the positive externalities, suggesting a multi-niche industry.

Further, the study showed that only identifying negative and positive externalities did not suffice to fully understand the interactions leading to lock-in, and instead suggested that a more nuanced analysis is required to devise strategies to avoid lock-in. Regarding negative externalities, the inclusion of the system perspective shed light on the fact that the negative externalities might not be as large as they appeared with the techno-economic perspective. This because sunk costs could be avoided by introducing AETs to other lanes than the ones that already have MET charging installed or by searching for new customers to further utilize the MET chargers. However, this approach requires increased coordination and deliberate firm strategies, which will be discussed more in section 6.4. Regarding positive externalities, the empirical results showed that some positive externalities appeared to be location-specific, meaning that to obtain the positive externalities developed by the MET charging niche, one must replace MET charging with AET charging.

Moreover, due to the strong positive externalities present in the knowledge and know-how dimension, we would argue that actors that have MET operations will also be the most suitable actors for AET operations. In line with what is suggested by Onufrey & Bergek (2015), actors that have a broad portfolio of technologies (METs and AETs) and applications (different routes) are more prone to create a favorable environment for cross-technology spillovers, i.e. positive externalities, and hence avoid a lock-in. However, these actors are also the ones that probably have sunk costs due to large investments.

This leads us to the conclusion that there appear to be two main ways one could build up AET charging infrastructure. The first option is to install AET charging on lanes that have not yet been electrified (which was illustrated by Scenario 2 in the scenario model), and in this way avoid sunk costs from investments made in MET charging that are no longer usable. Although this option would not remove all negative externalities, since we had negative externalities in all dimensions, many of the sunk costs in the technology dimension could be avoided. However, this option misses out on the possibility to obtain location-specific positive externalities. It could also slow down the wide diffusion of AETs since MET charging will not be replaced with AET charging until the end of its lifetime. Further, this option assumes that there will be suitable lanes left to electrify when AETs mature. Although this assumption appears to be reasonable considering the big transport demand and the lack of economic viability for some routes with METs, it could be challenged by the intensive landscape pressure of climate change, and associated policy measures as well as possible limitations in terms of the number of routes that are suitable for electrification.

The second option, which is to install AET chargers on lanes where there are already MET chargers, implies a higher degree of sunk costs (which was illustrated by Scenario 1b in the scenario model), even if there are some strategies to avoid them. Sunk costs can be avoided if the timing of AET maturity aligns with the lifetime of MET chargers, if there is enough grid capacity to have both MET and AET charging solutions at the same site, if new customers can be found for the replaced MET chargers, and if the MET chargers can be moved to another location. This option implies that more positive externalities can be obtained, as also the location-specific positive externalities are gained.

Hence, actors who aim to avoid a lock-in could be torn by the tension between the two options, as there appears to be no option where positive externalities can be fully leveraged while simultaneously minimizing negative externalities. Instead, the study indicates that actors have to choose between minimizing the negative externalities, at the expense of the location-specific positive externalities, or maximizing positive externalities, at the expense of negative externalities. The resulting implications for firms are discussed in section 6.4. However, the possibility to avoid lock-in is still not clear-cut and this empirical case is especially interesting as the industry actors, in contrast to many traditional industry cycles, are already expecting that a new transition is approaching before the first transition is accomplished. As mentioned

by an interest organization, it is a big challenge to have two transitions in mind at the same time (Interview 12). On the one hand, one could formulate strategies that are influenced and steered by attempts to minimize negative externalities and leverage positive externalities for a future transition. On the other hand, while the timing of wide AET diffusion is unknown, it is of utmost importance to obtain a MET transition immediately. Moreover, the study highlights that it is not possible to build a fully optimal charging infrastructure as there will always be sunk costs. Therefore, one should continue to build up MET charging and not wait.

## 6.4 Implications

In this section, theoretical implications and suggestions for further research will be discussed followed by implications for both policies and firms.

### 6.4.1 Theoretical implications

This study confirms that the understanding of niche-niche interactions is important to fully understand transitions, which was already highlighted by literature (Markard & Truffer, 2008; Pistorius & Utterback, 1997). Primarily, we saw that the development of one niche (MET charging) could result in positive externalities on another less mature niche (AET charging) and thereby impact the possibility of the breakthrough of that niche (AET charging). However, in line with Geels & Schot (2007), there were also negative externalities, which could hinder the less mature niche (AET charging) to succeed in the market, indicating that the more mature niche (MET charging) could outcompete the other (AET charging). Moreover, there was also a risk that niche development of the mature niche (MET charging) could lead to a lock-in that was suboptimal for the internal niche performance (MET charging). Hence, there is a risk that a more mature niche (MET charging) develops in a direction that is not only unfavorable for another niche (AET charging), but also for itself (MET charging), and could therefore inhibit its own diffusion to the mass market. That would result in transition delays and may thereby give opportunities for other niches to become apparent.

