CHOOSING ERS TECHNOLOGY FOR EUROPE

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CLIENT

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SUMMARY

Much effort has been put into evaluating alternative Electric Road System (ERS) technologies and discussing which criteria should be used in selecting the best technology. Three technologies are available: inductive embedded coils, conductive rail, and conductive overhead catenary lines. The evaluation processes itself has made it evident that it will be challenging to agree on a single technology for all of Europe. One option is to make an active decision on the EU level, which allows each country to select their own technology. An alternative is to allow the selection of ERS technology to be made when planning individual transport corridors. In short, the extent of political coordination will determine whether or not an active or passive decision is made (Note that a passive approach would essentially allow a dominant first-mover to set the game plan, which reflects how technologies have emerged in many other areas).

The aim of this report is to investigate how and at what decision level (EU, state, or transport corridor) the choice of technology could be made. There are many aspects of this question, all of which cannot be addressed in this report. Therefore, the report offers a structure for thinking about this new technology. The analysis provided here is based in part on interviews and desktop study.

Importantly, ERS technologies consist of several subsystems. These include e.g., electricity supply, road, power transfer to vehicles, daily road operation and type of vehicles. Decision-makers will necessarily have to address each of these subsystems, some of which can vary across countries while others are decided to be the same. In general, respondents in our interviews see no technological obstacle connected to payment systems. Rather, they regard it as a matter of designing incentives.

We find that the behavior of shipping companies has changed. In the past, many shippers changed trucks at EU borders, which would have made coordinating the choice of ERS technology unnecessary, since the consumer argument for choosing the same technology disappears. We also conclude that from a technological perspective, it is likely possible to combine several technologies on the same vehicle (despite some minor obstacles in combining inductive with conductive technologies, which are likely to be addressed in the future). However, there may not be a strong business case for including several technologies on the same vehicle. Therefore, the question of whether to coordinate the choice of technology remains. The strategy should aim for two goals:

1. That the network effect of ERS is fulfilled: users should be able to make use of the whole system.
2. That there is a competitive market for production of ERS technology, which will likely stimulate innovation and reduce costs.

One important question is timing: when should the testing phase transition to the selection phase (i.e., choice of preferred technology)? Based on the literature's description of the different phases of technological innovation systems, we conclude that ERS is on its way to entering a market formation phase. Some literature suggests that the interface between pilot/demonstration and market formation is characterized by learning processes (e.g., new technologies must be tested in markets with real customers).

Governments have two important but distinctly different roles in ERS. The first is to set the legislation and rules of the game for ERS, which can involve policy instruments aimed at reducing fossil fuels and/or providing incentives for green technologies. These instruments can result in increased electrification, which can be seen as direct support for the spread of green technologies like ERS. Importantly, these policy instruments should be ‘technology neutral’ so that the rules of the game can accommodate existing technologies as well as future ones that have not yet come to market (“policy instruments” here refers to fuel taxes, reduction quotas etc). The second role for governments is to provide necessary transport infrastructure for the economy. Some ERS infrastructure can be technology neutral (e.g., electric supply systems as well as payment systems can be designed to accommodate different ERS systems). However, at some point, investments will have to be technology-specific, which requires an active choice about the available and established technologies in the market.

Regulations or policy instruments also indirectly determine the demand for transport with ERS. Well-designed policy instruments define the market for green technologies (so-called “pull” policies). For climate, this means “pulling” users from fossil fuels toward other energy sources, e.g., electrification. ERS could play an important role in the sustainable electrification of the transport sector. Since policy instruments contain large uncertainties, it may be difficult to achieve technological shifts. Therefore, there is also a need for “push” policies aimed at stimulating and/or lowering barriers to innovation.

In general, policies tend to favor incumbent technologies, which may not be the best solution for society in the long term. These policies often allow the first-mover to set the agenda. In the case of ERS, the dominant national actor in Europe is Germany (although France also has potential here), which has essentially chosen the most mature technology (Siemens overhead lines has the highest technology readiness level since it is based on an old technology for rail). The important point here is not that overhead catenary lines are best (we have not evaluated technologies in this report; hence we have no ground to rank them), but rather that the first mover’s technology may not necessarily be the best.

There are potentially significant benefits of developing infrastructure that accommodates several different ERS technologies across time and/or space. First, technological advances may offer solutions that are more material-efficient. Second, different technologies offer flexibility and encourage competition which, in the long run, may lead to advantages for the economy. Choosing a technology too soon may prevent possibilities for creating new knowledge and potentially better systems. Further, the parallel development of different technologies creates a situation where vehicle manufacturers may not seek a monopoly on the market (which requires several competitors producing the same technology). One vehicle manufacturer stated that they only act when a "complementary" competitor enters the market. This is noteworthy as it contradicts classic economic theory, where all actors are assumed to strive for monopolistic power.

A general reflection from the interview study is that the topic of technological choice in relation to ERS engages actors. Although there are competing interests, not least in terms of what technology is “the best”, there appears to be a joint effort to make a fairly significant shift in transport infrastructure.

The political analysis finds that a multinational decision process regarding the choice of ERS technology would, if successful, likely result in a desirable outcome. However, multinational cooperation is difficult on the EU level, and is equally unlikely on the local decision-making level where transport corridors are implemented. Many prominent EU countries have contrasting interests, which implies a lack of incentives to lift the decision to the EU level (and thus a lower likelihood of successful coordination). Many of these countries have an interest in promoting technologies developed on the domestic level, which means their position may differ from international actors who may instead prioritize European interoperability. EU will nonetheless have an important role in defining standards for each technology. For example, the EU can develop standards for each of the different subsystems when these are not dependent on the ERS technology itself (e.g., power generation). The same type of coordination challenges is likely to occur when actors from different countries with different interests decide on a specific technology in a specific transport corridor. If the choice of ERS technology is done on a national or bilateral level, first-movers will play a decisive role since several second-mover countries will choose specific ERS technologies based on the choices made by first-movers. Although there are caveats we recommend aiming for an EU level decision since it brings the most benefits. The most important one being to enable the network effects of ERS. There is also a momentum for this now, judging from discussions at EU meetings. It would be advantageous to build the discussion at EU level around criteria’s that then determines the choice of technique. Example of possible criteria’s are safety aspects and whether the technique should allow for cars.

We end up with four policy recommendations for the Swedish government.

1. There are two paths to choose between: a passive path where we follow a dominant first mover and do not strive for compatibility and an active path where Sweden tries to influence so that the best technology and subsystems are chosen in a way that is compatible all over Europe. We advocate for choosing the active path since it brings the most benefits for the climate and accessibility in Europe.

As we pointed out above, there are a lot of caveats: but there are no disadvantages in trying. The process needs to be closely coordinated with the revision of AFIR.

Choosing the active path has implications both for the Swedish government and for the Swedish authorities. The Swedish government needs to push for a decision on investments in an ERS network and for a choice of technology. The risks for non-decision when it comes to choice of technology holds for investment in ERS corridors as well, until there is an active decision involving several countries, there will most likely not be an ERS network. The Swedish authorities needs to support this by:

- Spread the result of the Swedish work on ERS.
- Participate and coordinate tests with other EU countries.
- Participate in identifying how an ERS network should take form when it comes to technology, accessibility, emission effects etc.
- Aid the political level in developing a vision for a future ERS network, both in terms of the full deployment and the sequential steps.

2. When discussing which ERS technology to choose it is important to keep in mind that ERS consists of several subsystems. It is likely to be the case that some of these subsystems will be the same in Europe and some not.

3. The possibility to create a well-functioning market where is both pressure on prices and stimulus for innovation should influence the choice of technology.

4. Sweden is not a potential dominant first mover that other needs to follow, the economy is too small, and the country is in the periphery of Europe. On the other hand, Sweden is one of the leading countries when it comes to ERS tests and research. Hence Sweden’s ability to influence lies in information sharing and “thought leadership”. This means that a lot of effort should be put into spreading the results from the Swedish tests etc.

1 INTRODUCTION

1.1 BACKGROUND AND AIM

A lot of effort has been put into comparing the different Electric Road System (ERS) technologies and discussing on what basis the choice of technology should be made. Three technologies are available: inductive embedded coils, conductive rail, and conductive overhead catenary lines. During the evaluation processes, it has become obvious that it will be challenging to agree on one technology for all of Europe (it might not even be desirable). The choice of technology should be coordinated so that:

1. The network effect of ERS is fulfilled: users should be able to make use of the whole system.
2. There is a competitive market for production of ERS technology, which stimulates innovation.

The choice can be made by different constellations. One alternative is that each country chooses their technology, another that decisions are made when planning transport corridors, and a third that the choice is coordinated by the EU. Organizations within the EU now develop the standards for each technology, but making the choice between technologies would be a new task. The choice of political coordination can be made actively or passively (the passive alternative would be to let a dominant first mover set the game plan – the way that technologies have emerged in many other areas).

Answering questions regarding how the choice of ERS technology should be made in Europe requires input from economic theories about technological development and knowledge about the market structure today. Technological development or shifts is often complex and results from a combination of several factors, including different policy choices societies make. In fact, ERS is part of the electrification of the economy needed to phase out fossil fuels. Analysis of the potential market for ERS gives also important knowledge about the role of different actors and different challenges when choosing ERS technology.

Answering questions regarding the choice of ERS technology also requires technological knowledge. One important technological question is whether it is doable (with a reasonable amount of legislative force) to have more than one technology on the same truck. If so, the need for choosing the same technology in Europe diminishes. Another important technological question is whether only some of the subsystems need to be the same for ERS in Europe for the network aspects to work. Power transmission is the main difference between the technologies, but it is only one subsystem of ERS. Maybe power transmission could differ as long as, for example, the payment system is the same?

The aim of this report is to investigate how and at what decision level (EU, state, or corridor) the choice of technology should be made. Since there are so many aspects of this question, we cannot aim to treat them all in this report – we rather try to give a structure. The plethora of aspects also means that an objective and clear-cut recommendation is hard to reach. Setting criteria for which technology to choose is outside the scope of this report: it is a separate question from whom should make the choice.

This report is written within CollERS, an ERS cooperation between Sweden-Germany and Sweden-France. CollERS is part of an innovation partnership between the countries aiming to enhance innovation and knowledge exchange. The CollERS homepage is electric-road-systems.eu. The report is written by the Swedish CollERS team. Our aim is that the report should enable policymakers in Europe to make more informed decisions about how to proceed with ERS.

The choice to be made is elaborated on in Chapter 2: which are the technologies, which are the decision-making levels etc. Chapter 3 is a review of the literature on the development of technologies. Chapter 4 is a market analysis: what characterizes ERS as a good and what does the market look like? The conclusions are in Chapter 5.

1.2 METHOD

1.2.1 Literature review

The theoretical part of the report is covered by a literature review, including a market analysis. The literature review has been conducted to obtain a broader understanding of the technological development of markets, specifically in the context of technological shifts. Various aspects of technological innovation systems, such as phases and drivers within these systems, have therefore been examined. The literature review regarding technological shifts is followed by a review of how such shifts interact with environmental policy, a review of phases of technology innovation and a review regarding standardization. These introductory parts of the literature review ensure a comprehensive understanding of the relevant fields in the context of ERS, as well as a solid foundation for the understanding of the following market analysis and conclusions from the interview study.

Another part of the literature review is the market analysis. This investigates the relevant market conditions, trends, and dynamics to aid informed decision-making regarding pricing, strategies, and product development. The market analysis assesses both market aspects such as supply and demand, as well as the political background of ERS development and how it affects the relevant stakeholders. The methodological approach for the theoretical part enables a deeper understanding of both technological development and market conditions within the ERS sector.

The literature review has been based on academic publications and research articles within the field, thus it has been limited to literature topics such as ERS, innovation and technological shifts, transport economics, environmental policy, EU, and standardization.

1.2.2 Interviews

'Interview' is a central method within the qualitative toolbox. This method is suitable to gain a deeper understanding of a certain phenomenon by gathering actors'/individuals' perceptions and understandings of it[1]. What is your opinion on…? How do you perceive…? What does it mean to …?

In the study presented in this report, the aim of performing an interview study has been to understand how different actors within the ERS landscape perceive the mechanisms behind the choice of ERS technology. For example:

- Is it actually necessary to make a technological choice?
- If so, how could one or several technological choices be designed? What is considered to be suitable or even possible? What is not possible, and why so?
- What conditions, incentives and processes support the shift towards ERS?

Data generated through an interview study with a selection of actors should not be seen as representative of all actors, there may be nuances and contradicting opinions amongst those who have not been interviewed. Neither should the data be seen as objective "truths", but rather as subjective statements. However, this is actually what makes the method interesting for the study presented in this report. Here we have the possibility to trace how a selection of key actors perceive important components and mechanisms behind the choice of technology. As such, the interview study provides a ground for further investigation, analysis, and dialogue.

Although the main purpose of performing interviews is to gather (qualitative) information, it should also be noted that the interview method supports other purposes such as to strengthen legitimacy of or gain approval for a certain project or issue. Notedly, it has also been a sub-purpose of this interview study to support legitimacy of the national process of choosing ERS technology. This process dimension of the interview can

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[1] Examples of methodological references: (Bryman, 2008) (Kvale, 1996) (Ten Have, 2004).

be mutual; when performing the interview study, it has been noted that some of the respondents regard the interview session as a tool for communicating their statements (“truths”) towards the Swedish Transport Administration. Furthermore, from our side, there has also been an ambition to some extent to contribute to learning, for example by posing questions that force the respondent to reflect upon mechanisms behind driving forces, incentives etc.

Before the interview

The format of the interview method ranges from open interviews to structured ones. In the middle of this scale is the semi-structured interview format, which is the format applied in this study. The semi-structured format is based on an interview guide with themes and guiding questions but allows for follow-up questions and a high degree of flexibility to explore and elaborate upon themes that arise during the interview. The semi-structured interview format thus supports in-depth understanding.[2]

The interview guide used in this study is developed in relation to themes and statements from the literature review presented in Chapter 3. It covers the following themes.

- **Choice of Technology**
  Could two or more technologies exist at the same time? On the same vehicle? In Sweden? In Europe? Why, why not?

- **Payment Systems**
  How do actors perceive the topic of payment systems, what is technologically possible, and are there any obstacles? Furthermore, is standardization into one joint payment system necessary? In Sweden? In Europe?