Moreover, the study shows that METs, AETs, and their respective charging systems could be combined to increase the performance of the total charging system. This was seen in the scenario model, as some market applications appeared more suitable for the AET charging niche, while other market applications were not possible for the AET charging niche but possible for the MET charging niche, e.g., city distribution. This is in line with the literature arguing that two substitutes may be used in combination to increase performance (Sandén & Hillman, 2011). Hence, if viewing METs and AETs as subsystems of the broader niche *Electric Trucks (ETs)* one could argue that a larger part of the diesel regime could be transformed. This way, the two technologies together share the burden of structural change and experience symbiosis (Sandén & Hillman, 2011). Similarly, as different market applications, even *within* the MET charging niche, appeared to prioritize different charging technologies, this also suggests that the coexistence of several technological substitutes could increase

the overall system performance. In this case, we saw that a technology (inductive charging) that was primarily supported by the less mature niche (AET charging) is also relevant for certain market applications within the more mature niche (MET charging). Therefore, we argue that it is important to have a holistic view when investigating the transition to electric vehicles, and not necessarily look at METs and AETs separately. Moreover, we argue that sustained technological variety could improve MET niche performance and thereby facilitate the overall transition.

We saw tendencies of interactions in the other direction but due to the immaturity of the niche, it could not yet be stated how these will play out. However, as there were tendencies of both positive and negative externalities, we suggest that similarly as there were both negative and positive externalities from the more mature niche to the less mature niche, it is likely that both types of externalities will be present in the other direction as well. Therefore, the development of a less mature niche is likely to impact the ability of a mature niche to break through and the niche-niche interaction could then be described with the concept of bridging technology (Sandén & Hillman, 2011; Andersson & Jacobsson, 2000; Bergek et al., 2015). Thus, two emerging niche innovations can compete internally (e.g., for market share) simultaneously as the bridging niche is helping the other (commensalism or parasitism), or even help each other (symbiosis), to grow at the expense of the established regime (Sandén & Hillman, 2011). In line with Bergek et al. (2015) regarding the interactions between a focal TIS and contextual TISs, it is likely that when a less mature niche develops it can affect a more mature one. Hence, although the impact of a less mature niche might be less relevant at this time, it is likely that it could impact the other niche later on. Therefore, as the less mature niche is developing one could argue that it will be possible to discover additional interactions in the other direction over time. A suggestion for further research is hence regarding niche development for AET charging and the mirroring externalities for MET charging. This will be interesting to investigate when the niche is more mature to further analyze niche interactions in both directions in relation to Sandén & Hillman's (2011) multi-mode-framework.

Taken together, by understanding these different niche-niche interactions we can better understand transitions as it gives a more nuanced and holistic explanation compared to how interactions traditionally are described within the MLP as it often assumes only one niche (Geels, 2005; Geels et al. 2017 b). While the empirical evidence of this study showed that niche development of one niche could have a positive influence on another niche, the reasons for such positive externalities to occur could not fully be confirmed. This study supports the suggestion made by Bergek & Onufrey (2015) that the positive externalities could originate from different market applications. An interesting topic for further research is therefore to investigate various charging technologies with different market applications to analyze how they can sustain over time. Such research should include battery swapping which was mentioned as a promising technology as well as the other conventional charging technologies.

Lastly, what also appeared interesting during this study, however not related to the concepts in this research, is the need for new business scenario models. For instance, how can actors that have invested in charging infrastructure create new revenue streams? How is value shared among actors? What implications can business scenario model innovation have on the adoption of charging infrastructure and the incentives to invest? These are argued to be important questions to consider for further research.

### 6.4.2 Policy implications

Investments in charger hardware are central to a wide diffusion of charging infrastructure, simultaneously as there appears to be a reluctance to invest because of the high investment costs. Supportive policies are therefore seen as crucial for actors to enable such investments in MET charging. However, the study highlighted tendencies of lock-in to an inferior MET charging system, which indicates that such investments could imply both positive and negative outcomes for MET charging. For instance, regarding the AFIR proposal, which suggests charging stations every 60 km on selected routes, such a strict regulation would contribute to solving the chicken-and-egg dilemma that was described in the background. That is because it enables actors to invest in METs without investing in charging infrastructure, implying increased adoption of METs which could result in positive feedback in the form of additional investment in charging stations. However, although the transport demand is argued to be bigger than the installed charging infrastructure in the short run, aggressive expansion policies could lead to overcapacity in the longer run. Even though there will always be sunk costs, policies are suggested to be carefully investigated in cooperation with industry actors.

Further, although investments in MET charging in general appear to imply positive externalities on AET charging, there is a risk for negative externalities. Returning to the AFIR example, such policies are likely to benefit AET charging as the empirical evidence shows several positive externalities from MET diffusion. However, if policies imply investments in MET charging on routes that would have been more optimal for AET operations it could instead result in sunk costs.

Furthermore, although this study has not investigated how supportive policies for AET charging could impact MET charging, such policies could harm MET charging. Therefore, even though this study suggests that certain actions can be beneficial for AET charging, these actions might not be relevant if the political goal is merely to achieve fast electrification.

In conclusion, we argue that different policy measures are required depending on if the political aim is to achieve fast electrification, a long-term optimal MET charging system, or to support autonomous initiatives, as the subsidies might result in overcapacity of MET chargers or sunk costs in a transition to AETs if the support is not thoroughly considered. This implies that policymakers have to cautiously examine investments so that the outcome of policies is in line with the political goals.

### 6.4.3 Implications for firms

As suggested by the literature (Garud, Kumaraswamy & Karn e 2010), self-reinforcing mechanisms and the establishment of positive externalities can, at least partly, be strategically managed by firms, although not all self-reinforcing mechanisms can be caused by conscious actor decisions. Hence, depending on what aim a specific firm has, i.e. electrification and/or automation, there will be different actions made.

For firms that only have MET operations, the focus lies on exploiting positive feedback. That could for example imply investment in training, participation in projects regarding MET operations as well as searching and applying for subsidies for MET charger investments. However, as mentioned in subsection 6.1.3, the prevailing uncertainties in the technology dimension imply that there is a risk to get locked in to an inferior MET charging system. Although this should not discourage investments in MET charging, we suggest that some actions can be taken to future-proof these investments as much as possible. As many of these actions are similar to the actions we suggest for firms with both MET and AET operations, they will be discussed below.

Firms with both MET and AET operations should, despite exploiting positive feedback, also aim at leveraging positive externalities and minimizing negative externalities. The difficulties of such an approach were highlighted in section 6.3 and in this subsection, we will further suggest strategies for how such tension could be handled. For instance, if a firm aims to leverage the positive location-specific externalities, sunk costs could still be mitigated by an increased focus on flexibility when building up charging infrastructure since the study shows that we do not know what the future will look like for either MET charging or AET charging. Increased flexibility reduces the risk of getting locked in to a charging hardware today that may be outdated in the near future as it enables actors to more easily change hardware type, thereby reducing sunk costs and leveraging the general investments made in the location, such as grid capacity. Another strategy for leveraging the location-specific positive externalities while mitigating sunk costs is to add AET chargers next to the MET chargers instead of replacing the MET chargers. However, this implies that new MET customers need to be found, which requires coordination among actors. Firms must either have a broad customer base and possess coordination skills, or be able to cooperate with competitors to sell charging sessions to other customers.

Moreover, if firms aim to minimize the negative externalities by initially introducing AETs on other routes than the ones with MET infrastructure they should carefully consider what routes they want to electrify directly and what routes they want to keep for AET operations. Therefore, if a route is suitable for AET operations in the near time, actors should reconsider their decision and select another route for MET operations.

Further, in order to decrease sunk costs, we suggest that both types of firms should work with forecasting, i.e. to compare the lifetimes of a charging station or hardware with forecasts of factors that could make those investments obsolete. For both firms,

such factors could regard grid upgrades and battery improvements. For firms that intend to operate both METs and AETs, it is also relevant to forecast the introduction of AETs as AETs require other hardware and might imply new locations. This way, firms could decrease sunk costs and make more informed decisions. However, the study shows that both MET charging and AET charging are immature which implies that the industry is dealing with many uncertainties. Hence, firms do not have all facts which is complicating the decision-making process.

What also seems important for firms is to not underestimate the importance of coordination with other actors. In contrast to the current diesel regime, the transition studied in this report implies that the road-haulage industry will be more dependent on the energy sector which implies new players to cooperate with. Hence, cross-border projects and participation in knowledge-sharing forums are argued to enrich and facilitate the ongoing transition.