- **Incentives, Driving Forces and “Rules of the Game”**
  What incentives facilitate the transition to ERS? What are the main driving forces behind the shift? What “rules of the game” support a well-functioning ERS market?

After performing a few initial interviews, the interview guide was slightly adjusted in order to facilitate the discussion around these themes within the set time frame. This is a common procedure when it comes to semi-structured interview studies.

The selection of respondents, i.e., the choice of persons to interview, is made based on two logics:

- The first logic is to interview vehicle producers with the aim of the first theme, namely if a technological choice at all is necessary or if several technologies could exist at the same time.
- The second logic is to deepen the understanding of all three themes by interviewing representatives for a broader set of actors that in some way have a stake in the technological choice of ERS. They may for example contribute to (or hinder) certain technological aspects or may be affected by a certain technological choice. As key actors, such respondents can be supposed to have a deeper knowledge of the phenomena.

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[2] It should however be noted that the method is to some extent of a co-creating character, something that is also reflected in the term ‘inter-view’ – crossing of views. The person performing the interview influences the respondent by posing certain questions and through mimics and “body language”. Furthermore, the person performing the interview interprets the answers given by the respondent. As such, the person performing the interview is a co-creator of the empirical result of the interview. When interpreting the interview data, we are aware of potential problems of bias. Furthermore, by having two persons from the interview team attending each interview, we reduce the risk of bias as there are “double sets of ears”.

To some extent “snowball sampling” has been applied, i.e., we have asked some respondents to recommend actors/persons to include in the interview study. Focus has been on actors in a Swedish context.

In total, the interview study plans to include interviews with 12 respondents that represent 14 actors:

- Producers of vehicles
- Producers of ERS technologies
- Actors within logistics or freight business
- Municipalities and regions that have taken part in pilot studies
- The Swedish Transport Administration

During the interview

The interviews have been performed as individual interviews in digital format over Teams. From WSP, two persons participated in each interview, one with the role of leading the discussion, the other with the role of documenting the discussion in interview notes. It should be noted that the interviews have not been recorded and transcribed.

After the interview

The respondents have been anonymized as far as possible. The complete list of organizations interviewed is presented at the end of this report, References. When presenting interview observations, we do not refer to specific organizations, unless doing so is necessary for the reader’s understanding.

Throughout the report, we present observations and patterns from the conducted interview study, based on the themes from the interview guide. We trace both such issues on which there seems to be a joint opinion between actors and issues where actors’ opinions deviate. Further, to some extent, we make references to the theoretical review presented in Chapter 3.

2 THE CHOICE TO BE MADE

In this chapter, we try to frame the question about the choice of technology:

- Which are the technological concepts? This chapter is meant to give an overview for readers that are new to ERS.
- Which are the subsystems of those technological concepts? Should some subsystems be the same all over Europe and some not?
- Do technical or logistical motives make the choice of technology irrelevant? If there can be more than one technology on a truck or if the shippers change truck at the border anyway, there is no longer a consumer argument for choosing the same technology all over Europe.
- What does it mean that the choice of technology can be made at EU, national or corridor level?

2.1 THREE TECHNOLOGICAL CONCEPTS

This chapter will present the different ERS technologies and the different components of the respective technologies. The purpose of this chapter is to set the stage for the analysis in the following chapters, not to provide a new analysis. Since ERS technologies develop at a rapid pace, we have searched for information to get the most up-to-date status of the different ERS technologies. There are three main technological concepts of ERS technologies: overhead catenary lines, conductive in-road rails, and inductive embedded coils (wireless ERS)[3].

2.1.1 Overhead catenary lines

With overhead catenary line (OCL) electricity is brought to the vehicle through pantograph technology integrated into the truck, allowing power draw from the OCL. The OCL is composed of two wires: the upper wire, known as Tragseil (TS), and the contact wire, known as Fahrdraht (FD). There are minimal current flows between these two wires thus the inductance between them is considered negligible. The power transfer from Siemens OCL is 400 kW. As an illustration Figure 1 shows a Scania truck connected to the OCL on a test track by Siemens.

Figure 1. Siemens overhead catenary lines

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[3] Inductive on-road rail is another technology. However, as producers of ERS are moving away from on-road to only in-road (for example Elonroad) we do not present the on-road rails in this study.

Infrastructure components

Siemens has developed packaged power solutions (PPS), electricity substations which are placed either next to the road or further away if desired. How frequently the PPS need to be spread depends on the number of trucks connected and their operational speed. The PPS capacity is approximately 1 MW and is in the test track of Elisa situated every 5 km. The test track in Sandviken, Sweden, was engineered for 750V direct current (DC), but trials were conducted at 600V DC.

Road components

Catenary technology will not directly affect road structures. However, it will require infrastructure development along the road, including support masts, concrete foundations, and longitudinal guardrails. Consequently, side-verge areas, drainage ditches with culverts, and cable-infrastructure will be impacted requiring geotechnical investigations before installation. Construction will involve excavations or piling in side-verge areas, potentially influencing road structures, and causing various types of damage.

Vehicle components

Pantograph technology is incorporated into the truck, enabling it to draw electric power from the OCL. Positioned atop the vehicle, the pantograph features two contact shoes for power collection. One shoe connects to the OCL's positive line, while the other connects to the negative line. The current pantograph is in the 4th generation and is ready for industrialization, with reliable and operational design. Pantograph wear tends to be minimal, requiring replacement only during regular truck maintenance.

Monitoring

Monitoring can be done through GPS tracking or Geo-fencing on the vehicles. Identification system which relies on satellite data. Mobility provide gives access to vehicles to use the eHighway for certain periods, like systems already in use for satellite tolling.

2.1.2 Conductive in-road rail

A modular receiver arm extends down from the vehicle to a coil in the road for power transfer. The coil is installed into the asphalt via mounting plates and rails are glued or bolted on the road surface. For road handling and safety, the coil needs to have the same friction as the rest of the road.

There is a public test track in Lund by Elonroad, see Figure 2, where the power transfer was 200 kW and the operating speed was restricted to 40 km/h. However, as the technology develops, Elonroad's technology can now power up to 350 kW at higher operating speeds. Another producer, Alstom, argues that the conductive in-road technology has the highest deliverable power among the ERS technologies as they have managed to deliver up to 400 kW for dynamic charging on a 300 m demonstration track in Gothenburg, Sweden. To propel and recharge trucks, the power transfer needs to exceed 350-400 kW.

Figure 2. Elonroad conductive in-road rail

Infrastructure components

For Elonroad, substations are planned to be placed 0-20 meters from the road, even though the distance could technically be longer. Each substation is planned to be 3 MW and there is then a need for a substation every 1,5 km to provide energy to a maximum of 10 trucks per section. However, there are some limitations on the frequency and the number of vehicles that utilize the power transfer at any given time, see Figure 3 below.

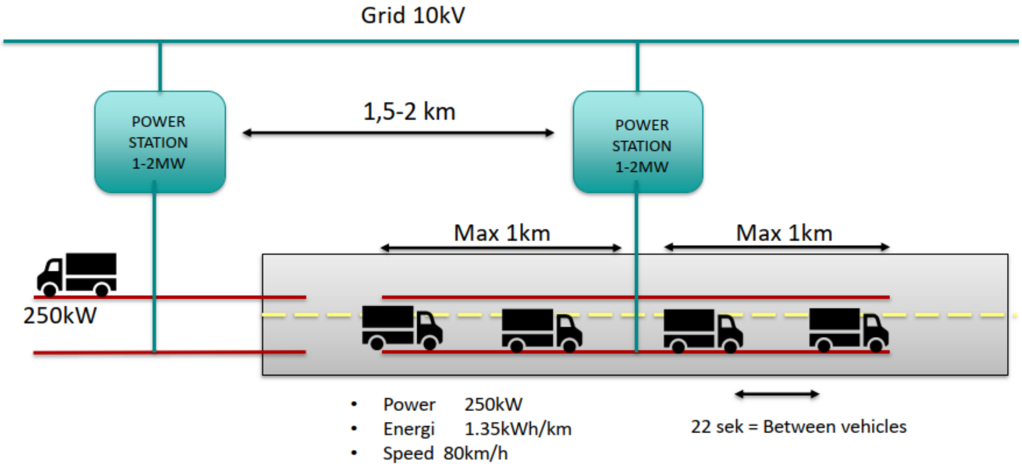

Figure 3. System and infrastructure of Elonroad's conductive in-road system

Road components

First, a groove needs to be carved out that is 6,5 cm deep and 30 cm wide for Elonroad, where the coils are then installed, and the groove is asphalted again. Feeding cables (from the substations) are needed every 1,5 km and there is no need for additional barriers.

Vehicle components

The main vehicle component in the conductive in-road rail is a modular receiver arm extending down and connecting to the rail to transfer power from the rail to the vehicle.

Monitoring

Energy measurement can take place both in the electric road system (for each vehicle) and/or in each individual vehicle, in the receiver's control box. There is the possibility of using the open and standardized protocol OCPP (Open Charge Point Protocol) to provide access to transaction data. OCPP is an application protocol for communication between Electric vehicles (EV), charging stations and a central management system. This is also known as a charging station network, like the one for cell phones and cell phone networks.

Sealed third-party metering can also be connected and take place in the same way as a standard electrical network connection to meet possible such requirements.

Energy consumption in the ERS is measured and then summed up per vehicle and uses 4G or 5G to communicate with the vehicles to enable sending data back to the system (e.g., energy consumption). There is also a communication (radio signal) between the rails and the receiver on the vehicle that sends an encrypted signal that confirms that the vehicle should get access to the road and then turns on the energy.

2.1.3 Inductive embedded coils

The coils of wireless ERS are hidden beneath the surface of the road, thus embedded within the road structure with no visible signs of an ERS wireless charging system (WCS). Electricity is transferred from the coil to the vehicle by High-frequency Resonant Inductive Power Transfer (RIPT) between the (primary) coil and a receiver (secondary) coil on the vehicle. Figure 4 shows the basic operating principles of WCS. Electreon and Magment are two leading producers of inductive embedded coils.

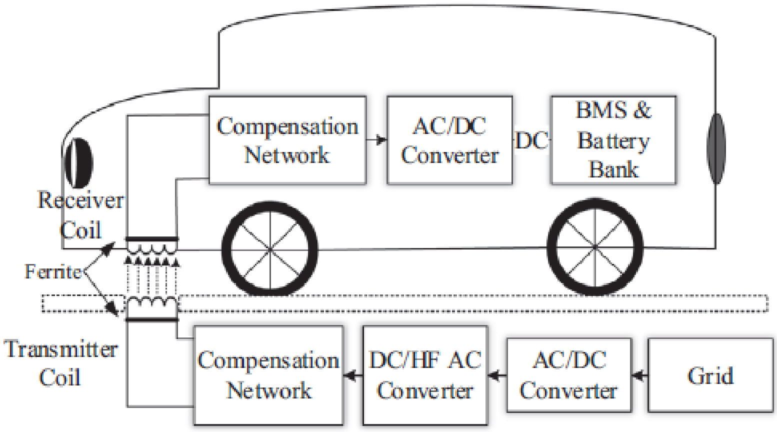

Figure 4. The basic operating principles of WCS. Source: (Panchal, Stegen, & Lu, 2018)

To name a couple of the main producers, there is Electreon[4], ENRX[5], Magment and the Online Electric Vehicle (OLEV) system of Dongwon/KAIST in South Korea.

Infrastructure components

Substations can be placed outside roadside area with approx. 1 km longitudinal spacing. If management units can be placed beneath ground surface, there will be no need for side barriers.

Road components

The transmitter coils are embedded into the road as Figure 5 shows. Then the coils are covered with asphalt.

Figure 5. Inductive embedded coils, wireless ERS

There are different installation technologies for the construction of embedded inductive ERS: Trench or-micro trench based and full lane width dependent on how much effect is required.

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[4] Electreon's wireless technology has been demonstrated in 12 projects including the following places: DuraBASt, Köln, E|MPOWER, Bavaria, Tel Aviv (two), Gotland, Karlsruhe, Brescia, MDOT, USA

[5] Have demonstrated projects in Lommel, Belgium for buses and cars and in Mannheim, Germany for buses and trucks.

In Figure 6 a cross section of the inductive embedded coils by Magment (although the principle is general) is displayed.

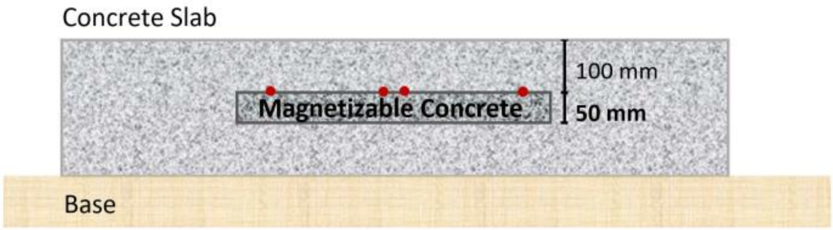

Figure 6. Cross section of Magment's inductive embedded coils

Vehicle components

To receive electricity from the ERS, vehicles need to be fitted with Wireless Electric Vehicle Charging Systems Commonly the systems are placed on the bottom of the vehicle, Bottom Mounted Wireless Charging Systems. There are four methods for inductive power transfer, capacitive wireless power transfer magnetic gear wireless power transfer and resonant inductive power transfer (Panchal, Stegen, & Lu, 2018).

Modular receivers on the vehicle that can capture 25 kW have been tested. A large truck can apply up to 5 receivers. A truck can run at speeds up to 80 km/h. Electron themselves claim that their technology supports up to 180 kW to the truck. According to ENRX their technology has an overall efficiency of more than 90 percent and has delivered a capacity of 180 kW. Magment systems merely have 50 kW power transfer.

Monitoring

Monitoring of charging is done both at the car and control unit supplying electricity to the road. Electron is working on a system to store data on charging to the cloud. As opposed to other technologies, monitoring is built into the system.

2.2 ERS CONSISTS OF SUBSYSTEMS

In the introduction, we stated that the rules for the choice of technology should be set up so that:

1. The network effect of ERS should be fulfilled: users should be able to make use of the whole system.
2. A competitive market for production of ERS technology is enabled and innovation stimulated.

It might be the case that the best way to reach goals 1 and 2 is by determining that only some of the subsystems need to be the same for ERS in Europe for the network aspects to work. Power transfer to vehicle is the main difference between the technologies, but it is only one subsystem of ERS. Maybe the method for power transfer to vehicle could differ as long as, for example, the payment system is the same?

We try to explore this question in this chapter. Since this question is very complex and requires a thorough technical and market analysis of all subsystems which is beyond the scope of this project, we only provide a structure and some thoughts. We start by describing the different subsystems.

Table 1. ERS subsystems

Subsystem	**Definition**
Electricity supply	Grid along the ERS, including substations and management units
Road	Installation in road (pavement, barriers, rails/coils)
Power transfer to vehicle	Transfer of energy into vehicles (receiver)
Daily road operation	Energy measurement, vehicle identification, payment & billing solutions
Vehicles	Truck, bus, van, passenger car

As some interfaces between components and subsystems are not fully defined today, the above division can probably be changed both in the short and long term. Also, individual components could be argued to belong to another subsystem. As one example, management units could be argued to belong to the specific ERS technology and hence be included in the subsystem for Road. There could also arise situations where a specific ERS provider decides to include more generic technical solutions or systems (e.g., solutions/systems used in other applications than ERS) in their own system design of one or several subsystems of the ERS.

See Figure 7 below, to understand how the evaluated subsystems above refer to the Swedish Transport Administration's previous definition of components and services of an ERS.

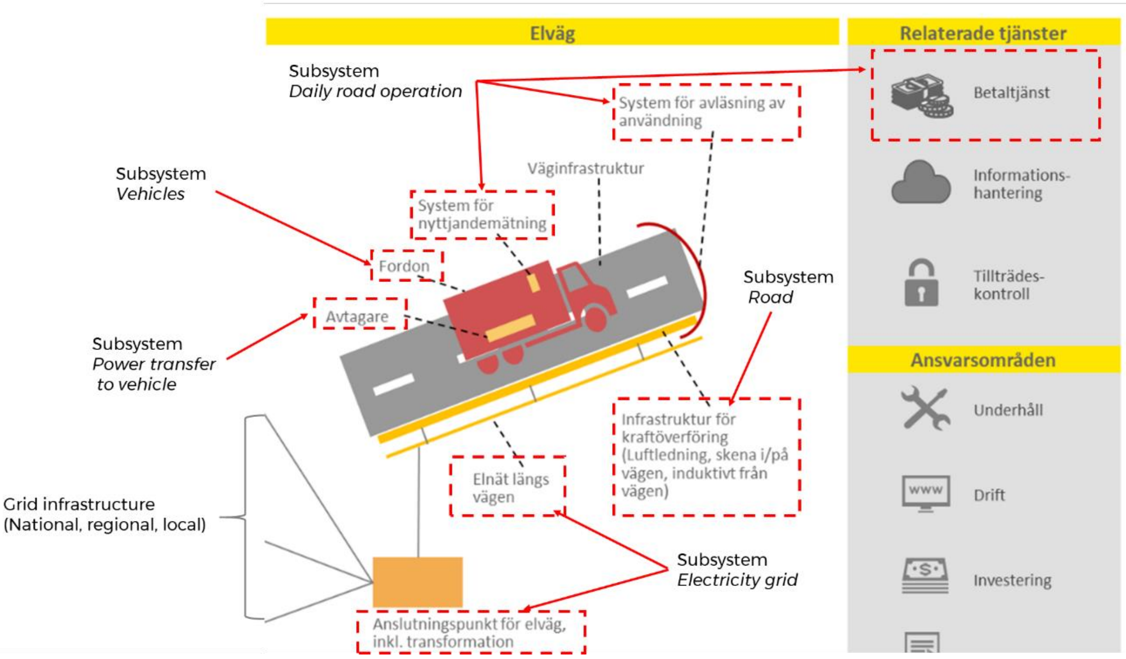

Figure 7. This assessments subsystems in relation to the Swedish Transport Administration's ERS-system definition. In this figure, Swedish terms have been translated to corresponding English terms.

The payment system might be a candidate to standardize, if the ERS choice of ERS system differs between European countries. Regardless of the choice of technology for the energy transfer, the ERS system will need revenue management for the users' payment of the electricity.

In a preliminary study on payment systems for electric roads, the analogy is made to modern telecommunications (Gustavsson, Börjesson, Kenani Dahlgren, Moberger, & Petersson, 2015). This mainly applies to three aspects: infrastructure, mobility, and collaboration. Since for electric roads there will be different actors that manage the road and provide electricity, the infrastructure can be compared to the network infrastructure of the telecom industry.

Collaboration is crucial to create competition without hindering users' options. For example, users need to know that access to electricity is guaranteed regardless of the electricity retailer and grid company. It is also of the highest importance that all consumption of electricity is collected in one bill to reduce difficulty and administration (Gustavsson, Börjesson, Kenani Dahlgren, Moberger, & Petersson, 2015).

For the existing electric vehicle market, the multitude of different payment systems for charging is seen as a central issue. Several systems for end-user payment of energy to charge an electric vehicle exists today, systems that range in design from the so-called "pay as you go"-method to charge subscriptions. Furthermore, differences in payment rates between charging stations complicate the usage of electric vehicles. Discrepancies regarding the different payment systems are according to the UK Department of Transport seen as a significant issue among electric vehicle users (Chamberlain & Al-Majeed, 2021).

Having a unified payment system for energy used when charging might therefore be seen as an important part of the electrification process (although the interviews made in this project do not indicate that). The absence of which could make the usage of future innovative electrification technologies more difficult, thereby limiting its dissemination. Thus, when considering different payment solutions for ERS one should consider lessons from the already existing electric vehicle market and the benefits of a unified method of user payment.

2.2.1 Payment systems from an actor's perspective

Regardless of which technology is chosen for the transfer of energy to the vehicle, the ERS system will need to manage the users' payment of the electricity consumed[6]. This section describes how respondents in the interview study regard this topic.

Not a technical challenge

In general, the respondents consider payment systems to be "not an issue", not a technical problem. Several respondents refer to other forms of payment systems in connection to infrastructure, such as road tolls, parking, and stationary charging.

In connection to ERS, respondents refer to two possible payment solutions. A few refer to some form of a "fixed fee", either in the form of a monthly or yearly fee or as a road toll that you pay when using the road per se. Most however refer to a system of paying for the amount of energy used. This requires two parameters; to identify the user and to measure how much energy is used, for example by placing a measuring instrument in the vehicle. A few discuss the possibility of "subscription" including a certain number of kilometers.

Regarding the matter of measuring, some respondents stress the importance of accuracy and security, to reduce the risk of "free riders". Most respondents however see no (technical) problems in making sure that the vehicle's system manages to supply the correct information to a payment system. Several argue that such systems already exist. Some actors have developed their own technology for a payment system, while others point towards existing aggregating systems as well as reference measuring systems.

Related to the payment system, some of the respondents argue that it is important that using ERS is heavily subsidised, one even argues that it should be for free. The reason is that this would be an incentive to speed up the process of more actors taking ERS into use, and thereby an important step in the sustainable transition. There are however counterarguments. For example, a couple of respondents argue that it is important that one pays for the energy one uses. One argument is that this provides incentives to use as little energy as possible which is important from an environmental perspective. Another argument, put forward by a respondent

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[6] Unless electricity is provided for free. One of the respondents is in favor of such a system, arguing that it should be regarded as a public good.

representing the freight and logistics sector, is that their clients want to take part of the gain by using a cheaper form of energy. Today with traditional fuel, the cost of fuel represents around 35% of the total cost of transportation of goods. This means that freight customers potentially drive strong economic incentives connected to electrification and further so incentives of paying for the electricity used.

Need for standardization or not?

The literature on payment systems presented above, which is based on international examples, stresses the importance of a standardized payment system for charging. It is even argued that this is an important part of the electrification process. One study refers to UK Department of Transport arguing that discrepancies regarding the different payment systems are seen as a significant issue by the electric vehicle users. Today, a variety of payment systems exist, systems that range in design from the so-called “pay as you go”-method to charge subscriptions (Chamberlain & Al-Majeed, 2021).

A few of the respondents in the interview study presented in this report likewise stress the importance of standardization of payment systems in Europe. They argue that it would make it easier and smoother to use ERS, “reduce the need for lots of different apps”; hence strengthen incentives to shift towards ERS. However, most respondents see no problem with combining several payment systems in Europe or even within Sweden, as long as it is “seamless”, transparent, foreseeable and smooth for the user. One even argues that some degree of competition supports technical development.

This view reflected by many respondents in our interview study thereby contrasts with the view presented in one of the studies referred to in the literature on payment systems above. That study stresses that users need to know that access to electricity is guaranteed regardless of the electricity retailer and grid company. In contrast to arguments presented by respondents, the study further argues it is of the highest importance that all consumption of electricity is collected in one bill to reduce difficulty and administration (Gustavsson, Börjesson, Kenani Dahlgren, Moberger, & Petersson, 2015).

2.3 DO TECHNICAL OR LOGISTICAL MOTIVES MAKE THE CHOICE OF TECHNOLOGY IRRELEVANT?

This section reflects upon the matter of choosing ERS technology based on an actor’s perspective. One important technological question is whether it is doable (with a reasonable amount of legislative force) to have more than one technology on the same truck. If so, the need for choosing the same technology in Europe diminishes. If not, or if it is too expensive, the motives for having the same technology increase.

However, this question of “technological choice” widens as actors approach the matter of “technological choice” from different starting points and with different incentives. Actors are likely to perceive problems, as well as solutions, differently depending on the type of actor and role in the system. Persons representing these actors (i.e., respondents in this interview study) may also perceive problems and solutions differently based on for example background, perspectives, knowledge, etc.

Within the ERS landscape, a variety of actors hold different pieces of the puzzle. One category of actors is producers of vehicles. Another is producers of ERS technology. Furthermore, there are users of the (ERS) infrastructure system such as companies working within the logistics and freight business. There are electricity producers, both energy companies and grid owners, who provide the supply and deliver electricity to power the electric road system. There are public authorities on different levels involved due to a variety of reasons such as owning infrastructure, planning, or financing road infrastructure, or handling and granting permits connected to environmental legislation. There are public and private landowners. There are also actors and networks of actors that drive technical knowledge and innovation, for example, universities and institutes in network with companies and trade organizations. And there are (national) actors that politically, legally, or economically facilitate the shift towards ERS. From a general perspective, the actors are mutually dependent on each other in this complex governance landscape. Vehicles, technical systems, and infrastructure must all be in place for the ERS system to function. Further, the system is only of relevance if someone uses it. However, as there are a few different technologies, some of the actors are in some sense competitors.[7] The actors within the ERS landscape are further discussed in the market analysis in Chapter 4.

2.3.1 Combining technologies – possible but not suitable

Most respondents agree that the main challenge of choosing ERS technology is not a technical one. When constructing a truck, almost everything is customized today. Thus, adding one or several ERS technologies is not an obstacle technically speaking. However, it is not, according to several respondents, a good business case to do so. It will be too expensive, there will be a lack of space having two technologies installed on one vehicle and/or make the vehicles too heavy to carry several technologies. In other words: the challenge lies within the vehicle integration (the cost and finding the space on the vehicle for the installation), not within the technology itself.

Moreover, a good business case needs the production volume to increase rapidly and competition between at least two actors. Hence, it is an ERS vs truck interface in the vehicle that should be standardized, not the ERS technological charging system. Having two or more different ERS technologies will delay the increase in production volume, some respondents argue.

As reported by a few respondents, one complication is that several vehicle manufacturers are quite uncertain about alternative technologies (alternatives to plug in). The vehicle manufacturers do not want to lose control of components in the vehicle, which could have an influence on insurance amongst other things. Thus, the challenge is not mainly technical, but it lies in the uncertainty of the vehicle manufacturers and of the ERS market.

Put differently, ERS is regarded by respondents not only as a choice of technology but also as a matter of politics. There must be political decisions, both national and from the EU, for something to happen that enables investment. According to many of the respondents, consumers already have an interest in ERS, but the infrastructure must be in place before a functioning market can emerge. A challenge is therefore that countries in the EU have different systems for how infrastructure is paid for. Additionally, several respondents have expressed concern over the (in)ability to produce enough green electricity to make ERS work in all EU countries.

2.4 DO THE SHIPPERS CHANGE TRUCKS BETWEEN COUNTRIES ANYWAY?

A relevant question for the choice of specific ERS technology is if cargo transported by truck changes truck when crossing between different countries. If the shippers change trucks between countries, for example, the need for the same power supply diminishes. This section will therefore discuss this topic.

In general, cargo transported within Europe, including both EU member states and non-EU countries, does not change trucks when crossing between different countries. This is partly the result of the significant efforts made in Europe to facilitate movement of goods between countries and efficiency within its transport networks. The EU, through the principle of free movement of goods, has created a harmonized customs union and a common market, which allows for seamless transportation of cargo across its member states. This means that

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[7] Examples of references within the field of “Planning Governance”: (Allmendinger, 2002) (Cars, Healey, & de Magalhaes, 2002) (Flyvbjerg, 1998) (Healey, 2007) (Hillier, 2007)

trucks carrying cargo within the EU typically do not require truck transfers at internal borders, ensuring smoother and more efficient logistics operations. For non-EU countries in Europe, various agreements and conventions are in place to facilitate streamlined processes and minimize the need for cargo transfer between trucks at international borders.

While the general trend in Europe is that cargo does not change truck, there are situations where cargo may need to change trucks when crossing between different countries within Europe. These reasons can include compliance with local regulations, change of transport companies, border security inspections, or logistical requirements. Regarding compliance with local regulations, some countries within Europe have specific regulations or requirements for the transportation of goods across their borders. These regulations may involve the use of domestic carriers or specific types of trucks authorized to operate within their territory. If a cargo's journey spans multiple countries and involves different trucking companies, it may be necessary to transfer the cargo to a new truck operated by a different company at the border. This change in trucking companies can occur to ensure a smooth transition and adherence to contractual or operational agreements. International border crossings often involve customs and security inspections. If cargo is selected for inspection, authorities may require the goods to be unloaded from the original truck for thorough examination. Additionally, in some cases, cargo may need to be transloaded at a border for logistical reasons. For example, if the cargo needs to be transferred from one type of truck (e.g., a long-haul truck) to a different type of vehicle (e.g., a local delivery truck) that is better suited for the last-mile delivery within the destination country.