# 7

## Conclusion

The aim of this research was to investigate how one of two related niches, that have not yet broken through the existing regime, is influencing the other niche as a result of investment and learning effects. To fulfill this aim, niche development for the first niche (MET charging) was investigated by identifying investment and learning effects. Then, the mirroring externalities from these effects were examined for the second niche (AET charging) in three selected dimensions.

Through a contemporary study of charging for manual electric trucks as well as autonomous electric trucks, we have shown that several types of investment and learning effects, that are described by previous literature, were present within the more mature niche. Further, by the use of a scenario model as well as industry actors' expectations, we have shown that these investment and learning effects can influence the niche development of a less mature niche. Whereas previous literature on transitions mostly focuses on the interaction between the three levels in the MLP perspective (Geels, 2005; Geels et al., 2017 b), the main contribution of this thesis is that it captures transition dynamics by illustrating the complexity of interactions between two niches. A deeper understanding of these complex niche-niche interactions is hence argued to be crucial for facilitating transitions.

By showing positive externalities, this study supports the literature that the niches could interact in other forms than competition (Sandén & Hillman, 2011; Nykvist & Whitmarsh, 2008; Onufrey & Bergek, 2015; Markard & Truffer, 2008; Pistorius & Utterback, 1997). Further, this study confirms previous literature (Sandén & Hilman, 2011) by showing that both positive and negative externalities can be present simultaneously in *different* dimensions. While the scenario model, with its focus on the technology dimension, illustrates the risk of negative externalities and thereby potential benefits of waiting with investments in MET charging, the scenario model neglects the positive externalities that were illustrated by the other dimensions. Further, this study contributes to previous literature by showing that different types of externalities can be present *within* the same dimension, at the same time, and even originate from the same investment and learning effects. Further, we showed that whether there will be positive or negative externalities depends on what perspective one has as the type of externality differs if a techno-economic or wider system perspective is used. We argue that in order to fully understand niche-niche interactions and thereby formulate deliberate strategies, both perspectives are needed. Thus, we have seen that the inclusion of various perspectives as well as different dimensions could further nuance the understanding of these influences, as

it shows that the type of externalities could differ both within and between dimensions depending on perspective.

In line with the literature (Onufrey & Bergek, 2015), the study shows that lock-in can be avoided through positive externalities. However, there is always a risk of lock-in as long as negative externalities are present. By combining the techno-economic and system perspective, we suggest that these externalities can be mitigated by certain strategies on how to build up charging infrastructure, but some negative externalities seem to be unavoidable. However, in the empirical case, the positive externalities appear to outperform the negative externalities, which indicates that actors can continue with the diffusion and development of the more mature niche and simultaneously support the less mature niche.

Although a more comprehensive study is required to understand the conditions for positive externalities to occur, this study confirms what is suggested by literature (Onufrey & Bergek, 2015; Sandén & Hillman, 2011) that positive externalities are likely when two niches have shared resources or when a non-exclusive resource, such as non-patentable knowledge, or market is created by one niche and can be exploited by both niches. The empirical study shows that when two niches are related, they can together share the burden of changing the regime, as they appear to require similar transformations of e.g., user practices. As stated by the literature, such elements of a socio-technical system are not to be neglected and are necessary for a transition (Turnheim & Nykvist, 2019; Foxon et al., 2010; Geels 2005), which shows that even if two niches require different technological changes, and may hence compete in some elements, they may still experience benefits in other elements. Further, internal niche development of the less mature niche is argued to be crucial as the benefits of positive externalities do not suffice for necessary niche momentum.

However, in line with previous literature (Bergek et al., 2015; Sandén & Hillman, 2011) the study showed a tendency that the interaction could change over time, particularly as the less mature niche develops. Therefore, although positive externalities appear to be prominent at present, the dominant interaction mode is subject to look different in the future. Similarly to the literature on regime integration (Raven & Verbong, 2009), we saw tendencies of niche-niche integration if the two niches would adopt the same technology. However, opposite tendencies could also be seen as it appeared as different market applications would select different technologies due to different prioritization of performance criteria. This is however a subject for further investigation and should be contemplated against other self-reinforcing mechanisms such as coordination effects.

Regarding implications for firms, they should focus on leveraging positive externalities and minimizing negative externalities. To leverage positive externalities, this thesis suggests building a flexible charging infrastructure as well as adding AET chargers next to MET chargers instead of replacing them. To minimize negative externalities, it is important to future-proof investments to ensure that the investments are fully exploited over their lifetime. This could be done by strategically

planning the location of the charging station to increase the possibility of finding new customers that could take over chargers when, or if, investments in chargers become suboptimal for the first customer. By considering such strategies, firms will be able to prepare for an autonomous future.

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# A

## Interview guide to external interviews

The questions are listed in Swedish since all interviews were held in Swedish. The questions were adapted depending on the role of the interviewee.

### A.1 Personlig introduktion

Vad gör du i din roll på XX?

Hur tror du att utvecklingen av elektriska och autonoma lastbilar kommer se ut?

Vad är din personliga åsikt?

### A.2 Överlapp mellan MET- och AET-laddning

Vad ser du som de tre största likheterna mellan snabbbladdning för elektriska lastbilar och autonoma lastbilar?

### A.3 Skillnader mellan MET- och AET-laddning

Vilka ser du som de tre största skillnaderna mellan snabbbladdning för elektriska lastbilar och autonoma lastbilar?

### A.4 Technology dimension

Hur har den tekniska utvecklingen för laddteknik gjort att det blivit mer attraktivt med elektrisk laddning?

Hur kan den tekniska utvecklingen för elektrisk laddteknik komma att användas för autonom laddning? Finns det delsystem eller komponenter som kommer kunna användas?

Vilka laddtekniker kommer inte kunna användas i ett laddsystem som används av autonoma elektriska lastbilar? Vilka kritiska delsystem kan man inte använda? Är det något som är inkompatibelt?

Vilka ytterligare tekniker måste utvecklas för att få ett fungerande AET system?

## A.5 Knowledge and know-how dimension

Vilken kunskap kring laddning för elektriska lastbilar har gjort att det blivit mer attraktivt med laddning?

Vilka är de tre viktigaste lärdomarna man tar med sig från att ha byggt infrastruktur för elektriska lastbilar till ett system för autonoma lastbilar?

Vad är de kritiska kunskapsområdena? Är det någon av dessa kunskaper som inte kommer kunna användas i ett laddsystem för autonoma lastbilar?

Vilka kunskaper fattas fortfarande och behöver vidareutvecklas för att snabbbladdning för automa lastbilar ska kunna “ta fart”. Är det saker som skulle kunna vara kompatibelt? Är det bara att lägga på det på systemet eller krävs det ändringar av systemet då?

## A.6 Societal dimension

Vilka förändrade normer, beteenden, lagändringar och tankesätt inom logistik och sättet att se på tankning/laddningar har möjliggjort snabbbladdning för elektriska lastbilar?

Vad är det alltså som har krävts för att laddning ska accepteras av samhällets aktörer?

Tror du att dessa förändrade normer och regler kommer underlätta även för autonom laddning?

Finns det någon risk att de normer inom laddning för elektriska lastbilar kommer missgynna utvecklingen av autonoma elektriska lastbilar?

Kan det vara någon lagändring som kan komma att förhindra för AET?

Finns det fler normer och regler som du tror måste förändras för att laddning för autonoma elektriska lastbilar ska kunna ta fart i utvecklingen?

## A.7 Investments

Vi tänker oss ett framtidsscenario där där autonoma ellastbilar har tagit över många av de vanliga ellastbilarnas transportsträckor. Vilka investeringar tror du att man kan återanvända från uppbyggnaden av laddning till elektriska lastbilar till ett system för autonoma lastbilar?

Vilka investeringar relaterade till laddning tror du inte längre kommer kunna användas i ett framtidsscenario där autonoma ellastbilar har tagit över många av de vanliga ellastbilarnas transportsträckor?

## A.8 Wrap-up

Är det någon viktig aspekt som du tycker att vi missat för att få en bättre förståelse för hur utbyggnaden av laddinfrastruktur för manuella ellastbilar kommer påverka uppbyggnaden av autonoma ellastbilar?

# B

## Workshop discussion points

The discussion points that were discussed during the workshops 2 and 3 are listed in Table B.1.

**Table B.1:** Discussion points during workshops 2 and 3.

<b>Discussion subject</b>	<b>Question</b>
Charging scenario model Results	Based on the scenarios and the results you have now seen, are there any spontaneous reflections on the design of today's charging system vs the future? Please reflect from three perspectives: <ul style="list-style-type: none"><li>● technology</li><li>● knowledge and know-how</li><li>● societal</li></ul> Were the results in line with your expectations or is there anything that's contradicting what you know from before?
Charging hardware - investments and sunk costs	Do you consider it to be a major risk that we are locking ourselves into the current system and creating challenges for an optimized future system? Why or why not?
Charging locations - investments and sunk costs	What are your thoughts on where and how we should place our chargers so that the system is optimal for a future that includes AETs and longer ranges?