Although the trend has been towards not changing trucks at borders, it might be the case that ERS affects TCO to such an extent that it will start to happen.

2.5 THE RULES CAN BE SET AT EU, NATIONAL OR CORRIDOR LEVEL

Rules regarding the choice of specific ERS technology could be set at different political levels, most likely the options are EU level, national level, or transport-corridor level. This section will discuss the advantages and disadvantages of each of the three alternatives.

2.5.1 Choice of ERS technology made by each country independently

The first alternative is that each country makes their choices of ERS technology independently. Democratically elected governments are accountable to the needs of their citizens, in contrast to the EU, which has been criticized for lacking democratic legitimacy due to the distance between its institutions and the general population. (Demetriou, 2015). Therefore, letting the technology choice occur at the nation-state level could be seen as more democratic. Furthermore, nation states implementing ERS within their borders are better able to relate the choice of technology to the strengths and weaknesses of their own political administrative systems. It also reduces the risk of inter-state deadlock and conflict caused by disagreements on the technology choice. One initial downside of letting countries choose technology independently is the risk of a heterogenous implementation. If the countries involved were to implement different technologies to a high degree, the usefulness of the technology and the gains in possible distance travelled would be limited. In turn, this might undermine trade and mobility between states having adopted the system. The political benefits of interconnectedness provided by the EU are reduced as vehicles with smaller batteries would be more dependent on domestic ERS infrastructure.

2.5.2 Choice of ERS technology made when planning transport corridors

A possible alternative for rule-setting is that the choice of technology is made when planning transport corridors. In comparison to a situation in which every country chooses a technology, the success of such an approach would result in coherent ERS technology choice on specific transport routes. It may also give countries more control over specific transport routes relevant to them. It would thereby create a decision-making framework capable of delivering cross-national routes requiring only one form of ERS technology for its users. Choosing technology when planning transport corridors requires coordination between a variety of different stakeholders with different backgrounds, therefore there is a risk that coordination issues complicate the decision process. When discussing cooperation in the context of governance related to fisheries and reduction of eutrophication, Hassler et al. (2019) point out diverse stakeholders as a hinder to international cooperation. In the context of ERS technology choice on a corridor level, both public and private actors from different countries relevant to each corridor reduce the likelihood of a successful cooperation. This process could also be further complicated by the fact that different ERS technologies may be suitable for different parts of a corridor. Such a constellation would also mean that countries get less control over the choice of ERS technology in Europe as a whole, in contrast to a situation in which the choice of technology is coordinated by the EU. Whilst countries receive more power over the corridors in their direct vicinity, they also lose power over the choice of ERS technology for corridors outside their vicinity. This is important since such corridors may affect them politically and economically even though they are further away from the country.

2.5.3 Choice of ERS technology made at the EU level

A third option is that the choice of ERS technology is made at the EU level. An EU-level approach, if successful, might lead to more a homogenized roll-out with a high level of international EU-wide coordination. As several of the important legislative and administrative functions like standardization are carried out at the EU level, decision-making at this level could benefit from the existence of an already formed framework for international decision-making institutions. ERS implementation is an issue which requires a lot of technical expert knowledge and is not likely to engage the population to any significant degree. Therefore, implementation may benefit from the wide pool of technical expertise available at the EU level (Christensen & Gornitzka, 2022). Furthermore, the choice being made at the EU level may result in greater possibilities to travel between the involved countries using ERS with the same vehicle, leading to more interconnectedness. The downsides include the separation of the various EU institutions. The administrative gap between the commission, the parliament, the court, and the council, gives interest groups and industrial lobbyists increased influence in steering the policy-making agenda. The EU member states derive their power from democratic legitimacy. Germany and France can be considered relatively dominant within the EU (Daehnhardt, 2022), and therefore arguably have more influence on EU-level implementation of ERS. As the EU is noted to suffer from a democratic deficit, the relative power of the states involved must be considered. The relative influence on some member states could lead to biased decision-making at the EU level. Neither of these countries can be presumed to be incentivized to facilitate decisions that do not benefit their respective industrial interests. This could undermine the legitimacy of the decision and therefore its implementation among states favoring another technology. As the EU relies on a “soft” approach in implementing its policies, the possibilities for member-states to undermine implementation are significant (Steunenberg, 2006). Thus, EU level decision-making should be seen as unlikely to result in successful coordination of ERS implementation. This view on difficulties surrounding coordination issues for countries with different interests is described by Hassler et al. (2019), underlining how contrasting economic and industrial interests decrease the likelihood of a successful international coordination.

3 THE LITERATURE ON HOW MARKETS DEVELOP TECHNOLOGICALLY

3.1 TECHNOLOGICAL SHIFTS

Technological shifts can be described as changes that occur when a new technology substitutes older established technologies (Lundqvist, Olander, & Martynovich, 2017). This may happen gradually or suddenly, depending on relative advantages of the new technology and its speed of spread. Technological shifts are crucial for society and the economy. These last two centuries, the world has experienced exceptional economic and welfare growth that would not be possible without technological advances.

A technological shift is often described as a process that typically starts with a scientific discovery or breakthrough in a particular field. It may however be more correct to describe it as a process that often involves a combination of scientific, engineering, market, and regulatory factors and it is not easy to determine when it starts and when it ends. Scientists may uncover new principles, materials, or technologies that have the potential to be applied in new ways. This is then gradually transformed into a functional technology. At the same time, market forces play a critical role in driving technological shifts. As consumers and businesses have new needs or demand new capabilities, and more efficient solutions, companies invest in developing and commercializing new technologies that can meet these needs. This creates a feedback loop where technological advancements drive demand, and demand drives further technological advancements. However, the technological shift may also be a process that is induced by changes in relative prices or a result of collective needs in a society that are expressed in changes in policies. The oil price shocks in the 1970s led for instance to major technological shifts in energy sectors around the world. The driving force behind ERS is the electrification of the economy, aimed at phasing out fossil fuels. It is in this context that the demand for ERS should be understood.

In the following section, we discuss ERS as a technological shift induced primarily by the need for electrification of the economy to reach climate goals. Consequently, it is interesting to study the process of technological shifts when they have multiple driving forces but are primarily caused by changes in environmental policy.

3.2 ENVIRONMENTAL POLICY AND TECHNOLOGICAL SHIFTS

The interaction between environmental policy and technological changes is complex. Technological shifts are transitions in the economy that potentially change the structure of the economy and societies. Policies do however play an important role and can affect the direction of technological shifts. Governments often need to work closely with technology companies and stakeholders to ensure that the market conditions, such as policy instruments, laws, and infrastructure, are in place that support innovation. Technological shifts may however be accelerated or slowed down by government policies or regulations. For example, subsidies for renewable energy or tax incentives for businesses that invest in new technologies can accelerate the adoption of sustainable technologies. Conversely, regulations that restrict the use of certain technologies or limit competition can slow down technological progress.

In recent years, technological shifts are increasingly seen as important to reduce the overall human impact on nature. This is particularly true in climate change. Much of the literature, including theories of environmental policy, focuses on stimulating innovation to conserve and protect nature (Smith & Raven, 2012) or argue for innovations towards new technological systems (e.g. (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008)). Another strand of the literature argues that it is also important weakening the core of current regimes that sustain incumbent technologies to open opportunities for new technologies (Kivimaa & Kern, 2016).

In theory, green technology advances do occur when environmental policies are designed properly. Specifically, if policies are designed to internalize the costs of polluting activities, this theory predicts that investments in green technologies will become more profitable, leading to a transition towards green technologies. In the literature, environmental policies inducing green technologies are referred to as the dynamic effects and is a long-term effect (Baumol & Oates , 1988, 2nd edition). In the real world, these theoretical predictions are empirically difficult to observe, which suggests that well-designed environmental policies are necessary but not sufficient to induce green technologies. They are necessary to change the rule of the game to direct private investments towards greener solutions, but they are not sufficient as there are other barriers that policy needs to deal with for these green investments to occur. One such important barrier is that private investors in the market tend to underinvest, i.e., invest below what is socially optimal, in knowledge, innovations and R&D. Therefore, if new knowledge is to emerge or green technological shifts occur, there is a need to simultaneously address environmental problems and barriers to innovation.

In the literature on design of policy instruments, there are two distinguished sets of policy instruments for green technologies: pull and push (see for instance Acemoglu et al. (2012), Greaker et al. (2018), Popp (2019) and Hart (2004)). Pull policies can be seen to increase demand for green solutions by increasing future profits from green investments while push policies are more direct support to green technologies.

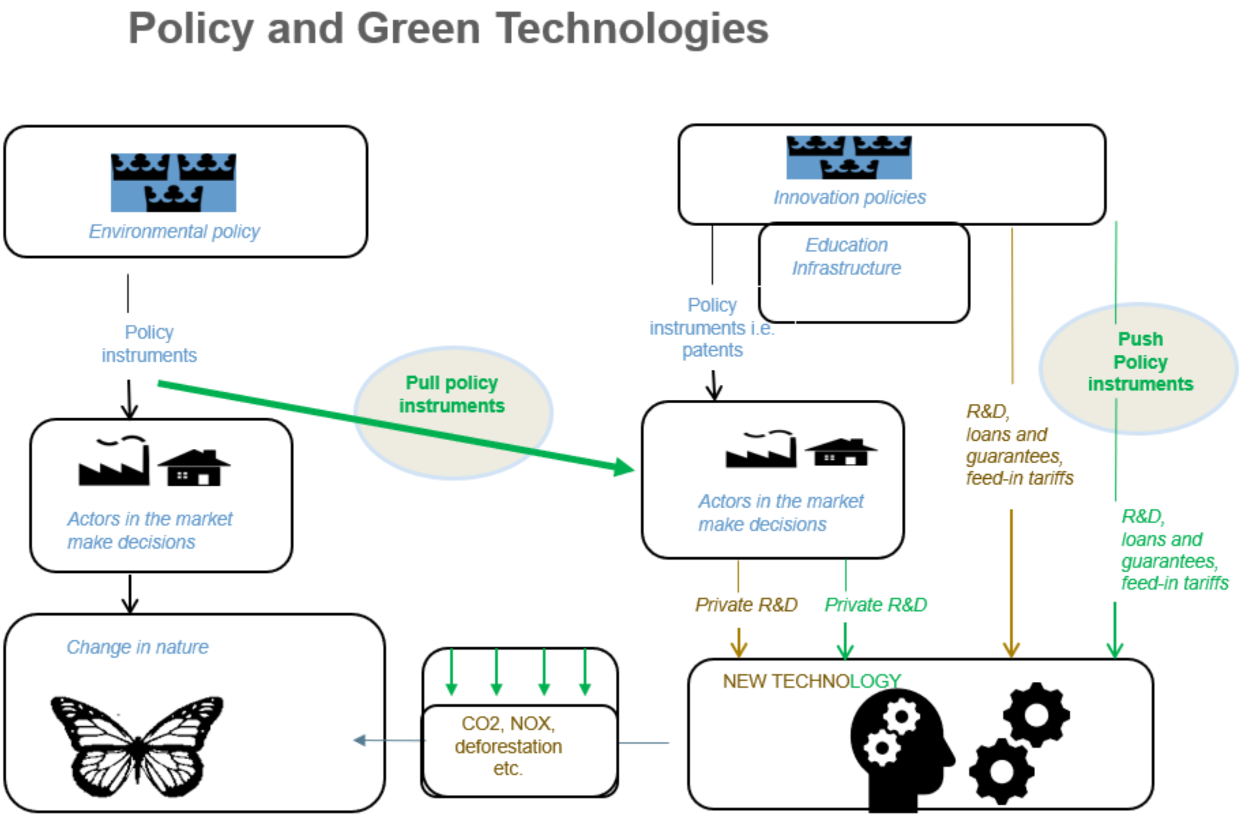

Figure 8. The figure is an illustration of how pull and push policy works. The main objective of pull policies is to regulate environmental problems and the main objective of push policies is to induce innovation. The figure shows how the two sets of policies complement each other to improve the environment.

3.2.1 Pull policies

Pull policies are designed to twist the rule of the game in the market to favor green investments, which creates market incentives for firms and consumers to adopt green technologies. These policies are classical environmental policies, with the aim to internalize environmental externalities by making polluters pay for the environmental damage they cause, such as environmental taxes or subsidies. The idea behind pull policies is to increase costs in the economy of all activities in proportion to pollution or environmental damage they cause such that green technologies have a cost advantage compared to dirtier technologies. Pull policies tend to be effective when green technologies are available in the economy but are more costly to use than dirtier technologies. By increasing the cost of using alternatives to green technologies, pull policies can increase the use and diffusion of green technologies in the economy.

However, the availability of green technologies in the market is often limited. In such cases, there may be a need for new research and development or a need to adjust or direct existing technologies toward green solutions and reduce environmental problems. In either case, the need for investments is substantial.

Attracting investments to green technologies is however much tougher than it may seem. Investors generally look for technologies with significant potential for future growth in profits. Typically, this potential is related to products and innovations with large growing markets.

The potential market size of green technologies is defined by environmental policy. If properly designed, the potential size of green markets increases the tougher the environmental regulations are. If for instance environmental policy consists of only one emission tax, the potential market for green technologies would be determined by the tax level times the amount of emission that are obliged to pay the tax. In case these emissions are generated by vehicles, the potential market would then be all vehicles that might demand green technologies to reduce their emissions. Therefore, incentives to invest in green technologies are directly related to the environmental policies implemented around the world, which have several implications that are discussed below.

The main question to answer is when environmental policy attracts investment in green technologies. To summarize what is already stated: policies need to be well designed such that damaging activities should pay for the cost they cause. The design of environmental policy is crucial for investors. When properly designed, policies that increase the costs of polluting activities need to be stringent, transparent, and consistent over time. Stringent policies imply that polluters face high costs for emitting, and ideally, they pay for the environmental damage they cause. Transparency ensures that environmental goals and the means to achieve them are clear such that individuals and firms understand them. Policies that lack clarity in their goals or design will result in poor compliance and ineffectiveness. Consistency in time implies that policy is predictable. Since investors’ decisions are based on economic returns in future, predictability is crucial to give confidence to invest in green technologies.