# C

## Scenario model assumptions

This appendix outlines the assumptions made regarding calculating charging hardware costs and efficiency.

### C.1 Charger hardware cost

The scenario model investigates investment costs in charging infrastructure between different scenarios. The cost is primarily determined by:

- The number of charging stations required, which is determined by the truck ranges listed in subsection 4.2.1. It is assumed that a truck can drive the specific range without going below 20% of its battery pack.
- An indicative cost per charger outlet (see Table C.1), which differs depending on the following factors:
  - Manual conductive charging hardware or non-manual inductive charging hardware, where inductive chargers are assumed to be more expensive than conductive chargers
  - Charger power capacity, where chargers of higher power capacity (fast chargers) are assumed to be more expensive than chargers with lower power capacity (slower chargers)
- The number of charger outlets per location (see Table C.2), which differs depending on the following factors:
  - How many METs and AETs that chargers at the location, which is a consequence of the logistic set-up and the assumed number of trucks per scenario
  - Number of required charger outlets per site per truck (as mentioned in Table 4.2 in subsection 4.2.2, one charger outlet per truck per charging station was assumed).

**Table C.1:** Indicative cost per charger outlet. Indicative costs are retrieved from initial interviews

Charger type	Indicative cost (150 kW)	Indicative cost (500 kW)
Manual conductive charger	1	1.9
Non-manual inductive charger	-	3.9

As the unused chargers present in scenario 1b (see Table C.2) were installed in the current scenario (Scenario 1a), these chargers are slower manual chargers of 150 kW and cost accordingly. As seen in Table C.2, 18 of the 24 installed charger outlets installed in Scenario 1a (75%) became obsolete in Scenario 1b.

**Table C.2:** Charger outlets per location (#used manual chargers), (#unused manual chargers), (#used non-manual chargers).

Charging locations	Scenario 1a	Scenario 1b	Scenario 2
HUB A	(4), (0), (0)	(0), (4), (0)	(0), (0), (0)
charging station 1	(8), (0), (0)	(0), (8), (6)	(0), (0), (0)
charging station 2	(8), (0), (0)	(6), (2), (6)	(0), (0), (0)
charging station 3	(4), (0), (0)	(0), (4), (0)	(0), (0), (0)
charging station 4	(0), (0), (0)	(0), (0), (0)	(6), (0), (6)
<b>Total</b>	<b>(24), (0), (0)</b>	<b>(6), (18), (12)</b>	<b>(6), (0), (6)</b>

## C.2 Efficiency

Efficiency is measured in terms of the total weight of the transported goods multiplied by the total distance driven. In all scenarios, a consistent payload of 20 tonnes was chosen for all scenarios and it is assumed that all trucks are always fully loaded in both directions. Hence, what impacted the efficiency difference was how fast the goods could be transported from Hub A to Hub B. This implies that a scenario where the trucks in a shorter time can deliver goods from Hub A to Hub B will be able to drive more kilometers and hence transport more goods, within a set time frame. Except from the assumptions listed in Table 4.3 in subsection 4.2.2, the following factors determine the efficiency:

- How many activities are conducted per round trip, i.e. how many activities are conducted before a truck returns to its starting point and can conduct a new delivery (e.g., in Scenario 2 there are several charging stations while Scenario 2 only has one charging station and thus fewer charging activities per roundtrip).
- Time required for each activity. For instance, it is assumed that it takes one hour to load a truck with goods and it is assumed that trucks drive with a constant speed of 60 km/h. The charging time is more complicated as it, as mentioned in subsection 4.2.2, depends on the charging power capacity,

but also the energy demand which depends on several factors, e.g. energy consumption per driven kilometer and the kilometer driven since the last charging session.

- Both inductive and conductive chargers have an efficiency of 92%, i.e. a 500 kW charger can supply 460 kW per hour.
  - Average energy consumption is 2 kW per kilometer driven
- If a distance is driven by a MET or an AET, as a MET would need to stop for a 45 min long driver break within 4.5 hours (Transportstyrelsen, 2022). The driver can not embark on a new activity (e.g., driving) if the activity time is longer than the remaining time left before the driver needs to go on break.

# D

## Scenario model results of faster chargers

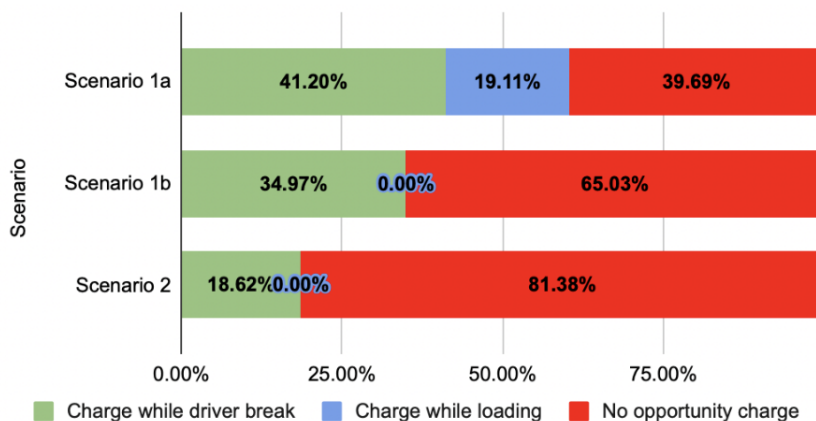
This appendix illustrates the benefits of faster chargers by comparing the results of different charging powers in the scenario model. First, we contrast 150 kW chargers to 500 kW chargers in terms of non-opportunity charging in the scenarios. Second, we contrast the impact of technological developments of manual chargers with non-manual chargers in the scenarios.

### D.1 Benefits of fast chargers

In this thesis, we have compared the scenarios in terms of efficiency and investment costs of charging hardware. The inclusion of the efficiency metric is important since charging is not only a one-time investment fee but is an activity that demands time that could otherwise be spent elsewhere. The cost of a charging session can be valued in terms of whether it is conducted simultaneously as another activity or not, i.e. whether opportunity charging or non-opportunity charging is conducted, and is hence a measurement of how efficient the scenario is. Naturally, all non-opportunity charging increases the round trip time and hence increases the logistic losses that an electrification of the transport route would imply compared to diesel. In contrast, all opportunity charging doesn't prolong the round trip since the other simultaneous activity had to be done anyway. This implies that if charging powers could be increased to eliminate the non-opportunity charging sessions, there would be fewer logistics losses and more efficient transport routes. However, as soon as charging sessions are shorter than the simultaneously conducted activity, the incentives to invest in faster chargers decrease as such investments would not result in time savings.

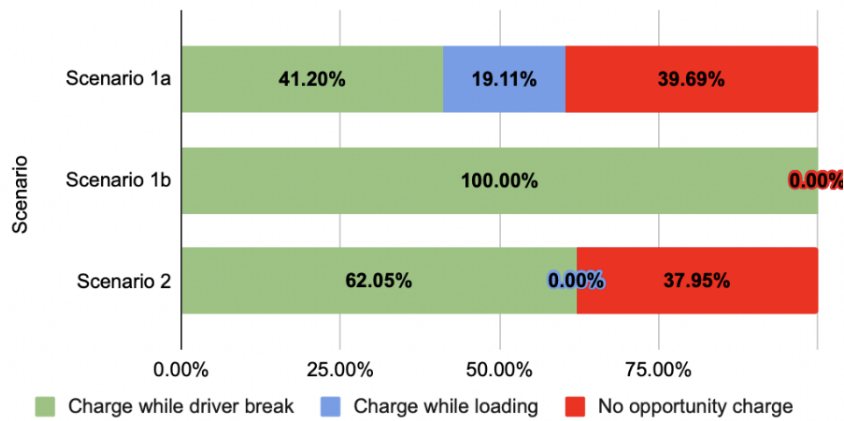
The scenario model shows the benefits of fast chargers, as higher charging power implies less logistic losses, i.e. lower degree of non-opportunity charging. Although it was assumed that chargers of 500 kW were used in Scenario 1b and Scenario 2 (see Table 4.3 in subsection 4.2.2), different values could be set to highlight the impact of faster chargers. For instance, when it is assumed that 150 kW chargers are used in all scenarios, the share of non-opportunity charging time becomes high (see Figure D.1). This means that even if the starting time of charging is aligned with the starting time of the driver's rest, the charging time required would be longer than the driver's rest of 45 minutes.