However, in general, policies introduce more uncertainty and are a major factor affecting the level of investments. Policies are short-sighted as governments often are elected for short periods, implying that environmental policies shape and direction change too often in the eyes of investors. Consequently, environmental policy uncertainty is associated with a reduced level of corporate investments in green innovation. Significant changes in environmental policy could therefore delay investments in green innovation, especially if the investments are irreversible (Huang, Wang, Jiang, & Zhong, 2022). Furthermore, considering that political decision-making processes are often slow, it may delay investments for many years, which may be a disadvantage to being at the forefront of the market for green technologies.

As mentioned earlier, many environmental problems are international. Thus, the market for green technologies is determined by environmental policies implemented in the whole worldwide. Although this might increase the potential market for green technologies increases it is often not the case. Often, the countries that have environmental policies are limited and even when environmental policies are implemented, they are often not well designed i.e., are not stringent, transparent, and consistent over time. Furthermore, when environmental problems are international, we need to account for a sort of uncertainty that is much more difficult to solve. The presence of the free rider problem in international environmental problems adds uncertainties that are very challenging to solve.

3.2.2 Push policies

Push policies are direct support of green technologies and aim to overcome market failures and barriers to entry for green technologies. These policies are directed to improve innovation rather than the environment. If pull policies can be described as classical environmental policy, push policies should primarily be seen as innovation policy. As described in Figure 8, push policies may however be designed to promote green innovations. Push policies may be subsidies, funds for research and development or even policies directed to reduce investment risks such as green loans, green guarantees, or feed-in tariffs.

The idea behind push policies is that market forces may not be sufficient to promote the adoption of green technologies, even when governments have introduced pull policies such that environmental policies. In most cases, there are other barriers to the establishment of technologies in general and green technologies in particular. Often the use of new technologies is associated with learning cots. New technologies require significant investments in time, effort, and money to learn and implement effectively. These costs are often a significant barrier to the adoption of new technology, in particular for individuals and firms with limited resources that cannot afford it. Many times, individuals and firms also have significant investments in incumbent technologies with advantages such as established market share, brand recognition, and network effects that may risk losing if they adopt new technologies. One adoption strategy when new technologies are developed is therefore to wait and see how competitors adapt and learn from their mistakes, which slows down the spread of technologies in the economy and may even make it difficult for new technologies to gain traction and establish themselves in the market, even if they offer superior performance compared to incumbent technologies. Push policies should therefore be seen as complements to pull policies and should be designed to overcome barriers to entry and establishment of green technologies.

There are even cases when pull policies are too difficult to apply. One reason is that the activities causing the environmental problems, i.e., polluters, are out of the reach of regulating authorities. This might be because polluters geographically are abroad, i.e., transboundary environmental problems, or that we have historical emissions or diffuse emissions that are difficult to identify. In these cases, push policies might be the only alternative to limit environmental problems.

3.2.3 Technological shifts need policy mixes

Transitions in the economy are necessary to reduce the overall human impact on nature. In the previous section, we discussed the theoretical predictions about pull policies needed to induce green technologies. In practice, however, pull policies are necessary but not enough to induce green technological shifts. In fact, the choice is complex, partly because the uncertainties involved are enormous and are partly related to the nature of policymaking. Consequently, when facing these uncertainties, decision-makers have tendencies to prefer solutions that provide tangible and visible impacts i.e., they tend to favor push policies to specific technologies rather than pull policies with uncertain outcomes further away in time. In the long run, this approach may however be inefficient. Push policies lead to specific solutions that might be good for specific purposes but are fragmented and poorly coordinated to target the overall and long-term goals. Furthermore, public capital alone may not be enough to reach some environmental goals, such as the transition to climate neutral economy. Push policies alone cannot curb global warming.

The above discussion indicates that a good policy to induce green technologies is a combination of pull- and push policies. The question is then how to combine these two sets of policies in the best way possible. The policy mix that is needed is illustrated in Figure 8. First, it is necessary that the rule of the game, i.e., prices on the market and other rules for actors in the market, are such that green investments are more attractive than other technologies. This can be achieved by pull policies designed such that polluters pay for the environmental damage they cause. Pull policies are however associated with uncertainties, non the less political ones, and are not enough to induce green technologies. Furthermore, there are other barriers to the use and spread of technologies that need to be addressed. Infant industry problems, learning costs and other costs of being at the forefront of green technologies might slow down or deter green innovations. Being at the forefront of green technologies implies, for instance, making choices that might risk being inadequate or replaced before investment costs are compensated. Push policies are therefore necessary as complements to pull policies.

Note also that push policies should be designed to help establish technologies, which for instance implies there is a time limit and should cease when technologies are well established in the market. Incumbent technologies have also direct and indirect structural support, which may be a barrier to establishment of new technologies. This structural support should be revised such that support is given to all technologies, including new innovations.

3.2.4 Incentives from an actor's perspective

This section draws on the findings of the interview study and concerns how actors perceive the topic of incentives that facilitate the transition to ERS. What do actors consider to be the main driving forces behind the shift?

Respondents agree that incentives are necessary to encourage operators to switch to electric vehicles, as the industry operates on very low margins. However, opinions vary on how the incentives should be designed. One proposal set forward by the majority of respondents is to provide some form of purchase support, primarily in the beginning, until the market stabilizes. Once Total Cost of Ownership (TCO) calculations are in place, purchase support can be reduced. Several also point to the importance of assessing how the market is evolving and direct support accordingly. One respondent even suggests that support could be differentiated regionally, so that support is direct where it is needed. However, another respondent argues that subsidizing a purchase support may not be the best solution because buying an electric truck does not necessarily mean using the electric road. The respondent points out that the aim of the electric road from a societal perspective is to have vehicles with fewer batteries and that the subsidy therefore becomes a blunt policy tool as it does not directly target the battery problem. Therefore, the actor suggests that incentives tied to the vehicle's weight could be a better approach, resulting in environmental gains such as less road wear, less battery consumption, and minimal energy consumption.

Furthermore, some respondents argue that stable electricity costs for the customer are necessary for long-term profitability. Nevertheless, one respondent emphasizes the importance of paying for the energy received, as it is unsustainable from an environmental perspective not to do so since it loses the incentive to drive fuel-efficiently.

The literature on incentives described above distinguishes between pull policies and push policies. It is therefore interesting to note that respondents refer primarily to push policies. Doing so may however be explained by the fact that push policies to specific technologies often provide tangible and visible impacts, whereas pull policies may have more uncertain outcomes further away in time. Nonetheless, learning from the literature on incentives is that "*in the long run, this approach may however inefficient. Push policies lead to specific solutions that might be good for specific purposes but are fragmented and poorly coordinated to target the overall and long-term goals"* (see p. 26 above).

3.2.5 Actors' perspectives on driving forces for overall systemic change

The literature review on driving forces on systemic change presented above concludes that initiatives such as CollERS and the development of ERS technologies should be seen as a, at least in part, politically driven process. Agreeably, most respondents argue that the implementation of ERS is primarily motivated by environmental politics. If the need to reduce emissions did not exist, there would be no need to develop alternative options to the existing infrastructure and fossil-fueled vehicles, argue respondents. The respondents also emphasize the environmental aspect as a driving force when discussing ERS in terms of the reduced amount of batteries compared to battery-powered heavy trucks, specifically concerning the extraction of metals required for battery production.

When it comes to technological advancements, the interview study shows different perspectives. Some respondents perceive that the current transition poses technical challenges, whereas others feel more confident in the technological progress and argue that the transition today is entirely contingent upon political decisions.

Additionally, economic impact is stressed as crucial and that the shift must be profitable for operators. One actor believes that the transition will not occur, irrespective of technological advancements, unless it becomes profitable for operators to switch to ERS.

Another aspect that can influence operators to switch to ERS, as highlighted by one of the respondents, is the depreciation period for heavy trucks. A heavy truck is depreciated over a period of five years, which implies that the incentives to switch to an ERS-compatible truck become stronger as we approach 2030. From that perspective, the transition is likely to accelerate in two years.

3.3 PHASES OF TECHNOLOGY INNOVATION

In the previews section, we have described policies needed to induce green technology. Technological shifts go through different phases: starting with invention and ending with diffusion. To assess the current state of ERS in the context of technology innovation we need to further explore the different phases of technology innovation. In this section, we discuss in more detail the different phases of technological innovations in the economy.

The literature divides the development of technological innovation into different phases. Although the phases are named differently, the meaning is largely the same as they describe the same emergence of the technology innovation and influencing factors. This section presents an overview of the different phases and their content.

Bergek et al. (2008) analyze technological innovation systems (TIS) which can be explained as socio-technical systems with focus on development, diffusion, and use of a technological product. The systems contain components, not just the technical ones, that affect the innovation process. The technological innovation system (TIS) perspective was in the beginning when it was introduced, in the 1990s, known as a technological system. Later, it evolved to a "function approach" in attempt to identify and examine possible key processes where there existed agreement between different innovation system approaches. The functions thus can be explained as key processes for the innovation system. The functions are *knowledge development and diffusion, resource mobilization, market formation, direction of search, legitimation, entrepreneurial experimentation,* and *development of external economies.*

Knowledge development and diffusion involve different types of knowledge, e.g., technical, production, market, scientific, logistics, and design. Also, the source of knowledge development can be distinguished between R&D, learning from new applications, and imitation.

Legitimation is a process that can take substantial time and can be complicated by competitive innovation systems. For new technological innovation to be formed, legitimacy is a prerequisite as the new technology needs to be considered attractive by relevant actors to form demand and for resources to be mobilized.

The market formation can be further divided into three phases. First, in the early stage, only a small market evolves, limited in size, which can be referred to as a "nursing" market. The market provides a place to form technology innovation. In the next stage, the nursing market gives way to "bridging" markets. In this phase, there is room for new entrants and increasing volume. Finally, if the innovation systems prove to be successful, mass markets, in terms of volume, evolve.

For technological innovations to evolve and diffuse, resources must be mobilized. Different types of resources are competence and human capital, financial capital, and complementary assets. Resource mobilization can thus be seen as a supporting function to other functions at different phases.

One part of the function *influence on the direction of search* implies guidance with respect to the growth potential of a new technology, and how to make incentives for organizations to enter the innovation system. The other part is the influence within the innovation system in terms of different competing technologies, applications, markets, business models etc.

During the whole TIS-process, there is considerable uncertainty regarding both technologies, applications, and markets. One source to reduce uncertainty is entrepreneurial experimentation.

Development of positive externalities refers to the creation of positive external economies which for example could be knowledge spillovers. Central to the development of positive externalities is the entry of new firms as it positively influences several other functions.

The TIS-approach also distinguishes between two phases: the formative phase and the growth phase. In the formative phase, firms and organizations enter, networks are formed, and experiments are taking place. The phase is characterized by uncertainties concerning technologies and markets, long development periods and small volume of economic activities and production. The formative phase is then followed by a growth phase, characterized by system expansion and large-scale technology diffusion.

What is incorporated in the formative phase within the TIS approach is analyzed by Söderholm et al. (2019) in further divisions. The authors analyze the network management throughout the technological development processes and discuss how various network characteristics could affect the development of sustainable technologies. The authors set up a framework addressing the changing roles of network management at the interface between various phases of the technological development process.

As shown in Söderholm (2019), technological development process is divided into four various phases: concept development, pilot and demonstration, market formation, and diffusion. Between the phases, there are also in total three interfaces. At the first interface, which can be found between the two first phases, the concept development and the pilot and demonstration, there is a need to create variation and expand the scope of learning processes promoting more learning-by-doing. Between the pilot and demonstration and market formation is the second interface which is characterized by a focus on various learning processes, for example, learning-by-using. For instance, new technologies must be tested in markets with real customers. The third interface, between the market formation and the diffusion, focuses instead on learning from the feedback of customers and the society, for example gaining legitimacy and developing standards.

Figure 9 also presents three categories of innovation policy instrument and their role in the development phases. Technology push instruments are primarily associated with the two first phases where it promotes provision of basic and applied knowledge inputs, through R&D grants and loans, pilot plants, patent law, tax breaks etc. The last two phases market formation and diffusion of new technology, are supported by demand-pull instruments, for example through standards, feed-in tariffs etc. Systematic instruments are less widespread in the existing literature compared to the other two and differ as they support the functions operating at the innovation system level, such as providing infrastructure, facilitating alignment among stakeholders, stimulating strategy and vision development, and providing organizational solutions.

Although largely context-dependent, collaborating actors in the process may include technology providers, research institutes, end-users, and various authorities on different levels. However, the role of the actors varies depending on which phase the development process is in.

Söderholm et al. (2019) emphasize characteristics of effective actor networks of which one is actor diversity. Compared to homogenous structures, a heterogenous group of actors that takes different roles tend to be more resilient, and successful in securing the necessary resources, for example, competence and funding etc. Another factor is the level of integration, i.e., how closely connected and centralized the network is.

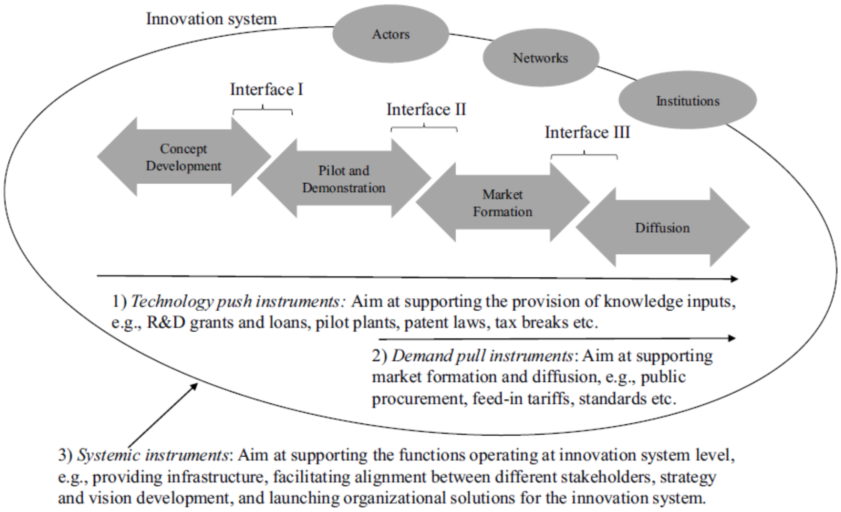

Figure 9. Different phases and interfaces, and role of policy instruments in the technological innovation process.

Lehmann (2023) describes the development of technology innovation in three phases: formation, stabilization, and dissemination. At the start, in the formation phase, there are often unstructured constellations of actors and informal communication. In this phase, new set-ups and applications of the technical system are created. In the next phase, stabilization, the actors start to interact, and networks start to emerge. With the emergence of networks risk and uncertainties are spread among more actors and are reduced. At this stage technology, prototypes and demonstrators are now being developed. In the dissemination phase, the technology has reached the point where there are one or more dominant designs and self-dynamic market demand develops. There is thus a need for a broader application scope. In line with the interface between market formation and diffusion, described by Söderholm (2019), there is also o focus on learning from feedback from users and suppliers.

Table 2. Stages of technology innovation as described by Bergek et al. (2008), Söderholm (2019) and Lehmann (2023).

Bergek et al. (2008)	**Formative phase**				**Growth phase**		
	Knowledge development and diffusion	**Resource mobilization**	**Market formation**	**Direction of search**	**Legitimation**	**Entrepreneurial experimentation**	**Development of external economies**
Söderholm (2019)	**Concept development**		**Pilot and demonstration**		**Market formation**		**Diffusion**
Lehmann (2023)	**Formation**		**Stabilization**			**Dissemination**	

3.3.1 Three perspectives concerning the phase connected to technological choice

The interview study illustrates different perceptions and attitudes towards the technological choice, especially concerning the current stage of “the choice process”. One group of respondents argues that the decision of technology concerning ERS has already been taken: conductive overhead catenary lines is the only technology that is proven and ready to be put on the market today. To meet the environmental goals both within nations and at an EU level, we need to start now and with the technology that we know works, this group of respondents argue. Moreover, a joint European system, and the choice of one technology, is needed to speed up the process and keep the costs down.

A second group of respondents argue that we are now in an initial phase of “the shift towards ERS”, and that it is, therefore, desirable to have different technologies. This is due to two main reasons. First, we need to start the implementation process as soon as possible, and different technologies can speed up this process. Second, competition is needed to create a functioning market. It is only after a couple of years that the technologies can be evaluated, and a decision can be made on which technology is best. If it is decided to only use one technology now, a considerable amount of knowledge and the possibility of developing better systems will be lost. Within this group of respondents, some argue that two technologies on the same vehicle are not only possible technically but are also feasible in terms of cost and terms of location. The other opinion within this group is that different technologies on the market are desirable, but not on the same vehicle due to cost and lack of space.

The third group of respondents widen the scope of the technological choice, arguing that it is not possible to regard the choice as only concerning technologies within ERS. Rather it should be regarded as a technological choice within the larger eco-system of electrical transportation. The shift towards electrification of vehicles could be supported through ERS and/or through other technologies such as hydrogen and improved batteries. As this group of respondents consider ERS as part of a larger electrical shift, they argue that the choice stands not between different forms of ERS but rather between ERS and batteries or hydrogen. Some argue that ERS could exist alongside other technologies to advance the processes of electrifying the transport sector, pushing the need for a technical choice further into the future. These respondents argue that it is essential to have the bigger picture in mind and not choose one technology that only can be used by one type of vehicle, but the roads need to be electrified for all types of vehicles.

The different statements concerning the phase of technological choice should not be regarded as “objective truths”. Rather, they express respondents’ beliefs. To a varying degree, they may also express actors’ statements and opinions in relation to that actor’s logic and motifs.

3.4 STANDARDIZATION

As described by Söderholm (2019) and Lehmann (2023), processes of standardization play a crucial part in the dissemination and market formation for new technologies. It is therefore a factor of importance for the matter of this report. In the following section, the concept of standardization will be discussed as well as relevant examples.

Standards are crucial for interoperability and functioning markets. Standardization aims to resolve situations where involved actors prefer a common solution to a problem but have not yet agreed on which option to choose. There are mainly three modes of standardization: committee-based, market-based, and government-based. And in addition, the large variety and number of actors involved in standardization processes for new technology may require all three standardization modes, a so-called multi-mode standardization. Wiegmann et al. (2017) argue that multi-mode standardization is likely to become more important in the future as a significant number of societal and technical trends bring actors from different backgrounds with no previous relation together. This plurality of actors will likely entail many different cultures regarding standardization, resulting in the emergence of multi-mode standardization processes (Wiegmann, de Vries, & Blind, 2017).

Blind (2002) discusses the driving forces for standardization and emphasis that early standardization can provide benefits such as compatibility but must be weighed against the loss of diversity and risk of a lock-in at an inferior level. At the diffusion stage, standards play a vital role in the economic success of goods and services with positive network externalities, like telecommunication and information networks and services. Common standards encourage trade and the exchange of products and services, and the diffusion of new technologies. Standardization improves the compatibility of different components and makes the diffusion process more efficient and takes safety issues into account.

Fulari (2021) investigate committee-market standard battles for the case of vehicle-to-grid (V2G) technology in Europe and identify relevant factors for standardization success in the automobile sector. On the V2G-market there is yet no single dominant standard for charging available leading to various standards competing against each other. Technologies compatible with other technologies may have an advantage over technologies that do not offer compatibility. The most important factor for standardization success was brand reputation and credibility. The second most important factor was compatibility followed by the third crucial factor, financial strength. According to the author, the most crucial factors found for the committee-market standards are also usually relevant in market-based standardizations.

The process studied by Fulari constitutes, according to Suarez (2004), the third stage in a so-called “technology-dominance process”. The process starts with an organization doing applied research and moves to the second stage when a prototype is developed. The third stage is when a first commercial product has been developed, followed by the fourth stage when there exists a clear early frontrunner. The fourth stage lasts until a dominant standard has entered which closes the process. The factors reputation and credibility seem to be most important from the first stage until the third stage (Suarez, 2004).

Note also that the need for standardization can be different. There are probably efficiency gains to be made if common solutions such as payment systems or how electricity is delivered to ERS are standardized. Standardization may however lead to difficulties to consider differences such as geography and climate.

3.4.1 Development of the railway

The railway development in the 19th century is an example of a process with a lack of common standards between countries. When railways were built in the 19th century, the aim was to link small towns together. The railways were therefore developed in each country with different signaling systems, differences in track gauge, power supply, etc. This means that there are currently around 30 different signaling systems in the EU that are not compatible with each other. As a result, locomotives passing through several countries (sometimes even within the same country) must be equipped with several different national signaling systems. A locomotive driver must then be doubly trained and authorized to drive with the relevant signaling systems. As mentioned, another obstacle to continental travel was that track gauge, the inside distance between railroad tracks, differs between countries.

To overcome the technical and bureaucratic obstacles and instead create a common European railway area, the railway industry developed a European system (ERTMS) in the late 1980s and early 1990s. It is a project to standardize control and improve the safety of the railway system. The goal is to replace all existing signaling systems in Europe with a common system to promote interoperability between national rail networks and cross-border rail transport. ERTMS is intended to guarantee a common standard that enables trains to run through different countries without obstacles. The countries of Europe, with some reservations, have committed to introduce ERTMS on the core network by 2030 at the latest and other networks by 2050.

The International Union of Railways states that the vision of ERTMS is ‘‘to enhance cross border interoperability and signaling procurement by creating a single Europe-wide standard for railways with the final aim of improving the competitiveness of the rail sector’’. With a common standard for the European railway, cross-border traffic is simplified, and a common train protection system is a step toward the vision. ERTMS not only involves the introduction of new technology but also affects the organizational levels of the actors involved. The introduction of ERTMS requires dialogue and an ability to make conscious decisions across organizational boundaries to drive the changes that follow from the ERTMS introduction. The introduction of ERTMS, as a common traffic management system for Europe, also means that the decision hierarchy is moved in such a way that decisions previously taken by government agencies or at a national level are moved to the EU level (Trafikverket, 2021).

4 MARKET ANALYSIS

This section discusses ERS in the context of a market analysis to assess relevant conditions, trends, and dynamics of ERS. The purpose is to help to make informed decisions on strategies, pricing, and product development for ERS. The section commenced with a description of the political background of ERS followed by a description of ERS as a good, its demand, supply, and value chain.

4.1 POLITICAL BACKGROUND

When discussing the development of ERS, it should be seen in the light of political goals. Environmental policy has been a major driver of green innovation and the goal of reducing greenhouse gas emissions is a key motive behind the electrification. As described earlier in Figure 8, there are several policy tools through which innovation processes such as R&D are affected. Several different policy instruments have been deployed by governments in the context of electrification of vehicles, instruments such as R&D-loans and guarantees. However, politically driven technology shifts are associated with higher uncertainty than privately driven ones. Additionally, electrification shifts are largely driven by environmental policy, which is associated with policy turnover risk, thus increasing the risk of investments in such technology (Huang, Wang, Jiang, & Zhong, 2022).

Initiatives such as CollERS and the development of ERS technologies should be seen as a, at least in part, politically driven process. In an EU context, the Implementation of ERS is a part of an overarching strategy to reach its goals of climate neutrality by 2050 to reduce fossil fuel emissions by decarbonizing the transport sector. On a national level, policy tools such as public investment have been used to support the innovation process of ERS. Thus, when conducting a market analysis regarding ERS, its political background must be acknowledged. Factors such as private investments in R&D-processes are the result of political goals and policies. This is because the return on investment for companies investing in ERS development is dependent on opinions and decisions from relevant authorities regarding which technologies to implement on public roads. One way solution may be to develop a road map. In turn, these opinions and decisions are affected by their interests as competing stakeholders. Furthermore, the political background of ERS background is also important when discussing relevant actors, it is for example important to include actors such as traffic and environmental authorities when discussing the supply and demand of ERS.

4.2 ERS – A CONGESTION GOOD

In order to conduct a market analysis, a classification of the good in question, ERS, is required. ERS can be described as a congestion good. Congestion goods become more valuable as more people use them, but their usefulness declines as their usage increases beyond a certain point. In other words, when the number of users of a congestion good exceeds its capacity, the product or service becomes less effective or efficient.

The basic characteristics of a congestion good are determined by its level of non-rivalry and non-excludability. A good is non-rival when a unit can be consumed without reducing the amount of the good left to consume by other individuals (Corners & Sandler, 1996). ERS is a non-rival good but as the number of users increases due to capacity limits such as space for new cars on the road or technical charging being limited, congestion occurs. This leads to undesired costs for all users due to the crowding effect of each additional user.

A good is excludable if it can be withheld costless by the owner (Corners & Sandler, 1996). ERS has characteristics of excludability as users are excluded as it requires permits and access to relevant payment systems. The user, often governments, can also exclude users that fail to pay charging or other fees. This may reduce congestion risks however roads deliver a basic need of transport in the economy and in general governments do not want to reduce users to satisfy this basic need. Furthermore, roads are not exclusive to ERS, and congestion may occur to the presence of other cars on the roads. Congestion may therefore be a problem for ERS, unless capacity is built up fast.

Another relevant characteristic in the context of ERS is economies of scale. Moreover, ERS is also characterized by economies of scope, meaning the benefit of ERS is dependent on the size of the network. The combination of economies of scale and economies of scope implies that ERS needs to be extensive in order to realize its full potential (Börjesson, Johansson, & Kågeson, 2021). These characteristics thereby also affect the supply and demand of ERS. One example is how the combination of economies of scale and scope entails that non-government market actors will supply either a smaller ERS network, or a higher charge price, than the welfare optimum. Therefore, the actions of public actors are crucial for the establishment of ERS since they provide market actors with relevant support for a full-scale optimal implementation of the technology.

4.3 CURRENT STATE OF ERS IN A MARKET CONTEXT

The literature review of the different phases of technology innovation presented an overall analysis, however, Lehmann (2023) has illustrated the development of ERS for each of the three phases. Also, the TIS-approach has been applied in the context of ERS by Langeland et al. (2018). They find that ERS technology as a transport innovation still is in its test phase, therefore lacking a commercial market. This differentiates ERS technology from EV technology, with the latter already having an established market formation. The authors also find that the lack of market formation partly can be seen because the technology still needs to prove its functionality and operability. ERS technology has however succeeded in mobilizing resources, something hydrogen has not yet managed. Conclusively, the authors state that there are many possible pathways toward more sustainable systems of transport in the Nordic countries, one of them being ERS technology.

Table 3. Main functions for the different transport innovations in the Nordics.

	EV	ERS	Hy	Bio	AV	MaaS
Knowledge dev. & diff.	X	X	X	X	X	X
Direction of search	X	X	X	X	X	X
Entrepreneurial experimentation	X	X	(X)	X	X	X
Market formation	X			X		
Legitimation	X	X	X	X	X	
Resource mobilisation	X	X		X		

Tongur (2018) investigates the relationship between business models and socio-technical change in the context of ERS. By examining two different cases of ERS development, one in Sweden and one in the USA, Tongur finds that the relationship between business models and socio-technical change differs depending on the type of project. Firstly, new business models were not found to be a part of pilot projects focusing on radical innovation. Regarding demonstration projects with user interactions, development of business models was found. Lastly, business models were found to be evaluated and rejected within deployment projects seeking to transform current the socio-technical system. Tongur thereby finds that the relationship between business models and socio-technical change in the early stages of transition is not homogenous and varies depending on the characteristics of a project.

A second finding presented by Tongur is the fact that the business model concept can be used to understand the evolutionary processes of the early stages of transition. The business model perspective focuses on what value is added for a plurality of different actors by a new technology. It therefore looks beyond the perspective of the relationship between the user and the firm, adding a useful perspective that includes both sustainable and environmental value to users, policy makers, and subsystem suppliers (Tongur, 2018). The third conclusion is regarding the fact that commercialization and deployment of systemic innovation, like ERS, are oftentimes more complex than described in business model and sustainability literature. The importance of investments in alternative infrastructure for the commercialization of new sustainable technologies is overlooked when only its possible benefits and drawbacks are discussed. Business models serve a central function in the emergence of alternative infrastructure regarding planning long- and short-term investments, as well as coordinating the involved actors (Tongur, 2018). Conclusively, Tongur emphasizes the role of business models in the context of socio-technical change. The relationship between business models and socio-technical change should not be overlooked or underestimated when examining challenges for new technology systems such as ERS.