As seen in Figure D.1, all three scenarios include small shares of opportunity charging which mostly originate from charging during the driver break. Scenario 1a also includes opportunity charging in the form of unloading and loading while charging. Further, the loading and unloading time exceeded the charging time at Hub A in Scenario 1a. This implies that the charger at Hub A could have been slower, without affecting the efficiency. Hence, investing in a faster charger at Hub A would be unnecessary. In contrast, investments in faster chargers up to 355 kW at the other charger locations than Hub A are motivated in Scenario 1a, as it would eliminate the non-opportunity charging.



**Figure D.1:** Illustration of MET charging, assuming 150 kW chargers in all scenarios.

In figure D.2, a charging power of 500 kW is assumed for the future scenarios which implies that charging is completed in a shorter time. The scenario model shows that when charger powers are increased to 500 kW, the share of non-opportunity charging and hence the logistic losses decreased (see Figure D.2). In Scenario 1b, the non-opportunity charging for the MET lane is completely removed as the truck was able to complete the charging required during the driver break. Investments in even faster manual chargers than 500 kWh are not required in Scenario 1b, since it would not increase efficiency. Similarly, opportunity charging increased in Scenario 2. However, as more energy is consumed in Scenario 2 due to the longer distance, Scenario 2 required faster chargers in order to completely eliminate the non-opportunity charging sessions. With the scenario model assumptions, non-opportunity charging is eliminated already with 430 kWh chargers in Scenario 1b, while Scenario 2 would require chargers of 807 kWh in order to charge the batteries within the 45 min driver break. However, such statements assume that charging with such high powers is feasible and that the METs and AETs are able to receive so much energy at once.



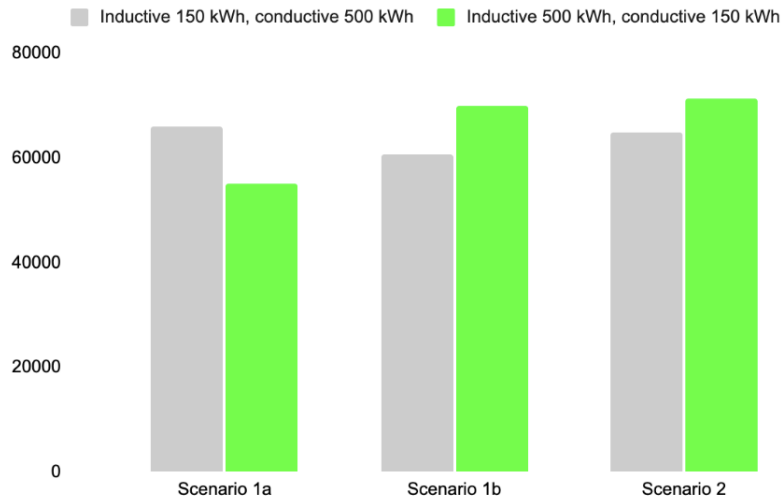
**Figure D.2:** Illustration of MET charging, assuming 150 kW chargers in the current scenario and 500 kW chargers in the future scenarios.

## D.2 Fast manual chargers or fast non-manual chargers?

In contrast to the MET charging, no charging time is conducted simultaneously as another activity when AETs are charged in the scenarios. This implies that all AET charging, i.e. non-manual charging, is non-opportunity charging which means that the faster chargers the better. The benefits of faster non-manual chargers are hence less limited than the benefits of manual chargers and might be even more beneficial than developments of manual chargers. For instance, as seen in Figure D.3, the efficiency in terms of transport tonnes \* km for Scenario 1b was 15% higher if 500 kW non-manual chargers and 150 kW manual chargers were assumed (green columns), than when the opposite was assumed (grey columns) (see Figure D.3). In Scenario 2, the corresponding number was 10%. However, if inductive chargers do not improve while conductive chargers improve, the most efficient scenario would be Scenario 1a, i.e. to not introduce AETs at all. With such assumptions, the inferior efficiency of AET scenarios (Scenario 1b and 2) compared to the scenario with only METs (Scenario 1a), would imply that other measures would need to be taken in order to transport the same amount of goods, e.g. prolonging delivery windows.

## D. Scenario model results of faster chargers

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**Figure D.3:** Transported tonne-kilometers in Scenario 1a, 1b, and Scenario 2 when inductive charger powers are low and conductive charger powers are high (in gray), compared to the transported tonne-kilometers in the same scenarios when inductive charger powers are high and conductive charger powers are low (in green)

However, as highlighted in subsection 5.2.2.1, the consequences of non-opportunity charging might be less significant for AETs, as it is exempted from labor costs.

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