As previously described, Lehmann (2023) divides the technology development into three phases: formation, stabilization, and dissemination. However, he also illustrates the development of ERS for each phase, how far the development has come, and what is required onwards. According to Lehmann, the emergence of ERS has already passed the first two phases. The formation phase involved research proposal to develop and test contact line type ERS, the development of test vehicles, private test track and applied industrial research with public co-funding by the government.

In the last decade, systematic research and funding with more than 25 ERS-related research and development projects have been implemented. Currently, there are 4 base contact systems with sub-variants: overhead catenary, ground, or lateral supplies, inductive and stationary. Consequently, the technology development has also made it through the stabilization phase.

We are now, according to Lehmann, in a transition to the dissemination phase, a phase that calls for several different developments. Firstly, in the context of re-configuration of the socio-technic network governments need to become actors in terms of creating international alliances and program expertise and funding. Secondly, this calls for integrated ERS innovation hubs and clusters with a self-sustaining ecosystem, as a way of developing a self-dynamic market demand. Thirdly, the emergence of qualified and standardized design regarding contact systems and vehicle configurations. Lastly, the transition into the dissemination phase calls for a search into combining dynamic and static charging in a fully electric transport system.

Today, several examples of how the dissemination phase is developing can be seen in Europe. In Germany for example, there are proposals for ERS innovations clusters in OCL technology. Another example can be seen in Sweden where there is a call for tenders for permanent ERS installation. According to Lehmann (2023), however, the most critical measure for the development of ERS is currently the reconfiguration of the socio-technic network. Measures such as international cooperation on governmental level and roll-out decisions for different electric supply technologies. These measures should therefore be seen as indispensable parts of the evolution of a full-scale ERS network in Europe.

The literature emphasizes that ERS lacks a commercial market but is on its way to entering the phase of market formation. Lehmann emphasizes that international cooperation is required at the government level and that governments need to enter as actors and form international alliances. Tongur (2018) emphasizes the importance of business models for the development of ERS and in the interface between the market formation and the dissemination phase, Söderholm et al. (2019) argue that the focus in the interface between pilot and demonstration and market formation must be on learning processes such that new technologies must be tested in markets with real customers. Some solutions may however be ahead and are in the market formation stage, while others have still not entered the market formation stage.

To sum up, ERS is now on its way to entering the phase of market formation, especially in the case of catenary overhead lines. However, other technologies, like conductive in road-rail, may still be in earlier stages of development. Entering the phase of market formation, a significant factor is what this report is examining, how the technology choice can be made in a situation where different countries prefer different technologies.

4.4 STANDARDIZATION IN THE CONTEXT OF ERS

As mentioned earlier, standardizations play a vital role in the market formation of new technologies. Standards improve the dissemination of new technology and have been named a central part of the market formation of ERS. In the context of ERS, a plurality of organizations and institutions are of importance in the standardization process. There are both relevant international actors such as the EU, IEC, ISO and ITU, and relevant European actors such as CEN, CENELEC and ETSI. Furthermore, national actors such as DIN in Germany, SiS in Sweden and AFNOR in France could also be of relevance. Relevant standards concern both the physical infrastructure and operational services. Several standards have already been agreed upon, for example regarding contact systems for ground feeding of ERS (TS 50717) and contact line interface for overhead catenary ERS (TS50712).

While standards play a crucial role in the economic success of goods and services, there is a risk that they are established too early. Early standards could result in a loss of technological diversity and a lock-in effect at an early stage of development, which in the case of ERS with multiple different existing technology paths constitutes a risk. If early standardization benefits one form of ERS technology more than others, it may result in a lock-in effect based on standards rather than technical or economic measures. Such a risk could for example arise when standards are set regarding aspects of ERS that are independent of specific technology choices, such as regarding payment systems.

Conflicts between different ERS technologies are also relevant in the context of governance regarding standardization, both within specific technologies and regarding overarching systems. Because of the importance of interoperability between different European countries, decision-making regarding standardization is likely to occur on an international, intergovernmental level. Since governments have an interest in promoting domestically developed technologies, they may advocate with a different intent than international actors acting with the intent of greater European interoperability. In the case of standardization within technologies, countries with domestic interest in specific ERS technologies have a bigger interest in working for standardizations for that specific technology than other ones. In the case of standardizations of overarching systems such as payment systems, these countries have an interest in creating beneficial standards for their respective domestic technology. Thus, the process of standardization may be affected by interest conflicts when countries become stakeholders in the choice of ERS technology.

4.5 SUPPLY

A multitude of different actors can be considered providers in the supply chain of ERS. An eco-system of actors supplying products such as ERS infrastructure, ERS vehicles, and electricity. In this section, actors with such involvement in the supply of ERS technology will be discussed.

On a political level, the supply of ERS technology is affected by decisions made by authorities relevant to fields such as transport, environment, and energy. The government can be seen as a main actor, acting as a financier. Another actor is the suppliers of the technical infrastructure needed for ERS, responsible for designing and producing the technology required to construct electric roads.

It is also worth noting that the market actors for ERS vary depending on the technology. For example, Siemens dominates the catenary overhead lines technology market, but due to its relatively simple technology, competitors can quickly enter the market, opening for competition. The conductive in-road rail technology is manufactured by several suppliers. However, it is challenging to see how the different suppliers' technologies can be combined within the same standard. Even though the inductive embedded technology is also manufactured by several suppliers, it is easy to see that they can compete within the same standard. This means that one supplier's product can be used on the road while another supplier's product can be used in the truck, with the central need for them to be able to function together.

The actors supplying ERS infrastructure are also affected by the supply of relevant factors of production, the supply of materials such as copper, aluminum, steel, rubber, and plastic. Different forms of ERS technology are dependent on specific materials to different extents. For instance, ERS technology from Siemens is estimated to be more construction steel intense than other ERS technologies. Differences regarding material intensities result in dependencies of different supply and demand.

Furthermore, the creation of compatible vehicles is essential for electric roads. Vehicle manufacturers offer the supply by producing and designing vehicles that are compatible with the required technology. Examples of actors are Scania, Renault, and Daimler.

Electricity producers, both energy companies and grid owners, who provide the supply and deliver electricity to power the electric road system are also crucial actors on the supply side. A functioning energy supply for the electric roads is dependent on working grid infrastructure, not only on a local level but also on a regional and national level. The electricity supply is also affected by the demand for ERS: if the number of ERS trucks increases, the demand for ERS and electricity for charging will increase consequently (Gustavsson, et al., 2021).

Finally, billing and payment solutions play a crucial role in daily road operations and are a critical aspect of the commercialization and wider adoption of ERS. Although significant progress has been made in the technological development of electric roads, the issue of a feasible payment and billing system for the electricity supplied, as well as the actors to be regulated in such a system, remains under discussion and has yet to be decided.

4.6 DEMAND

As explained earlier, authorities are relevant actors in the supply of ERS technology. However, authorities are also of importance regarding the demand for ERS technology. Funding of pilot projects and the call for tenders are not just examples of how authorities affect the supply of ERS technology, but also its demand. Since authorities control the planning and building of the road infrastructure, they also control the demand. Their decision whether to incorporate ERS infrastructure into roads or not is therefore central to the demand for ERS.

Transportation companies and their customers are also important contributors to the demand for ERS. As described in a previous report by WSP within CollERS, the logistics sector is important for the uptake of ERS technology. Their demand for transport innovation should therefore be seen as an important factor in the demand for ERS technology. Transport providers such as DHL, Ernsts Express, DB Schenker and DSV are all examples of such users.

However, there are indirect users as well, as Borin and Tjernlund (2020) point out in their report conducted on behalf of Electreon. This approach acknowledges that the complexity of the transport industry suggests that there may be additional actors beyond direct users who can influence the dynamics of the market and driving forces for the introduction of ERS. As just described, transport providers are direct users of ERS while logistics hubs, freight forwarders, and transport buyers are indirect users who have a vital in shaping the demand for ERS. Consequently, the high competition and wide range of transport providers in the market for goods transport means that transport buyers have a significant influence.

4.7 ACTORS’ PERSPECTIVES ON THE MARKET AND “RULES OF THE GAME”

This section concerns how actors perceive the market perspective. What comes first? And what characterizes the “rules of the game” that support a well-functioning ERS market?

A common opinion is that the infrastructure must be established before the market becomes a reality. Initially, traffic will be low, and ERS will initially be a loss-making business. Several respondents emphasize the importance of long-term thinking and argue that the state should be responsible for the significant investments and risks, even though ERS involves many uncertainties. The extent to which the State should have a role varies among the respondents, but the majority argues that the State should have a significant role and take much of the risks and costs for the transition to occur and be accelerated. Some are concerned about the environmental politics in Sweden and argue that it hinders the transition. One respondent even argued that the industry is outpacing politics in Sweden at present. Long-term policies are a prerequisite for the predictability that many actors demand.

Some respondents demand stricter laws from the EU as they believe that their national governments are doing too little and acting too slowly. Some argue that the EU must govern the transition more due to the risk that decisions made at the national level in Sweden may be overturned by EU decisions. Clear policies and a clear roadmap are required. One respondent believes that the transition to ERS will occur with 100% certainty if a joint decision is made in the EU and that the probability is lower than 50% otherwise. In other words, decisions and laws from the EU are required, an opinion shared by several respondents who argue that there is little coordination today.

Germany is at the forefront of the transition, and opinions vary on whether Sweden should follow or not. Some believe that Sweden should wait and see how things develop in Germany and then act accordingly, while others think Sweden should not wait. Furthermore, some believe that the most important thing is to build something, instead of waiting for other countries and actors. One respondent expressed that two countries will not choose different systems at the same time, one country will choose after another, and to choose differently one must be completely convinced that the other system is better. Regardless of technology, respondents agree that competition is needed. If there is only one supplier for the technology(s), there will be no market.

The belief that construction must start as soon as possible is shared by most respondents due to the long lead times required to increase the number of vehicles and expand the road network. One respondent compares electric roads to mobile networks and argues that the potential and benefits will be limited if the system is not built to a sufficient scale. The same respondent asserts that it is difficult to assess the utilization rate, which is crucial for electric roads, since electric trucks will also charge at depots during their daily rest periods. In other words, he suggests that electric roads compete primarily with stationary charging for supplementary needs.

4.8 CONCLUSIONS OF THE MARKET ANALYSIS

ERS as a technology that affects the logistics market, can be classified as a congestion good and characterized by large initial investments and economies of scale. ERS is currently on its way to entering the phase of market formation, a market where the relevant supply actors are governments and authorities, vehicle manufacturers, and energy providers. Since the development of ERS is mainly climate-politically driven, government and authorities should be seen as important actors. Also, how this policy is designed and implemented ultimately determines the need for phasing out fossil fuels and therefore the need for technologies able to substitute them. This means that policy determines the demand for electrification in the economy and consequently even the demand for ERS. Relevant demand actors are transport and logistics companies, an industry with many actors and a high level of competitiveness. If climate policy accurately targets emissions causing climate changes it will be mirrored in market prices. That means that a tough, transparent, and consistent climate policy is needed to create a low carbon intensive economy, increasing demand for electrification such as ERS. The logic is simple, policy instruments, i.e., pull policies, are needed to make clean means of production such as ERS more attractive and profitable than fossil fuels-based means of production. These policies are necessary but are not enough to lead to a green technological shift and need complementary policies such as subsidies to green technologies, i.e., push policies.

One major conclusion from the market analysis regarding ERS is that the government has a dual role. On one hand, it formulates relevant policies and rules for ERS. On the other hand, it is a main actor in the supply of technology. The role as a policy maker is to introduce as general policies or policy instruments as possible, but its role as a supplier does at the same time require a choice of specific ERS technology. However, this choice is complicated by the fact that the government is not a market leader and thereby must wait for the technology to be developed by other market actors. The choice of which specific ERS technology to supply on the market is therefore made by relevant companies, while governments have the final word as they invest in the necessary infrastructure and thereby determine what technology is to be used on public roads. Thus, the choice of ERS technology is a result of governments choosing amongst the supplied technologies on the market, thereby also being affected by competition between the technical developments of different domestic industries. This status quo outcome may however not be desirable for society, and governments can influence this choice towards more desirable outcomes.

Another conclusion regarding market dynamics is about the role of first movers in the context of market leaders. Since ERS is associated with large economies of scale, only countries with a large transport sector will have the economic means to invest in such technology and become so-called first movers while others follow later. Between the first movers and the following actors there may exist differences regarding what kind of market dynamics and legislations are seen as desirable. In the context of the choice of ERS technology, an important conclusion is also that policy tends to favor incumbent technologies although it might not be the best long-term alternative. This tends to favor technologies developed by first movers although it may not be the best solution in the long run. Germany and France are the two countries that are ahead in ERS that may fit the description of first movers. Which of these countries and their technologies that are finally established is however determined by their followers. The country and technology that get the most users will probably be the ones that will dominate the market. It is also possible that different technologies will be in the market at the same time. If the costs of having two or more technologies in Europe are high, there is a need for regulation at the EU level for a standard technology.

Regarding standardizations, one initial conclusion is that it is dependent on timing. If the standardization happens too early in the process it may result in extensive lock-in costs and if it happens too late it may result in comprehensive coordination issues. These risks are relevant for both standardizations within technologies and overarching systems. The existence of large economies of scale should also increase the need for standardization.

The implementation of ERS is an inherently political issue with public authorities as the main players. The ERS regulation is shaped by the policy-related opinions and decisions of public and private stakeholders, which are influenced by the stakeholder interests of the public and private actors involved. In turn, which actors are included as stakeholders are determined by distributional conflict tied to the resources dedicated to the project and the benefits of the implementation of technology choice. Furthermore, standardization of ERS is also political as countries may promote standards compatible with their preferred technology choice.

In Chapter 2.5. we discussed the different approaches to the implementation of ERS technology, national-level, transport corridor level, and EU level. On the one hand, successful international coordination regarding the ERS technology choice is likely to result in desirable outcomes such as interoperability and homogeneity. However, the likelihood of such a multi-national coordination to succeed is low and national decision-making processes are therefore more likely to result in an effective process. Thus, decision-making on a national level may be the most realistic alternative in the context of ERS compared to EU- or transport corridor level. However, the implementation processes of second-mover countries like Sweden are likely to be affected by first-mover countries such as Germany or France. Resulting in some form of international cooperation and therefore some of its related benefits and problems.

5 CONCLUSIONS

There are three main ERS technologies: inductive embedded coils, conductive rail, and conductive overhead catenary lines (OCL). A major difference is that OCL is only applicable to trucks while the other technologies may also be utilized by cars. A lot of previous studies have focused on comparing the technologies and discussing how best to choose between them. In this report, we have instead investigated by whom the choice should be made and whether it should be coordinated.

In the past, many shippers changed trucks at the border. This would have made coordinating the choice of ERS technology unnecessary since the consumer argument for choosing the same technology all over Europe disappears. However, it is not the case anymore (although they might start changing trucks at the border again if ERS offers enough total cost of ownership-benefits). We also conclude that from a technological perspective, it is possible to combine several technologies on the same vehicle, although there might be obstacles combining inductive with conductive technologies. However, this will most likely not happen. The actors see it as unlikely that there will be a business case that includes several technologies on one vehicle. Therefore, the potential benefits of political coordination of the choice of technology for ERS in Europe are most likely big (the network effect of ERS would be fulfilled if users are able to make use of the whole system).

Based on the literature's description of the different phases of technological innovation systems, we conclude that ERS is on its way to entering a market formation phase. Some of the literature states that the interface between pilot, demonstration, and market formation is characterized by learning processes. For example, new technologies must be tested in markets with real customers. This process appears to align with the current stage in which we find ourselves today.

Governments have two important but distinctly different roles in ERS. One is to set the legislation and rules for ERS. It can involve policy instruments aimed at reducing fossil fuels and that provide incentives for green technologies, such as making electrification as direct support to the spread of green technologies including ERS. These policies should be designed as technology neutral as possible such that the rule of the game in the market can accommodate existing technologies as well future ones. Governments' second role is that they usually provide necessary transport infrastructure in an economy. Many highways in Europe are publicly owned, although there are exceptions such as France. The second role, governments being the buyer and provider, separates ERS from markets for private consumption.

It is important to remember that ERS consists of several subsystems: electricity supply, road, power transfer to vehicle, daily road operation, and vehicles. The choice of some of these subsystems may be coordinated to ensure similarity across countries, but not necessarily. In general, respondents in our interviews see no technical obstacle connected to payment systems. Rather, they regard it as a matter of designing incentives. When investing in ERS infrastructure some parts can be technology neutral. For example, electric supply systems such as payment systems can be designed to accommodate different ERS systems. However, at some point, ERS investments need to be technology specific, and a choice needs to be made by the governments depending on the available and established technologies in the market.

Regulations or policy instruments also indirectly determine the demand for transport with ERS. Well-designed policy instruments define the market for green technologies (so-called “pull” policies). For climate, this means “pulling” users from fossil fuels toward other energy sources, e.g., electrification. ERS could play an important role in the sustainable electrification of the transport sector. Since policy instruments contain large uncertainties, it may be difficult to achieve technological shifts. Therefore, there is also a need for “push” policies aimed at stimulating and/or lowering barriers to innovation.

In general, policies tend to favor incumbent technologies, which may not be the best solution for society in the long term. These policies often allow the first-mover to set the agenda. In the case of ERS, the dominant national actor is Germany (although France also has potential here), which has essentially chosen the most mature technology (Siemens overhead lines has the highest technology readiness level since it is based on an old technology for rail). The point here is not that overhead catenary lines are not the best (we have not evaluated technologies in this report; hence we have no ground to rank them), but rather that the first mover's technology may not necessarily be the best.

A well-functioning market there is both pressure on prices and stimuli for innovation. The conductive in-road technology is manufactured by several suppliers. However, it is challenging to see how the different suppliers' technologies can be combined within the same standard. Although inductive technology is manufactured by several suppliers, it is easy to see that they can compete within the same standard and there are standards existing today (IEC 61980). This means that one supplier's product can be used on the road, while another supplier's product can be used in the truck, and that a well-functioning market is very likely. Overhead catenary lines are most likely the middle case here, there might be competition since it is a straightforward technology that is easy to produce.

The interview study raised several themes including the broader topic of systemic change and incentives for facilitating the transition to ERS. With respect to incentives, respondents primarily emphasized so-called push policies. The theme of systemic change also relates to the market perspective, as it raises the questions: what should come first and what should characterize the "rules of the game" of a well-functioning ERS market? Most of the actors interviewed did not consider different technologies in different countries to be a problem at the early stage we are in now. Some actors even advocated for it, arguing that otherwise we might lose knowledge and potentially better systems. We also found that vehicle manufacturers generally did not want a monopoly on the market, instead preferring to see that other competitors produce the same technology. One vehicle manufacturer stated that they only act when a "complementary" competitor enters the market. This is noteworthy and contradictory to classic economic theory, where all actors are assumed to strive for monopolistic power.

A general reflection from the interview study is that the topic of technological choice in relation to ERS engages actors. Although there are competing interests, not least in terms of what technology is "the best", there appears to be a joint effort to make a fairly significant shift in transport infrastructure.

The political analysis finds that a multinational decision process regarding the choice of ERS technology would, if successful, likely result in a desirable outcome. However, multinational cooperation is difficult on the EU level, and is equally unlikely on the local decision-making level where transport corridors are implemented. Many prominent EU countries have contrasting interests, which implies a lack of incentives to lift the decision to the EU level (and thus a lower likelihood of successful coordination). Many of these countries have an interest in promoting technologies developed on the domestic level, which means their position may differ from international actors who may instead prioritize European interoperability. EU will nonetheless have an important role in defining standards for each technology. For example, the EU can develop standards for each of the different subsystems when these are not dependent on the ERS technology itself (e.g., power generation). The same type of coordination challenges is likely to occur when actors from different countries with different interests decide on a specific technology in a specific transport corridor. If the choice of ERS technology is done on a national or bilateral level, first-movers will play a decisive role since several second-mover countries will choose specific ERS technologies based on the choices made by first-movers. Although there are caveats we recommend aiming for an EU level decision since it brings the most benefits. The most important one being to enable the network effects of ERS. There is also a momentum for this now, judging from discussions at EU meetings. It would be advantageous to build the discussion at EU level around criteria's that then determines the choice of technique. Example of possible criteria's are safety aspects and whether the technique should allow for cars.

We end up with four policy recommendations for the Swedish government.

1. There are two paths to choose between: a passive path where we follow a dominant first mover and do not strive for compatibility and an active path where Sweden tries to influence so that the best technology and subsystems are chosen in a way that is compatible all over Europe. We advocate for choosing the active path since it brings the most benefits for the climate and accessibility in Europe.

As we pointed out above, there are a lot of caveats: but there are no disadvantages in trying. The process needs to be closely coordinated with the revision of AFIR.

Choosing the active path has implications both for the Swedish government and for the Swedish authorities. The Swedish government needs to push for a decision on investments in an ERS network and for a choice of technology. The risks for non-decision when it comes to choice of technology holds for investment in ERS corridors as well, until there is an active decision involving several countries, there will most likely not be an ERS network. The Swedish authorities needs to support this by:

- Spread the result of the Swedish work on ERS.
- Participate and coordinate tests with other EU countries.
- Participate in identifying how an ERS network should take form when it comes to technology, accessibility, emission effects etc.
- Aid the political level in developing a vision for a future ERS network, both in terms of the full deployment and the sequential steps.

2. When discussing which ERS technology to choose it is important to keep in mind that ERS consists of several subsystems. It is likely to be the case that some of these subsystems will be the same in Europe and some not.

3. The possibility to create a well-functioning market where there is both pressure on prices and stimulus for innovation should, along with other ciriteria’s, influence the choice of technology. We conclude that inductive solutions provide the best basis for a well-functioning market.

4. Sweden is not a potential dominant first mover that other needs to follow, the economy is too small, and the country is in the periphery of Europe. On the other hand, Sweden is one of the leading countries when it comes to ERS tests and research. Hence Sweden’s ability to influence lies in information sharing and “thought leadership”. This means that a lot of effort should be put into spreading the results from the Swedish tests etc.

6 REFERENCES

6.1 LITERATURE

Acemoglu, D., Aghion, P., & Bursztyn, L. (2012). The environment and directed technological change. *American Economic Review*, 131-166.

Allmendinger, P. (2002). *Planning Theory.* Basingstoke: Palgrave.

Baumol, W. J., & Oates , W. E. (1988, 2nd edition). *The Theory of Environmental Policy.* New Jersey: Cambridge University Press.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research policy*, 407-429.

Blind, K. (2002). Driving forces for standardization at standardization development organizations. *Applied Economics*, 1985-1998.

Borin, F., & Tjernlund, L. (2020). *Exploring Barriers towards Adoption within Electric Road Systems: A Case Study of the User Perspective.* KTH.

Bryman, A. (2008). *Social research methods (3rd ed).* New York: Oxford University Press.

Börjesson, M., Johansson, M., & Kågeson, P. (2021). The economics of electric roads. *Transport Research Part C*.

Cars, C., Healey, P. M., & de Magalhaes, C. (2002). *Urban Governance, Institutional Capacity and Social Milieux.* Aldershot: Ashgate.

Chamberlain, K., & Al-Majeed, S. (2021). Standardisation of UK Electric Vehicle Charging Protocol, Payment and Charge Point Connection. *World Electric Vehicle Journal, 2*.

Christensen, J., & Gornitzka, Å. (2022). Expertise in EU policy making. i T. Jale, & P. Graziano, *Elgar Encyclopedia of European union public policy* (ss. 148-157). Northampton, Massachusetts: Edward Elgar Publishing.

Corners, R., & Sandler, T. (1996). *The Theory of Externalities, Public Goods, and Club Goods.* Cambridge: Cambridge University Press.

Daehnhardt, P. (2022). Germany in the EU: An assertive status quo power? i K. Larres, *The oxford handbook of German politics* (ss. 529-558). Oxford: Moroff, Holger; Wittlinger, Ruth.

Demetriou, K. N. (2015). *The European Union in crisis: explorations in crisis and democratic legitimacy.* Springer.

Flyvbjerg, B. (1998). *Rationality & Power. Democracy in Practice.* Chicago: The University of Chicago Press.

Fulari, S., & van de Kaa, G. (2021). Overcoming bottlenecks for realizing a vehicle-to-grid infrastructure in Europe through standardization. *Electronics (Basel)*, 1-16.

Greaker, M., Heggedal, T., & Rosendahl, K. (2018). Environmental policy and the direction of technical change. *Scandinavian Journal of Economics*, 1100-1138.

Gustavsson, M., Börjesson, C., Kenani Dahlgren, H., Moberger, L., & Petersson, J. (2015). *Förstudie om betalsystem för elvägar.*

Gustavsson, M., Mottschall, M., Hacker, F., Jöhrens, J., Helms, H., Johnsson, F., Taljegård, M., Almestrand, P., Hasselgren, B., Lindgren, M. (2021). *Key Messages on Electric Roads.*

Hart, R. (2004). Growth, environment and innovation- a model with production vintages and environmentally oriented research. *Journal of Environmental Economics and Management*, 1078-1098.

Hassler, B., Gilek, M., & Jönsson, A. M. (2019). Cooperating for sustainable regional marine governance: The case of fisheries and nutrient runoff from agriculture to the Baltic Sea. *Synthesis report, Working Paper 2019.1*.

Healey, P. (2007). *Urban complexity and spatial strategies: Towards a relational planning for our times.* London: Routledge.

Hillier, J. (2007). *Stretching beyond the horizon. A multiplanar theory of spatial planning and governance.* Aldershot: Ashgate Publishing Limited.

Huang, J., Wang, Z., Jiang, Z., & Zhong, Q. (2022). Environmental policy uncertainty and corporate green innovation: evidence from China. *European Journal of Innovation Management*.

Kivimaa, P., & Kern, F. (2016). Creative destraction or mere niche support? Innovation policy mixes for sustainability transitions. *Research Policy*, ss. 205-217.

Kvale, S. (1996). *InterViews - An Introduction to Qualitative Research Interviewing.* London: Sage Publications.

Langeland, O., Andersson, M., Julsrud, T., Sarasini, S., Schnurr, M., & Tongur, S. (2018). *Decarbonizing the Nordic transport system: A TIS analysis of transport innovations.*

Lehmann, M. (2023). European ERS Symposium., (ss. 1-21). Berlin.

Lundqvist, K.-J., Olander, L.-O., & Martynovich, M. (2017). *The technology shift thesis.* Lund: Lund Universtity.

Panchal, C., Stegen, S., & Lu, J. (2018). Review of static and dynamic wireless electric vehicle charging system. *Engineering Science and Technology, an International Journal*.

Popp, D. (2019). Environmental Policy and Innovation: A decade of research. *International Review of Environmental and Research Economics*, 265-337.

Smith, A., & Raven, R. (2012). Transitions ahead : politics practice and sustainable transitions management. *Environment and Planning*(A 39), ss. 763-770.

Steunenberg, B. (2006). Turning Swift Policy-making into Deadlock and Delay. *European Union Politics*, 293-319.

Suarez, F. (2004). Battles for technological dominance: an integrative framwork. *Research policy*, 271-286.

Söderholm, P., Hellsmark, H., Frishammar, J., Hansson, J., Mossberg, J., & Sandström, A. (2019). Technological development for sustainability: The role of network management in the innovation policy mix. *Technological forecasting & social change*, 309-323.

Ten Have, P. (2004). *Understanding Qualitative Research and Ethnomethodology.* London: Sage Publications.

Tongur, S. (2018). *Preparing for takeoff - Analyzing the development of electric road systems from a business model perspective.* KTH Royal Institute of Technology.

Trafikverket. (2021). *Analys och kvalitetssäkring av införandet av ERTMS i det svenska järnvägssystemet - Slutredovisning.*

Wiegmann, P. M., de Vries, H. J., & Blind, K. (2017). Multi-mode standardization: A critical review and a research agenda. *Research Policy*, ss. 1370-1386.

6.2 INTERVIEWS

Interviews have been conducted with representatives from the organizations and companies listed below:

- Region Örebro
- Region Skåne
- Region Gävleborg
- The Swedish Transport Administration (Trafikverket)
- Scania
- Volvo Trucks
- EON
- MAN
- Renault
- Siemens
- Electreon
- Elonroad
- Ernsts Express
- DHL Freight

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